SEABED ECOLOGY STUDIES : COMPOSITE REPORT

GEO REPORT No. 93

ERM-Hong Kong, Ltd

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
THE GOVERNMENT OF THE HONG KONG
SPECIAL ADMINISTRATIVE REGION

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PREFACE

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The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
September 1999

FOREWORD

This report summarises the survey results and assessments of the eight specific sites, and makes comparisons of the benthic abundance and diversity and substrate characteristics among sites.

The report was prepared by ERM-Hong Kong for Geotechnical Engineering Office (GEO) of the Civil Engineering Department under Agreement No. CE 98/95. Dr K.C. Ng of GEO coordinated the study and reviewed the report.

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1 *INTRODUCTION*

1.1 *SEABED ECOLOGY STUDIES*

Environmental Resources Management-Hong Kong, Ltd (ERM) in association with EVS Consultants, the Hong Kong University of Science and Technology (HKUST), Electronic and Geophysical Services Limited (EGS) and Striplin Environmental Associates (SEA), were commissioned by the Geotechnical Engineering Office (GEO) of the Civil Engineering Department of the Hong Kong Government SAR to undertake a series of benthic marine surveys, collectively known as the Seabed Ecology Studies.

These Studies form part of an ongoing series of marine monitoring studies, designed to address the cumulative impacts of dredging and disposal projects on the marine environment of Hong Kong. Such projects have been necessary to accommodate Hong Kong's rapid economic expansion over the past few decades, and comprise an extensive civil engineering and building works programme that has involved a level of dredging and disposal activity among the highest found anywhere in the world.

The Seabed Ecology Studies were both a continuation and refinement of previous soft-bottom ecological surveys, with specific Study tasks outlined in eight different areas of Hong Kong's waters. The sites that were surveyed under these Studies are presented in *Figure 1.1a* and include the following:

- open water disposal sites: East of Ninepins and South Cheung Chau;
- marine borrow areas: Tathong Channel, the Sokos, Eastern Waters;
- ambient reference areas: Basalt Island and South Lamma;
- backfilled marine borrow area: East Sha Chau; and,
- far field reference areas associated with each of these sites.

The broad objective of the Studies was to provide GEO and the scientific community with a clearer understanding of the environmental impacts of the dredging and disposal activities under GEO supervision. Such information can be used during the decision-making processes to assist in the proactive management of dredging and disposal activities in Hong Kong.

1.2 *STRUCTURE OF THE REPORT*

The structure of this report is as follows:

- *Section 2* provides the objectives and a description of the methods and techniques used in the Studies;

- *Sections 3 -10* comprise individual assessments of the eight selected survey sites providing a description of the:

    - Study objectives at each site;
    - a brief outline of the site history;
    - geophysical characteristics;
    - findings of previous studies at the site;

  - results of the Seabed Ecology Studies carried out at the site; and,
  - a discussion of the results with reference to the findings of previous studies carried out in that area.

- *Section 11* provides a largely qualitative discussion of comparisons between sites in terms of abundance, biomass, taxonomic richness and physical characteristics of the sediments.

2 *GENERAL OBJECTIVES AND METHODOLOGY*

As the global trend for coastal zone development continues, there is an increasing need for active management so that the potentially conflicting uses of ecological resource harvesting (eg fisheries, shell fisheries) and physical resource exploitation (eg dredging of marine sand, reclamation) can be met. A key resource in this regard is the soft bottom seabed, and considerable efforts have been expended in characterising the benthic assemblages and processes which affect it, as a basis for the management of coastal areas. For example, it has been identified that physical factors such as salinity, sediment grain size and sediment organic content are important in determining benthic assemblage structure, (Gray 1981, Bachelet *et al* 1996), although ecological interactions such as competition and predation have a demonstrated influence as well (Posey and Hines 1991).

Benthic assemblages experience natural, often seasonal, perturbations in response to changes in physical conditions. These include storm events, hypoxia and salinity fluctuations (Shin 1990; Breitburg 1992) as well as anthropogenic disturbance due to pollutants (Anderlini and Wear 1992; Dauer *et al* 1992), dredging activities (Marques *et al* 1993) and fishing operations (Currie and Parry 1996). Recovery from disturbance may be achieved by active movement of juveniles or adults to a site (by swimming or crawling), or passive recruitment via water currents, thought to be a key process in many areas (Santos and Simon 1980, Diaz-Casteneda *et al* 1993). The presence of chemical and biological cues which trigger or interfere with larval settlement (Rodriguez *et al* 1993) and the time of year in which disturbance occurs (Diaz-Casteneda *et al* 1993) affect the rate of recovery from perturbation. As the generation time (time to reproductive maturity) of many benthic organisms is greater than one year, recovery of a disturbed site may take several years to complete (Warwick 1993).

Impacts from anthropogenic disturbance to soft bottom benthos may be difficult to detect due to the considerable spatial and temporal variation exhibited by benthic assemblages (Morrissey *et al* 1992 a and b). This problem has generated an interest in techniques and methodologies for impact detection and monitoring, involving both experimental design and methods of data analysis (Stewart-Oaten *et al* 1986; Underwood 1991, 1992; Schmitt and Osenberg 1996). These include the use of community parameters such as abundance/biomass comparisons, lognormal distributions and species ratios (Warwick and Clarke 1991, Warwick 1993), as well as the use of indicator species (Jones and Kaly 1996).

The general objective of the Studies was to provide a broad understanding of the environmental impacts associated with dredging and disposal activities in Hong Kong waters. However, as the levels of impacts due to dredging, disposal and other activities vary between sites, specific objectives have been defined for each site and are described in detail in their respective sections. This section provides an account of the general methodology employed for all eight Study sites.

2.1 *DEFINITION OF SITE CLASSIFICATION TERMS*

The terms used in this report to refer to areas of the seabed sampled during the Seabed Ecology Studies, are defined as follows:

Study Site:	the Marine Borrow Area (MBA), disposal site or reference area which was surveyed during the Studies, eg East Ninepins and Tathong Channel MBAs;
Impact Zone:	the area of seabed surrounding the MBA or disposal site in which an impact from dredge and backfill activities may be detected in terms of the physical characteristics of the seabed;
Mound:	the impact zone comprising disposed material raised above the depth of the natural seabed;
Pit:	the impact zone comprising a Marine Borrow Area which lies below the depth of the natural seabed;
Apron:	the impact zone comprising disposed material which has moved off a mound as a result of natural forces;
Pit Lip:	the impact zone comprising the area surrounding an MBA;
Mass Flow Area:	the impact zone comprising disposed material which has moved away from a mound as a result of mound failure; and
Reference Area:	an area within the Study site which is not within the impact zone.

2.2 *SURVEY DESIGN*

In order to design and execute the surveys in manner which facilitates obtaining statistically valid conclusions, a clear statement of the initial monitoring objectives is essential. As a first step, the survey sites have been categorized by general class of Study objectives as shown in *Table 2.2a* below.

Table 2.2a ***Description of Survey Types and Locations***

Type	Description	Study Site
I	Quantitative assessment of recolonization in and around MBAs and disposal sites to determine the environmental impacts of dredging and disposal on benthic communities (comparison of impact vs. reference areas)	East of Ninepins South Cheung Chau East Sha Chau Sokos Islands Tathong Channel
II	The quantitative assessment of seasonal variation in benthic community structure (time series analysis)	Eastern Waters
III	The collection of benthic community baseline data (descriptive characterization of new and non-impacted areas)	Basalt Island South Lamma Far-field areas adjacent to all above sites

As another step in developing a sound sampling design, benthic ecological data from CED's previous studies was analysed statistically to provide a basis for the allocation of sampling effort (ie the number of replicates required within each Impact Zone/Reference Area) and to assist in refining the objectives for each Study site. The analysis of historical data comprised the following tasks:

- obtaining and formatting the database of CED's previous benthic monitoring studies from East Sha Chau, South of Ninepins, South Cheung Chau, Victor Rock, and East Lamma Channel;
- standardising the data to account for differences in sampling gear (grab size) in each Study;
- stabilizing sample variances to meet the assumption of homogeneity of variance, required for parametric statistical tests;
- conducting clustering analysis to determine spatial patterns in the data set (in terms of dominant taxa); and,
- conducting power analysis, to determine the number of replicates required to reduce the probability of committing a Type II error (ie not detecting a difference between two samples when it does exist) to within an acceptable level for parameters of interest.

In summary, the results of the above tasks indicated that:

- the data were most appropriately standardised for sampling gear by adjusting for the area that the grabs sample (other procedures such as rarefaction - a procedure which permits standardising samples of different numbers of individuals so that their species richness can be compared - not being applicable);
- fourth-root transformation stabilized the variances of the data;
- total invertebrate density was similar at most sites, with approximately 400 individuals m^{-2}, except for East Sha Chau which had the lowest density (114 individuals m^{-2});
- polychaetes were the dominant component of the infaunal community, with the most common polychaete family being Spionidae (present at all locations); and,
- power analysis indicated that 16 to 20 benthic grab samples were adequate to detect a large effect size in density of the dominant family or total invertebrate density.

For Type I and II studies, the sampling effort is allocated to maximize the number of stations within different impact zones (eg mound / pit versus mound apron / pit lip; see *Table 2.2b*). Type III surveys depart from the objectives of Type I and II in that they do not involve any comparison or testing, instead a descriptive approach is adopted to establish a baseline against which future differences can be assessed. The data will be available to generate power curves for any parameter of interest for future monitoring studies, and will feed back into the survey design process as described above. The sample design for each site is summarised below in *Table 2.2b*.

Table 2.2b ***Summary of Sampling Design for each Site***

Location	Type	Grab Stations[1]				SPI Stations[2]
		M/P	A/L	R	Total per site	
East of Ninepins	I	16	19	32	67	53
South Cheung Chau	I	32	32		64	60
Sokos MBA	I	16	16	16	48	46
East Sha Chau	I	16		16	32	46
Eastern Waters	II	16		32	48	60
Tathong Channel MBA	I	16	16	16	48	50
Basalt Island	III			16	16	20
South Lamma	III			16	16	20
Reserve[3]					16	10

Note: 1 One grab per station
2 Three SPI images per station
3 Reserve effort to be allocated as necessary during the course of the Studies
M/P = Mound or Pit impact zone A/L = Mound Apron or Pit Lip R = Reference Area

2.3 *DATA COLLECTION*

All field operations were conducted in coordination with EGS, on a geophysical survey vessel. Vessel positioning was accomplished with Differential Global Positioning System (DGPS), ensuring station location accuracy to ± 5 m. The system on the vessel was a SERCEL NR103 10-channel DGPS receiver, with the differential signal broadcast from the EGS differential transmission station at Tin Fu Tsai, New Territories. Throughout the sampling period the number of satellites and the quality of differential signal received were closely monitored and logged through the computerised navigation system on board the vessel. Station position information was automatically logged by the navigation computer when each sample was retrieved.

2.3.1 *Grab Sampling*

All grab sampling stations were sampled using a modified Van Veen grab sampler (960 cm^2 sampling area; 11,000 cm^3 capacity) with a supporting frame attached to a swivelling hydraulic winch cable. This was designed to prevent the sampler twisting during deployment and to ensure proper contact with the bottom. The grab was lowered slowly through the water column (at an approximate rate of 30 cm s^{-1}) to prevent it from flipping during descent or creating a pressure wave sufficient to grossly disturb bottom sediments. After it had triggered, the grab was raised at a constant rate, carefully retrieved, and placed in a level position on a stand. The sample was evaluated for acceptance based upon the degree of disturbance, penetration depth, and amount of leakage from the grab. Samples with minimal disturbance of surface sediments and adequate penetration depth were accepted, however, samples were rejected if the grab was overfilled or there was leakage of sample material from the grab.

Upon acceptance, sediments were characterized with respect to colour, odour, type, and the presence of non-sediment materials (eg shell, wood, debris). A uniform amount of sediment (approximately 300 g) was then removed from the centre of each sample, double-bagged in a labelled ziplock bag, and stored on ice for later grain size and Total Organic Carbon (TOC) analyses in the laboratory. Grain size analysis required wet sieving through a stack of sieves with mesh sizes ranging from 2 mm to 63 μm), whilst TOC analysis involved a combustion infra-red method with a detection limit of 0.05 %.

Remaining sediments in the grab were washed into a sieve stack (comprising 1 mm^2 and 500 μm meshes) and gently rinsed with seawater to remove all fine material (*Figure 2.3a*). A 250 μm mesh sieve was used for 16 of the stations, allocated on a random basis. Material remaining on the screens was rinsed separately into thick ziplock plastic bags, using a minimal volume of seawater, and a 10 % solution of buffered formalin in seawater was added to the bag to ensure tissue preservation. Rose Bengal stain was added to the sample to aid sorting. Samples were double-bagged, labelled internally and externally with indelible ink and inventoried, before chain-of-custody forms were completed. Samples were sealed in plastic buckets for shipment to the taxonomy laboratory for sorting.

In the laboratory, all samples from the 500 μm and 1 mm sieves were collected, sorted, weighed (as described in *Section 2.4.1*) and retained for either a reference collection or archive. The data from the 1 mm and 500 μm fractions were pooled for statistical analysis. The samples from the 250 μm sieve were collected, preserved and stored, for possible sorting and analysis at a later date.

2.3.2 *SPI Sampling*

Although grab sampling provides quantitative information about the biological component of the soft-bottom marine ecosystem, the integrity of the infaunal habitat is destroyed during sample collection and processing and information on the *in-situ* relationships of organisms to their sedimentary matrix is lost. SPI technology was therefore used to obtain a synoptic picture of the physical seafloor processes and provide further qualitative information on factors influencing benthic community structure.

The sediment profile camera works like an inverted periscope (*Figure 2.3a*). A 35 mm camera is mounted horizontally on top of a wedge-shaped prism, which has a Plexiglas® faceplate at the front with a mirror placed at a 45° angle at the back. The camera lens faces the mirror which reflects the image from the faceplate. The prism has an internal strobe mounted inside at the back of the wedge to provide illumination for the image. This chamber is filled with distilled water, so the camera always has an optically clear path to shoot through. The whole wedge assembly is mounted on a moveable carriage within a stainless steel frame.

The frame is lowered to the seafloor on a winch wire, and the tension on the wire keeps the prism in its "up" position. When the frame comes to rest on the seafloor, the winch wire goes slack, and the camera prism descends into the sediment at a slow rate controlled by the dampening action of a hydraulic piston so as not to disturb the sediment-water interface. On the way down, it trips a trigger that activates a time-delay circuit to allow the camera to reach maximum penetration into the seafloor before the picture is taken. The knife-sharp edge of the prism transects the sediment and the prism penetrates the bottom. The strobe is discharged to obtain a cross-sectional image of the upper 20 cm of the sediment column and an internal motor drive advances the film. The strobe recharges within 5 seconds, and the camera is ready to be deployed again.

At the beginning of each survey day, the time on the data logger mounted on the SPI camera was synchronized with the survey vessel's navigation system. Each SPI station replicate was identified by the time recorded on the film, and on disk, along with vessel position. Redundant sample logs were kept by the field crew and by computer printout. Test shots were fired on deck at the beginning and end of each roll of film to verify that the camera was working to design specifications. Spare cameras and charged batteries were carried in the field at all times to insure uninterrupted sample acquisition.

Three replicate images were collected at each station. After deployment of the camera at each station, the frame counter and a prism penetration depth indicator on the camera frame were checked. If images were missed or the penetration depth was insufficient, additional replicates were taken. A portion of the film was developed at the end of the first survey day and visually inspected under magnification. Any images that were of insufficient quality for image analysis were noted.

For these Studies, only SPI parameters of the physical benthic environment were used. The SPI images were processed for sediment grain-size major mode and range, prism penetration depth (a measure of relative shear strength), depth of the apparent redox potential discontinuity (also known as the RPD, or the depth of the "oxygenated layer" of sediment), whether or not sub-surface methane gas is present (an indicator of excess organic loading), and evidence of erosion or recent depositional layers.

2.4 *ANALYSIS AND REPORTING*

2.4.1 *Taxonomy*

Upon arrival at the benthic laboratory, all benthic samples were re-inventoried and checked against chain-of-custody forms. If a sample consisted of multiple containers all containers were processed as a group.

Sample re-screening was performed by the benthic laboratory after the samples had been held in formalin for a minimum of 24 hours to ensure adequate fixation of the organisms. Individual samples from the 500 μm and 1 mm^2 mesh sieves were gently rinsed with fresh water into a 250 μm sieve to remove the formalin from the sediments. Sieves were partially filled while rinsing a specific sample to maximize washing efficiency and prevent loss of material. All material retained on the sieve was placed in a labelled plastic jar, covered with 70 % ethanol, and lightly agitated to ensure complete mixing of the alcohol with the sediments. Original labels were retained with the re-screened sample material.

Standard and accepted techniques were used for sorting organisms from the sediments. Small fractions of a sample were placed in a petri dish under a 10-power magnification dissecting microscope. The petri dish was scanned systematically and all animals and fragments removed using forceps. Each petri dish was sorted at least twice to ensure removal of all animals. Organisms representing major taxonomic groups including Polychaeta, Arthropoda, Mollusca, and miscellaneous taxa were sorted into separate, labelled vials containing 70 percent ethanol. All sorted samples were systematically checked to ensure compliance with QA/QC program requirements (described below) before proceeding to the taxonomic identification, enumeration, and biomass determination phases of the project.

Taxonomic identifications were performed by regional taxonomic experts using stereo dissecting and high-power compound microscopes. These were generally to the family level except for dominant taxa, which were identified to species.

The careful sampling procedure employed in the Study minimised fragmentation of organisms. When breakage of soft-bodied organisms did occur, only anterior portions of fragments were counted, although all fragments were retained and weighed for biomass determinations. Rare or questionable taxa were compared against reference collection specimens held by HKUST or compiled under previous CED studies for confirmation and consistency of identifications. The nomenclature used in all reference collections referred to in these studies have been cross-checked and differences or discrepancies noted.

Sorting QA/QC was performed using 25-power magnification by someone other than the original sorter. Twenty percent of each sorted sample was re-sorted to ensure 95 percent sorting efficiency. A sample passed QA/QC if the number of organisms found during the QA/QC check did not represent more than 5 percent of the total number of organisms found in the entire sample. When the number of organisms found was greater than 5 percent of the total number, the entire sample was resorted. Samples that contained uncertain identifications were sent out for independent re-identification by a qualified regional expert. A reference collection of specimens, identified to discrete taxonomic units, has been developed and it is housed at HKUST until the completion of the Seabed Ecology Studies, when it will be provided to Government.

Within each of the eight Studies several phyla other than those identified to family were collected, but were not identified to family level, for the following reasons:

- the phylum Sarcomastigophora was identified to order only (Foraminiferida) owing to the lack of reference material available to enable further classification;

- Nemertinea (also named Nemertina or Nemertea) were identified to phylum only, as identification to family requires histological analyses which are beyond the scope of this Study; and,

- certain of the Arthropoda and Mollusca were not identified to family level as the specimens were either in larval form or were fragmented in the sample and could not be classified further.

Data from these specimens were, however, included in relevant figures of total abundance and biomass in their respective sections. Furthermore, samples also contained specimens of some or all of the following four families of planktonic taxa and three families of fish. These were regarded as being either captured incidentally in the grab, or introduced during the sieving process through the pumped washing water. These families include the following:

- copepods (Calanidae, Centropagidae, Paracalanidae);
- shrimp (Sergestidae);
- fish (Amphioxidae, Gobiidae, Taenioididae).
- squid (Cephalopoda);
- crabs (of the family Ocypodidae); and,
- foraminiferan protozoans (Sarcomastigophora).

These families were excluded from the data sets and all data analyses as they are not considered to be representative of the benthic macrofaunal assemblage.

2.4.2 *Statistics*

An advantage of this approach was that auxiliary information (bathymetry, grain-size, TOC, SPI parameters) was reviewed to determine if the separate sites were similar in these respects, to allow them to be grouped according to the type of impact the site had experienced (ie the eight sites were grouped as disposal areas, borrow areas, and reference areas). If the sites were not similar in terms of these parameters, and grouping was not possible, then the analyses was structured for comparison of a single reference versus a single impact site. The possibility of describing site differences in abundance by a covariate was investigated once data for each site was obtained.

Prior to statistical analyses, the data was evaluated to ensure that assumptions for the statistical tests, such as homogeneity of variance, were not violated. If necessary, appropriate transformations of the data was applied (eg normalization of the data or stabilization of the variance), or the most powerful alternative tests was used (eg nonparametric tests). Dependant upon the nature of the data obtained and the Study objectives and hypotheses to be tested for each Study site, one or more of the following statistical tests was applied:

1. *ANOVA AND MANOVA:* Simple, univariate measures was tested using an Analysis of Variance (ANOVA) and multivariate measure of community structure was tested using the Multiple Analysis of Variance (MANOVA). Both ANOVA and MANOVA test the same null hypothesis using similar methods. The method was essentially a comparison of the variability within a group (for example, the variance between stations on the mound) to the variability between groups (for example, the variance between mound stations and apron stations). If the ratio of these two variances (that is, the between-group-variance over the within-group-variance) is large enough, then any differences observed are due to true differences that exist between the groups and not just to random variation. ANOVA and MANOVA tests are based on several assumptions related to the underlying distribution of the data being analysed. If the data deviated significantly from these assumptions, then the tests are considered to be inappropriate. If this situation arose, alternative tests (ie, the nonparametric analogues) which address similar testable hypotheses but do not require such stringent assumptions were used.

2. *Cluster Analysis:* Identification of the similarity of the benthic community structure between stations was investigated using a multivariate technique called Cluster Analysis. Cluster Analysis is an exploratory tool designed to search the data for a structure of natural groupings among stations. These groupings are based on the similarity or distance between stations. The distance was measured using the Bray-Curtis metric which is specifically suited to taxonomic abundance data. The graphical output from a Cluster Analysis is called a dendrogram, also known as a tree diagram, from which groups of similar stations can be identified.

3. *Multi Dimensional Scaling (MDS):* MDS was used to depict the similarities between stations based on their benthic assemblages. MDS is a method for creating a low dimensional picture of the relationships between stations in a complex, multi dimensional problem. The Bray-Curtis distance metric was

used for both the clustering techniques and the MDS. The dendrogram from the cluster analysis, and the MDS ordination plot are complementary views of the same similarity information.

For the purposes of this report only the results of the first of these statistical tests are shown (ANOVA / MANOVA). The exception to this is for the data from the Basalt Island Study site where the Cluster analysis and the MDS tests are shown due to no ANOVA / MANOVA statistical analyses being conducted on the data from this site. For further detailed information concerning the statistical tests carried out on the data, reference should be made to the site specific Seabed Ecology Studies Final Reports.

2.4.3 *Geophysical Information*

CED's extensive database of information on the composition and physical nature of the seabed was utilized throughout these studies to provide information on the physical characteristics and processes which influence the benthic environment at each site. Due to the lack of existing geophysical information on the South Lamma Study site, a geophysical survey, comprising swath (multibeam) bathymetry, side scan sonar and benthic grab sampling was undertaken to fully assess the area (EGS 1997).

2.4.4 *Integration of Data*

The SPI images were processed by computer image analysis methods as used in previous analysis of Hong Kong SPI data. Due to the specialised nature of SPI image analysis and interpretation, this was conducted by the ERM Study Team with all aspects overseen and finalized by Dr Germano (of EVS Consultants).

The detailed taxonomic identification of species within the grab samples was performed by Professor Pei Yuan Qian and his laboratory at the Hong Kong University of Science and Technology. Integration of the grab sample data, the subsequent statistical analyses and the interpretation of the SPI images was accomplished through close coordination between Dr Germano, Professor Qian and the ERM Study Team.

3 *EAST SHA CHAU*

3.1 *STUDY OBJECTIVES*

A general objective of the Seabed Ecology Studies at East Sha Chau was to determine the impact of dredging and backfilling operations within the area on local benthic assemblages, using the techniques described in *Section 2*. This Study also expanded on previous work in the area, which is described below in *Section* 3.2.3.

The East Sha Chau area lies in the Pearl River Delta, and is subjected to considerable fluctuations in water quality throughout the year (see *Section* 3.2.2). It is Hong Kong's only site for the disposal of contaminated sediment and consists of a series of Contaminated Mud Pits (CMPs) which lie to the north of the new airport platform with the disused East Sha Chau Marine Borrow Area (MBA) lying to the east of the CMPs (*Figure 3.1a*). One of the CMPs (CMP I) was filled and capped with uncontaminated sediment in 1993, since which time it has not been disturbed by any further direct disposal activities. At the time of the Study little capacity for contaminated mud disposal remained in the CMPs, therefore it had been proposed that the East Sha Chau MBA be used for this purpose in the future.

The objectives of the Seabed Ecology Studies at this site were threefold:

- to determine if the benthic community at the capped CMP I (PIT area) differs from far-field reference areas (Reference West and Reference North - RW and RN areas);
- to characterise the benthic community of the pit lip of the MBA (PIT LIP area) for use in future impact assessments and possible monitoring; and,
- to investigate the benthic characteristics and features which structure infaunal communities in the East Sha Chau area.

3.2 *THE EAST SHA CHAU SITE*

3.2.1 ***Site History***

CMP I is situated approximately 1 km north of the Chek Lap Kok Airport platform and is the largest of 10 mud pits at the gazetted contaminated mud disposal site. The pit is approximately 50 ha in size and was dredged to -20 m in September 1992 to create a site for disposal of contaminated mud arising from the Airport Core Projects and other projects in the area. Contaminated mud was disposed in the pit between December 1992 and July 1993. A 1 m sand cap was placed on the top of the pit during the period between October 1993 and January 1994. This sand cap was then topped with a 2 m mud layer designed to isolate the contaminated material from the water column. Other CMPs were backfilled and capped between 1993 and 1996; at the time of the Study contaminated material disposal was occurring in CMPIIIb (*Figure 3.1a*).

The East Sha Chau MBAs were dredged in 1994 (Pit A), 1995 (Pit B) and 1993-1994 (Pit C). Pit C was partially backfilled in May 1995 to a depth of -14 mPD and again in 1996 to -12 mPD. At the time of the Study, it was proposed that disposal of contaminated material in these pits would commence in July 1997.

3.2.2 *Site Characteristics*

The hydrodynamic regime of the area is influenced by the lunar cycle (spring and neap tides), the season and the rate of flow of the Pearl River. In general, the main ebb tides flow from NW to SE across the pits, with the reverse pattern observed during flood tides. Current speeds are moderate, generally in the range of 0.2 m s^{-1} to 0.4 m s^{-1}. Salinity fluctuates on a seasonal cycle, reaching 10.5 ‰ in the surface layers during the wet season although stratification maintains the bottom waters between 19.3 and 32.5 ‰(EPD 1994).

The natural seabed in the area is relatively flat and varies between -5 and -7 mPD throughout the region with the deepest area situated in the north towards the Urmston Road. The backfilled CMP I has been filled to -5.9 mPD and is at the same depth as the surrounding seabed. The natural seabed at the site consists of very soft marine clay and silt which is between 10 and 20 m thick and overlies alluvial sands and clays. The disposed material (prior to capping) has a similar moisture content, bulk density and general properties as the original seabed, however, it is enriched in metals, particularly nickel and copper. Continuous sediment monitoring has been conducted by Binnie and CES since completion of capping and at the time of the Study was being continued by Mouchel. Results indicate that there has been no leakage of contaminants through the cap. However, there are consistently high metal levels at stations located between CMPI, CMPIIb and CMPIIc which are thought to be due to a breach in the pit walls, a breach in cap integrity or mud waves from dumping practices resulting in contaminated material being pushed out of the pit (Binnie & CES 1996d)

Sediment analysis of the top 1 m of the cap material, conducted in July 1994, indicated the presence of a distinct horizontal lamination beneath the capping layer. Therefore, the intended engineering objective of isolating the contaminated sediment with an overlying 3 m cap has been achieved, and the physical integrity of this cap had been maintained a year after capping was completed (GEO CED 1995).

3.2.3 *Previous Ecological Studies*

At the time of the Study, previous work on benthic ecology in the East Sha Chau area fell into three categories:

- academic research of benthic resources;
- studies for Environmental Impact Assessments (EIA) in the vicinity of the East Sha Chau CMPs (eg Binnie 1995a); and,
- monitoring programmes for the CMPs.

The academic research which has been conducted includes two studies using grab sampling techniques (Shin 1977; Shin and Thompson 1982) and two using trawls (Wu and Richards 1981; Taylor 1995). This review will focus on the results of the grab sampling study as this is directly comparable to the approach taken in this Study. Shin and Thompson (1982) reported that the Hong Kong infauna is characterised by high diversity, low abundances and low biomass. Twenty sites lying to the north of Lantau Island were sampled using a Smith Macintyre grab between November 1975 and January 1977. The infauna at these sites were found to be distinct from other areas in Hong Kong and it was inferred that this resulted from the shallow depth and low salinity condition of these sites. The assemblages in this region were dominated by polychaetes of the Spionidae family(1).

The most up to date EIA at the time of the Seabed Ecology Study in the area which has included benthic grabs was that of the Aviation Fuel Receiving Facility (AFRF) at East Sha Chau (ERM 1996). Twelve stations were sampled in September 1994 and June 1995 and in both times the infaunal community was found to be dominated by polychaetes. A study of the East Sha Chau MBAs undertaken in April 1995 (Binnie 1995a) sampled 8 stations at three sites in the East Sha Chau area and also recorded a dominance of polychaetes.

In the monitoring programme undertaken in 1993 (CES and Binnie 1994), low abundance was recorded and no impact from backfilling activities was detected. Foraminifera and polychaetes were most abundant in the samples for much of the year.

3.3 SAMPLING STATION SELECTION

For the benthic grab samples, sampling effort was allocated to maximize the number of stations within different impact zones, as illustrated in *Figure 3.1a*. SPI stations were located along known physical topographic gradients, to collect information on physical sedimentary properties and processes influencing the benthic community structure. The sampling locations for grab and SPI stations are indicated in *Figure 3.1a*.

3.4 RESULTS

3.4.1 *Grab Samples*

A total of 1069 specimens belonging to 53 families were collected from the 39 grabs, as shown in *Table 3.4a*.

Table 3.4a ***Organisms collected in the Grab Sampling Programme at East Sha Chau***

Phylum	Total number of identified families	Total number of individuals recorded	Total Biomass (g)
Annelida	27	705	2.82
Arthropoda	8	62	1.04
Echinodermata	4	12	0.50
Entoprocta	1	20	0.00005
Mollusca	13	42	7.94
Total	53	841	12.30

Some of the fauna collected were not identified beyond phylum level as described in *Section 2.4.1*.

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(1) It should be noted that Foraminifera are not mentioned in these studies and may have been excluded from the dataset.

The total abundance and composition of the benthic assemblage by major taxonomic group (Polychaete, Mollusc, Crustacea, Nemertinea) is presented in *Figure 3.4a (i)*. The numerically most abundant families identified at each area are presented in *Figure 3.4a (ii)*. These figures indicate that of the four areas, the west reference stations (RW) contained the highest total abundance of organisms, represented mainly by polychaetes. The lowest abundances were recorded from reference north stations (RN) and CMP I (PIT) stations, although the community was structured differently in the two areas. The polychaete family Pilargiidae were most numerous at RN whereas no one family was most abundant in sediments from the PIT stations. The infaunal assemblages at the PIT LIP stations were composed mainly of Spionid and Cirratulid polychaetes.

The total biomass and composition of the benthic assemblage by major taxonomic group is presented in *Figure 3.4b (i)*. The biomass of the gravimetrically most abundant families identified at each area are presented in *Figure 3.4b (ii)*. These figures indicate that the pattern in total biomass across the four stations is similar to that described above for abundance, however the main contributors to total biomass are different. The mean total biomass of the RW area is the highest of the four sampling areas, but is not composed of any one family. The lowest biomass was recorded from the RN and PIT station. These stations were largely composed of bivalve molluscs. Bivalve molluscs of the Veneridae family were responsible for the majority of the biomass of infaunal assemblages of the PIT LIP stations.

A summary of the results of the benthic grab investigations is provided below in *Table 3.4b*.

Table 3.4b ***Summary of Abundance Data from the East Sha Chau Sampling Areas****

Parameter	RW (n=8)	RN (n=7**)	PIT (n=16)	PIT LIP (n=8)
Mean Total Abundance (individuals grab^{-1}±SD)	50±21	12±2.8	5±3.2	39±54
Mean Total Biomass (g grab^{-1}±SD)	0.8±1.8	0.2±0.3	0.2±0.2	0.5±1.1
Mean Taxonomic Richness	14±4.2	6±0.5	4±2.3	7±3.9

* Note that these values were derived from the whole dataset, with no taxa excluded.

** This data has been taken from a total of seven samples instead of eight as one sample was missing.

3.4.2 *SPI Investigations*

Similar to results reported from earlier studies (eg Binnie 1995a; EVS 1996), this area is characterized by soft sediments with all stations surveyed showing a dominant silt-clay fraction (grain-size major mode $\geq 4\ \phi$). *Figure 3.4c* is a representative image of the sedimentary fabric from the RW area, showing low disturbance conditions in the form of a well-developed redox layer, the presence of feeding voids and a lack of mud clasts.

The main distinguishing characteristics among stations, which were evident from the SPI images were the presence of a layer of dredged material and the presence of a loosely packed layer of mud clasts at the surface. These features have been documented in earlier sediment profile imaging surveys (Binnie 1995a). *Figure 3.4d* is an example of the sediment profile of a station where a surface layer of dredged material is present. A map showing the spatial distribution of those stations where dredged material was evident in the SPI photographs is presented in *Figure 3.4e*. With the exception of the recently deposited sediment layers detected at E-25, E-30, and E-49, all of the stations where dredged material was unequivocally present were confined to the East Sha Chau gazetted disposal area and for the most part were within the confines of the CMP I site. Two of the stations outside the CMP I area (E-20 and E-18) also showed evidence of dredged material layers at the sediment surface. Mud clasts, which indicate disturbance from waves, trawling, dredged material trailing or anchor scour, were observed at stations in all areas. Within the PIT and RN areas mud clasts were seen in greater numbers and of much greater thickness than in other areas (*Figure 3.4f*). Although biological community parameters were not measured from the SPI images there was frequent evidence of deposit-feeding taxa, in the form of feeding voids, at stations surveyed within the PIT boundary as well as at stations on the seabed outside the gazetted mudpit area (*Figure 3.4g*).

3.4.3 *Sediment Characteristics*

Data on grain size analyses and TOC content from the stations at East Sha Chau are summarised in *Figure 3.4h*. The laboratory data support the grain size determinations compiled from SPI image analysis: the East Sha Chau area is largely comprised of fine sediments, as generally over 80 % are smaller than 63 μm particle sizes. The PIT LIP station exhibited the most heterogeneous sediments, with larger particle sizes (>63 μm) comprising approximately 20 % of the sediments. PIT LIP stations also exhibited the lowest TOC content. In the other stations, mean TOC was between 0.84 and 0.94 %.

3.4.4 *Data Analysis Results*

As described above, total abundance and biomass data from the RN and PIT stations are similar, and both show lower abundances and biomass than the RW sampling area. This suggests that RN may have been disturbed such that it is not valid to consider it as an unaffected reference area. As the data were found to be non normal and variances heterogeneous, parametric statistics (one-way ANOVA followed by SNK multiple comparison test) were inappropriate, so a nonparametric equivalent to one-way ANOVA, the Kruskal Wallis test (based on ranks) and a nonparametric multiple comparison procedure, were applied to test the significance of the comparisons listed above (significance $p = 0.1$). The outcome is summarised below in *Table 3.4c*.

Table 3.4c ***Summary of Univariate Analysis and Multiple Comparison Test of Grab Sample Data***

Benthic Faunal Parameter	Outcome of ANOVA analysis (p value)	Comparison Between Stations (SNK Tests)
Comparing three stations		
Total Abundance	<0.001	RW > RN PIT
Total Biomass	<0.1	RW > RN PIT
Taxonomic Richness	<0.001	RW > RN > PIT
Comparing all stations		
Total Abundance	<0.001	RW > PIT LIP RN > PIT

Benthic Faunal Parameter	**Outcome of ANOVA analysis (p value)**	**Comparison Between Stations (SNK Tests)**
Total Biomass	NS	
Taxonomic Richness	<0.001	RW > RN PIT LIP PIT

Multiple Comparison Test. Stations underlined are not significantly different at < 0.05, (ie for taxonomic richness at all stations, RN is not significantly different to pit lip but greater than pit, however, pit lip is not significantly different to pit).

The outcome indicates that:

- Total biomass did not differ among sampling areas when all stations were compared, however, when PIT LIP was excluded from the analysis the remaining stations were significantly different;
- Differences in total abundance as shown in *Figure 3.4a* were found to be significant between RW and all other stations, PIT LIP and RN were not significantly different but had significantly more individuals than PIT;
- The PIT station had significantly lower taxonomic richness than both reference areas but not PIT LIP; and,
- RW had significantly greater biomass, abundances and taxonomic richness than all other stations.

3.5 *DISCUSSION*

The significance of the findings of the Study with respect to the Study objectives, as defined in *Section 3.1*, is discussed below.

3.5.1 *Objective 1: Investigating Differences Between Pit and Reference Areas*

The results of this Study confirm the findings of previous work (eg Shin and Thompson 1982; CES and Binnie 1994; see *Section* 3.2) that benthic communities at East Sha Chau are characterized by high diversity (in comparison with other areas in Hong Kong) but low abundance and biomass. For example, over 50 % of the samples collected in this Study had fewer than 10 individuals grab^{-1} (*Figure 3.5a*). In order to allow a comparison between the results of the present Study and previous Studies, key community parameters identified in each Study are presented below in *Table 3.5a*.

Table 3.5a ***Community Parameters Recorded in the Present and in Previous Studies***

	East Sha Chau MBA Stations (Binnie, 1995a)	Lung Kwu Chau Reference Stations RSW (Binnie, 1995a)	Territory-wide survey (Shin & Thompson, 1982)	Present Survey
Total Number of Taxa	16	35	139	53
Mean Abundance m^{-2} (± sd)	181 ± 337	157 ± 65	101 ± ??	468 ± 652
Average Biomass (g m^{-2})	no data	no data	23.9[1]	7.5

Note: 1 Biomass reported for the stations sampled by Shin & Thompson which are located in same area as East Sha Chau survey

It is apparent from these results that colonization of the initially abiotic capping material is occurring at CMP. This is in accordance with the conclusion reached by previous monitoring efforts in this area (reviewed in EVS 1996), ie that increases in richness and abundance are occurring over time as part of the recovery from disturbances. Both this Study and past work, however, have identified differences between the pit and the surrounding seabed indicating that richness and abundance of benthic invertebrates are lower in the capped pits than the 'far field' areas. Past studies have excluded sediment contaminant levels at the capped pits as a potential cause for these differences and suggested other possible explanations, such as higher organic carbon levels at the far field sites, sampling artifacts, or disturbance effects at the near field site.

Internationally published experimental studies on successional patterns of subtidal soft bottom habitats in Hong Kong waters have not been undertaken and thus a benchmark for the time constant of ecosystem recovery is lacking. The time an ecosystem takes to recover is dependent on recolonization periods which, as reported by Warwick (1993), are at least partially dependent upon the generation time (time to reproductive maturity) of the benthic organisms, and may take several years. Despite the lack of a time constant in Hong Kong, there is evidence from the present Study which suggest that the differences between the CMP I and reference areas are a result of as yet incomplete colonization of the CMP I stations following the completion of capping operations.

SPI images from stations within CMP I showed a depositional layer of dredged material, and many also exhibited a layer of 'puzzle fabric'. 'Puzzle fabric' is a term that is applied to sediment that has been disturbed due to any one of several different means of physically disturbing the surface of the seafloor. These have been attributed to such disturbances as dynamic collapse from initial deposits or spreading of hydraulically dredged mud clasts over large areas, intensive bottom trawling, scour residue caused by propeller wash in shallow areas, or anchor scars from large ship moorings (Selby and Evans 1996). Regardless of the cause, the effect of creation or deposition of this mud clast layer will have caused disturbance that will have affected the local benthic community structure at the time when it was carried out.

Re-examination of the SPI images indicated that 80 % of all the images from the RN area had a considerable 'puzzle fabric' layer at the surface, while none of the images from RW showed any evidence of this mud clast layer. Stations from the PIT LIP area were a mixture of all types of sediment profiles found in the other 3 areas. These ranged from undisturbed sediment-water interface with feeding voids diagnostic of area RW, to layers of organic-rich reduced sediment typical of the CMP I area, to stations with 'puzzle fabric' layers.

3.5.2 *Objective 2: Characterising Lip Stations*

At the time of the Study, a proposal to use the East Sha Chau MBA for contaminated mud disposal was under investigation. Eight stations at the north of the MBA were therefore included in the Study to provide baseline information on the current status of the pit lip.

The results indicate that the assemblage of the PIT LIP area, while showing some evidence of disturbance due to dredging is similar to the other reference areas in terms of abundance, biomass and richness.

3.5.3 *Objective 3: Identifying Factors Structuring Infaunal Communities*

The low abundances and biomass recorded during the Study constrained many of the multivariate techniques applied to the dataset. Relationships between physical environmental factors (eg grain size, TOC, RPD) and biological assemblage parameters (abundance, biomass), however, were examined using the cluster analyses and multi dimensional scaling techniques. For a detailed examination of these techniques please refer to the East Sha Chau Final Report (ERM 1997).

These exploratory techniques identified the dominant patterns in the dataset, ie that PIT stations are characterised by low abundances and differ from RN stations only by their low abundances of the families Pilargiidae and Capitellidae. These analyses also identified that RW and PIT LIP stations were similar, and characterised by high abundances of Cirratulidae.

3.6 *SUMMARY*

In summary, this Study has shown that:

- the benthic assemblage in the East Sha Chau area when sampled during the wet season, is generally characterised by low abundance and biomass and is dominated by polychaetes;

- while colonization of the capped CMP I appears to be occurring since the pit was capped in 1994, the assemblage has a lower abundance, biomass and richness than an undisturbed far field reference station (RW);

- the benthic assemblage of one of the far field reference areas (RN) indicated that disturbance of the seabed in the East Sha Chau region occurs in areas other than those close to the contaminated mud pits; and,

- the sediments of the pit lip area to the north of the East Sha Chau MBAs were more heterogeneous than the other stations, despite this, the benthic community was similar to far field reference areas.

4 *SOKOS ISLANDS*

4.1 *STUDY OBJECTIVES*

A general objective of the Seabed Ecology Studies at the Sokos was to determine the impact of dredging operations on local benthic assemblages, using the techniques described in *Section 2*. This Study also provides baseline ecological information from the site, as it has not been sampled in detail in the past.

The objectives of the Seabed Ecology Studies at this site were threefold:

- to examine recolonization by infaunal taxa of sediments within the MBA pit;
- to examine differences between the assemblages of the MBA pit, the lip and a far-field reference area; and,
- to examine the benthic characteristics and features which structure the infaunal assemblages at the areas sampled.

4.2 *THE SOKOS ISLANDS SITE*

4.2.1 *Site History*

The Sokos marine borrow area (MBA) is located to the south of Lantau Island, and extends westwards from the Soko Islands to the border with Chinese waters. The MBA originally contained shallow sand resources which were dredged prior to July 1993, using cutter suction dredging techniques. Some minor volumes of sand have been extracted since 1993, but further extensive dredging works at this site are not anticipated. At the time of the Study there were no plans to undertake backfilling at this site.

4.2.2 *Site Characteristics*

Hydrodynamic conditions at the Study site are greatly influenced by freshwater discharges from the Pearl River, to the west of Lantau Island. Water quality data from the Environmental Protection Department's (EPD) routine water quality monitoring stations located to the south of Lantau Island indicate estuarine conditions, with mean recorded surface salinities of 28.4 ‰ (range: 20.2 - 33.5 ‰) and mean bottom salinities of 32.3 ‰(range: 31.4 - 33.5 ‰) (EPD 1994).

Investigations using Sediment Profile Imagery (SPI) were undertaken in October 1993 along a transect through the area of original sand deposits, between Tai A Chau and Lantau Island (SAIC 1994). Images obtained from 7 stations along this transect indicated that the seabed was composed of very fine to medium sands (3-4 ϕ and 2-1 ϕ), which formed physically unstable ripples on the seafloor. These sands had a dark reflectance, implying a basaltic composition. Images from several stations to the south of the MBA showed low reflectance of sediment and depressed redox potential discontinuity depths, suggesting that organic enrichment was occurring.

A geophysical survey of the site, which included side scan sonar and seismic profiling, indicated that the MBA now comprises a shallow depression in the seabed, with pockets of recent siltation present (EGS 1996). Slight to moderate disturbance to the sediments was also recorded, and appears to be associated with dredger movement through patches of shallow sand resources. Currently the pit has a maximum depth of approximately -16 mPD, whilst the surrounding seabed lies at between -6 and -10 mPD (EGS 1996).

4.2.3 *Previous Ecological Studies*

There has been little ecological data collected previously from the Sokos site, and no studies have been undertaken to determine the current ecological condition of the MBA. However, two studies have included samples taken near the Sokos site. The first, undertaken as part of a Territory-wide survey of infaunal benthos between July 1976 and January 1977, used a Smith Macintyre benthic grab to sample two sites near the Sokos MBA (Shin and Thompson 1982). Results indicated that the fauna was dominated by polychaetes, with a mean abundance of 82.5 individuals m^{-2}. Two polychaete species, *Tharynx* spp and *Paraprionospio pinnatato*, were recorded as being the most abundant in the site.

The second study was the SPI work conducted by SAIC (in association with Binnie Consultants Ltd) as described in *Section 4.2.2* above. This provided qualitative information on the presence of organisms within the sediments at each station, and again found polychaetes to be the dominant infauna present. However, abundances appeared to be low, and results implied that unstable sediment present to the south of Lantau may be adversely influencing benthic assemblages in the area.

At the time of this Study an investigation of the rocky shore fauna of the Soko Islands was being undertaken by Binnie Consultants Ltd as part of the CED's ongoing Coastal Ecology Studies. This was completed in 1997 (Binnie 1995b).

4.2.4 *Sampling Station Selection*

The intended sampling design was to sample from within the pit, two pit lip areas (one within 100 m of the pit and one between 100 and 200 m of the pit), and two reference areas (to the north and the east of the site), all located using the site bathymetry (EGS 1996). However, the site was found to be highly variable in depth and, as the EGS 1996 survey depths were measured over a grid of 250 m intervals, the majority of the bathymetric plan was poorly extrapolated from the depth data and marked as "doubtful or projected contour'. As a result, a clear delineation between the different impact zones was not available to assist in selecting the sample stations prior to the survey cruise.

During the survey cruise the depth of each sampling station was recorded and it became evident, upon completion of the survey, that the intended allocation of samples between the different Study areas had not been achieved due to the lack of detailed bathymetric mapping. For example, the intended northern reference area was found to be located at depths indicative of the pit, as were some of the intended lip stations.

To allow data analysis to provide meaningful results, it was decided to reallocate stations between Study areas, prior to data analysis. It was assumed that, as the natural seabed in the immediate vicinity of the MBA generally lies between - 6 and -10 mPD (EGS 1996), any stations shallower than - 6 mPD will represent non-dredged areas. Similarly, any stations near the islands of Siu a Chau or Tai a Chau are likely to be non-dredged due to the presence of a submarine cable running through the eastern portion of the gazetted MBA. As these presumably non-dredged locations were still near the pit, although not actually within it, they were designated as lip, rather than reference stations. This revised allocation resulted in a total of 24 pit stations, 16 lip stations and eight reference stations as follows:

- PIT stations: S1, S2, S4 to S9, S25 to S32, S43, S47, S51, S54, S57, S59, S61, S63;
- LIP stations: S3, S10 to S24; and,
- RE stations: S33 to S40.

The revised sampling plan is shown in *Figure 4.2a.*

4.3 *RESULTS*

4.3.1 *Grab Samples*

A total of 9,979 specimens, belonging to 75 families in six phyla were recorded from the Sokos site. The data are summarised in *Table 4.3a.*

Table 4.3a ***Summary of Organisms Recorded from the Sokos Study Site During the Grab Sampling Programme***

Phylum	Total Number of Families Identified	Total Number of Individuals Recorded	Total Biomass (g)
Annelida	46	9,013	80.75
Arthropoda	11	456	14.66
Echinodermata	3	167	24.38
Mollusca	11	158	38.77
Sipuncula	4	9	0.08
Nemertinea	-	176	1.67
Unidentified	-	-	9.43
Total	75	9,979	169.74

Some of the fauna collected were not identified beyond phylum level (for the rationale behind this refer to *Section 2.4.1*). A summary of the results of the grab investigations is provided in *Table 4.3b.*

Table 4.3b ***Summary of the Grab Data from the Sokos Sampling Areas***

	PIT (n=24)	LIP (n=16)	RE (n=8)	ALL SITES (n=48)
Mean Total Abundance (individuals grab^{-1} ± SD)	173 ±128	277±155	177±70	206±136
Mean Total Biomass (g grab $^{-1}$ ± SD)	2.6±3.9	4.6±4.6	3.0±1.7	3.4±4.0
Mean Taxonomic Richness (Taxa grab^{-1} ± SD)	19± 7	24±6	23 ±3	21±6

The mean total abundance of animals recorded per grab in each sample area, and their composition by major taxonomic group, is presented in *Figure 4.3a (i).* The mean abundance per grab of the numerically dominant families recorded in each area is shown in *Figure 4.3a (ii).*

The overall mean abundance recorded from the Sokos site was 208 animals grab^{-1}. Mean abundances of 277 animals grab^{-1} recorded at the LIP stations were considerably higher than those recorded at the PIT and RE areas (173 and 177 animals grab^{-1} respectively). Polychaetes were the most numerous taxa present, representing 87 % of all identified individuals, with Spionidae the most abundant family recorded overall. Spionidae were recorded at densities of over 100 individuals grab^{-1} at six LIP stations (S14, S16, S17, S18, S20 and S21), whilst Magelonidae (another family of Polychaete) were recorded at similar densities at two LIP stations and one PIT station (S14, S17 and S51).

The mean wet biomass recorded in each area, and its taxonomic composition, is presented in *Figure 4.3b (i).* The mean biomass of the gravimetrically dominant families recorded in each area are shown in *Figure 4.3b (ii).* The overall mean wet biomass recorded from the Sokos site was 3.4 g grab^{-1}, with the mean value recorded at LIP stations (4.6 g grab^{-1}) higher than those from either PIT or RE stations (2.6 and 3.0 g grab^{-1} respectively). Large numbers of low biomass polychaetes and small numbers of high biomass molluscs typified the infaunal assemblages from the LIP and RE sites. Values from the PIT stations were also dominated by large numbers of low biomass polychaetes, although a single large sea cucumber (phylum Echinodermata, class Holothuroidea) recorded from PIT station S29 weighed 19.47 g.

Taxonomic richness also varied between sampling areas, with LIP and RE areas supporting a greater mean number of families per station than the PIT area (24, 23 and 19 families grab^{-1} respectively). Although several polychaete families were common throughout the sample areas (eg Capitellidae, Orbiniidae, Paraonidae, Cirratulildae, Magelonidae, Spionidae and Pilargiidae) other families showed distinct variation in occurrence between the three sample areas. For example, brittle stars (Class Ophiuroidea, Phylum Echinodermata) were present in 88 % and 94 % of LIP and RE stations respectively, but only 54 % of PIT stations.

4.3.2 *SPI Investigations*

Results from the SPI investigations showed a considerable difference in sediment characteristics between the area sampled to the east of the Soko Islands (RE stations) and those to the west (PIT and LIP stations). Images from the RE stations (taken at a depth of between -13 and -15 mPD) showed a depositional environment with little or no evidence of physical disturbance. Profiles were typical of the ambient sea floor in Hong Kong and showed uniform fine-grained sediment (>4 ϕ), a well-developed redox layer 2 - 3 cm below the sediment-water interface, and evidence of deposit feeders. No bedforms or mud clasts (indicative of sediment transport) were present and there was little evidence of physical disturbance. A typical reference station profile is shown in *Figure 3.4c.*

Images from the PIT and LIP stations (taken at a depth of between - 4 and -14 mPD) showed evidence of a much more complex sedimentary environment. Sediment layers were greatly altered by physical disturbance, and grain sizes varied substantially from fine grains of silt-clay (>4 ϕ) to coarse sand (1-0 ϕ) with no distinct pattern or correlation with depth (*Figure 4.3c).* No distinction could be made between PIT and LIP stations, and images from both areas showed evidence of localised sediment erosion, re-suspension and re-deposition (eg highly sorted medium - coarse dark sands or sand and shell lag at the sediment - water interface, *Figures 4.3 d - f*). Despite this, all sediments appeared to be of local origin and no mud clasts were observed. A range of other features present appeared typical of naturally re-worked sediment in a generally depositional environment, and included the following features (*Figures 4.3 g-j*):

- graded bedding planes;
- numerous graded depositional intervals of near uniform thickness;
- angled bedding of depositional units, indicative of low angle crossbedding;
- sorted surface sediments and bedforms; and,
- laminar mud agglomerate in the process of being resuspended and eroded.

4.3.3 Sediment Characteristics

The laboratory data support the grain size determinations compiled from SPI image analysis. PIT and LIP stations were comprised of heterogeneous sediments of a range of particle sizes, whereas the RE stations were dominated by fine material. Sediment heterogeneity was greatest in the PIT stations, less pronounced in the LIP stations and absent in the RE stations. Grain size data and TOC content from the stations at Sokos are presented in *Figure 4.3k*.

The differences between the three impact areas in terms of dominant grain size and sediment heterogeneity are illustrated graphically in *Figure 4.4l*. Sediments are grouped into three grain size classes for clarity, comprising 'large' (>150 μm), 'medium' (106 μm - 150 μm) and 'small' (<106 μm) classes. The high spatial variability in sediment parameters across the PIT and LIP stations is clearly illustrated, and contrasts sharply with the pattern for the RE areas. These patterns were also evident in the analysis for total organic carbon (TOC) content. The RE area also exhibited the highest TOC content, at 0.91 ± 0.07 %. PIT and LIP areas had lower mean TOC contents of 0.61 % (± 0.08) and 0.61 % (± 0.10) respectively.

4.4 *DATA ANALYSIS RESULTS*

Mean transformed measures of total abundance, total biomass and taxonomic richness were analysed using an ANOVA and SNK multiple range test for the pairwise comparisons. For all recorded variables the mean values observed at the LIP stations were higher than those from the other two areas. Despite this, the only significant difference (at $p = 0.05$) was the higher taxonomic richness of the LIP stations when compared to that of the PIT stations. Differences between station groups in mean abundance and biomass were not statistically significant at $p = 0.05$. These analyses are summarised in *Table 4.4*.

Table 4.4 ***Summary of Univariate Analysis and Multiple Comparison Test of Grab Sample Data***

Parameter	Outcome of ANOVA analysis (p value)	Comparison Between Stations (SNK Test)
Total Abundance	$p = 0.07$ (Not Sig)	PIT < RE< LIP
Total Biomass	$p = 0.09$ (Not Sig)	PIT < RE< LIP
Taxonomic Richness	$p = 0.03$ (Sig)	<u>PIT</u> < RE < <u>LIP</u>

Sig = significant at the $p < 0.05$ level. Values <u>underlined</u> are statistically significantly different.

4.5 *DISCUSSION*

The significance of the results are considered in the light of both the overall and the specific aims of this Study.

4.5.1 *Sokos Islands Site Characteristics*

SPI and sediment data revealed the highly heterogenous nature of the sea floor in the PIT and LIP areas. These areas appeared to be greatly affected by a dynamic hydraulic regime which alternately exerts erosional and depositional influences resulting in numerous bedforms and cross-bedding planes. Although the highly variable bathymetry, due to sand dredging, persists and indicates a previous anthropogenic disturbance, no indications of continuing anthropogenic impacts (eg mud clasts or non-local sediment) were evident. Based on the sediment data collected, the dominant structuring element in both the PIT and LIP areas is the physical disturbance caused by waves and currents. In contrast RE (reference) sites showed considerable homogeneity in particle size and sediment type, and no evidence of disturbance from either natural or anthropogenic sources was present. Values of TOC recorded throughout the Sokos site showed no correlation with grain size or assemblage composition, but were similar to those recorded elsewhere in Hong Kong waters (EPD 1996).

The overall mean infaunal abundance recorded in the Sokos Study site was very high for Hong Kong (2100 individuals m^{-2}), compared to that recorded by Shin and Thompson in 1982 (101 individuals m^{-2}). Despite this, overall mean biomass values for the Study site (43 g m^{-2}) were similar to those reported by Shin and Thompson (35 g m^{-2}). This is discussed further in *Section 5.2*.

4.5.2 *Study Objective 1: Recolonisation of Sediments Within and Surrounding the MBA*

All areas sampled contained very high numbers of macrobenthic invertebrates, with the LIP and PIT areas supporting average abundances of 2840 and 1790 individuals m^{-2}, respectively. Mean biomass levels at LIP and PIT areas were typical of Hong Kong waters at 47 g m^{-2} and 27 g m^{-2}, respectively. No significant differences were recorded between mean abundances and biomasses at LIP and PIT areas, although the two were significantly different from each other in number of taxa present (24 and 19 taxa grab^{-1} respectively). The high abundances present indicate that sediments within and surrounding the MBA have been recolonised or are in the process of being recolonised.

4.5.3 *Study Objective 2: Differences in Benthic Communities Between PIT, LIP and RE Areas*

Mean abundance, biomass and taxonomic richness recorded from RE areas (1810 individuals m^{-2}, 31 g m^{-2} and 23 taxa grab $^{-1}$, respectively) were not statistically different from either LIP or PIT sites for any of the measured parameters. Sediment characteristics in the RE area were, however, very different from those recorded from both LIP and PIT areas indicating that the RE area is not subjected to natural physical disturbance to the extent experienced in the LIP and PIT areas.

4.5.4 *Study Objective 3: Factors Structuring Infaunal Assemblages*

The sediment heterogeneity in the LIP and PIT areas has resulted in a complex environment, with no obvious correlations between benthic assemblage characteristics, sediment grain size, TOC levels or depth. As suggested in *Section 5.1*, the heterogenous sediment characteristics present in LIP and PIT areas are most likely the result of large-scale, natural hydrodynamic processes. The hydrodynamic regime is known to greatly affect the composition of soft bottom benthic assemblages in temperate areas (Emerson and Grant 1992), although difficulties in measuring physical processes such as wave climate and current strength in ecological meaningful ways and timescales makes such a hypothesis difficult to prove (Hall 1994).

If hydrodynamic conditions, rather than anthropogenic influences (eg dredging or trawling), are structuring the communities at the Sokos, all LIP and PIT stations should be similar in terms of abundance, biomass and taxonomic richness. While abundance and biomass are similar in both areas, PIT stations contain significantly fewer taxa than LIP stations. This result indicates that while the dominant processes structuring LIP and PIT communities are likely to be similar, other factors, perhaps related to previous sand dredging, may be operating in the PIT area.

The results from the RE stations, however, indicate that sediment characteristics, which result from the influence of the prevalent hydrodynamic regime, may not be the primary determinant of benthic community composition. Although the sediment characteristics of the RE area were substantially different from those observed in the LIP and PIT areas, the benthic community in the RE area was not significantly different from the communities in the LIP and PIT areas for any of the measured parameters.

It is possible, therefore, that a factor which operates on an even larger scale than the hydrodynamic processes is affecting all three sampled areas. Two potential hypotheses concerning this effect are provided below.

Hypothesis 1 - Recent large scale recruitment at the Sokos

Sampling of the Sokos Study site was undertaken in November 1996. There are no data available on the timing of reproductive events for benthic organisms in Hong Kong waters, and it is possible that the sampling occurred during a recruitment period for one or more of the dominant species. When such events occur, large numbers of planktonic larvae, reacting to chemical or biological cues, settle out of the pelagic environment to the sediment, where they mature if conditions are suitable, or perish if they are not. Recruits are, by their nature, abundant but very small, and if present, would be likely to be found widely dispersed throughout the Sokos Study area. The presence of such recruits would prevent other differences in assemblage structure between PIT, LIP and RE sites being detected.

Hypothesis 2 - Mature assemblages are present in each of the sites, but these are dominated by small individuals

Stressed assemblages may occur naturally (eg in areas with intense hydrodynamic regimes) or because of anthropogenic disturbance (eg trawling, dredging or pollution). Such assemblages could also contain high abundances of low biomass individuals, and this would not be distinguishable from recruitment events on abundance and biomass alone. Although the sediment characteristics in the RE area indicate that natural physical stresses differ between the RE area and the LIP and PIT areas, other factors not measured by this Study may be exerting a broad scale effect.

In the absence of further data on local recruitment, hydrodynamic regimes and anthropogenic disturbance, it is not possible to elucidate which factors are dominant in structuring the benthic community assemblages at the Sokos.

4.6 *SUMMARY*

In summary, this Study has shown that:

- the PIT and LIP areas at the Sokos have a very heterogeneous sediment structure, apparently the result of a naturally complex hydrodynamic regime, and perhaps compounded by previous dredging activity;
- both PIT and LIP areas currently support similarly high abundances of low biomass benthic invertebrates;
- despite this similarity, the PIT area supports a significantly lower number of taxa than the LIP area;
- the RE area to the east of the Soko Islands has much more homogenous sediment characteristics than the PIT or LIP areas, and natural physical disturbance appears minimal;
- despite this difference in sediment characteristics, the RE area was found to support a similar benthic assemblage to both PIT and LIP areas;
- this similarity in assemblage composition, despite locally different sediment characteristics, may result from an additional, undetermined factor, possibly a recruitment pulse; and,
- none of the PIT, LIP or RE areas showed a clear correlation between benthic assemblage composition and sediment size, TOC content or RPD depth.

5 SOUTH CHEUNG CHAU

5.1 STUDY OBJECTIVES

A general objective of the Seabed Ecology Studies at South Cheung Chau was to determine the impact of open sea disposal operations on local benthic assemblages. The Study also provided further baseline ecological information on the site, to compliment that obtained from previous studies.

The objectives of the Seabed Ecology Studies at this site were threefold:

- to examine infaunal recolonization of areas affected by deposition of dredged material;
- to examine differences in recolonisation patterns between 'old mound', 'new mound', 'apron' and far-field reference areas; and,
- to examine the benthic characteristics and features which may structure the infaunal assemblages at the areas sampled.

5.2 THE SOUTH CHEUNG CHAU SITE

5.2.1 *Site History*

The South Cheung Chau disposal site is an area of seabed of approximately 18.75 km^2 (7.5 km east-west by 2.5 km north-south), centred some 4.5 km southwest of Cheung Chau. It was first gazetted for "General Purpose" disposal in 1981, and has more recently been used as an open water disposal site for uncontaminated dredged material. In 1992, approximately 80M m^3 of grab and trailer dredged material was disposed at the site, although, as a result of site closure due to mounding, annual volumes had diminished to approximately 21M m^3 and 7M m^3 by 1994 and 1995 respectively.

Disposal of materials has been managed by allocation of grab and trailer dredged materials to different areas within the site. Grab dredged materials have been primarily disposed in the northern and western portions of the site, whilst trailer dredged material has been allocated to southern and central areas. No disposal has been authorised in the eastern portion of the site since 1991.

5.2.2 *Physical Site Characteristics*

Hydrodynamic conditions at the Study site are greatly influenced by freshwater discharges from the Pearl River. Data from routine water quality monitoring stations to the south of Lantau Island (EPD 1994) indicate that estuarine conditions prevail, with mean recorded surface salinities of 28.4 ppt (ranging from 20.2 to 33.5 ppt) and mean bottom salinities of 32.3 ppt (ranging from 31.4 to 33.5 ppt).

The seabed in the area was naturally flat before the commencement of disposal operations, and sloped gently southwards and eastwards to depths of -15 to -20 mPD. Disposal operations have altered this considerably, and two large disposal mounds are now present in the centre and east of the site's northern edge, rising to - 8 mPD at the shallowest point (BGS 1995).

Sediments near the disposal site historically exhibited a southeast - northwest gradient from sandy to progressively finer sediment (SAIC 1994a). Recent sediment profile imagery (SPI) surveys have shown that disposed sediments now present within the site are much more heterogeneous than nearby reference areas and include some very soft, fluid muds (BGS 1995). Dredged material is now present outside of the designated site boundaries in all directions, and different transport and dumping methods (and subsequent mass movements of material) have produced distinctive sea bed morphologies over much of the area. "Impact rings" produced by dumping from split hopper barges, and trawl marks are also present throughout the site (BGS 1995).

5.2.3 *Previous Ecological Studies*

A number of different benthic invertebrate surveys have been undertaken at the disposal site. These have included quantitative grab surveys and dive surveys, qualitative surveys using the Remote Ecological Monitoring of the Seafloor (REMOTS® system) and incidental surveys using remotely operated vehicle (ROV) techniques.

The earliest grab sampling in the area was undertaken between July 1976 and January 1977 as part of a Hong Kong wide survey of infaunal benthos, and used a Smith Macintyre benthic grab to sample two sites near the Soko Islands (Shin and Thompson 1982). Results indicated that the fauna was composed mainly of polychaetes, with a mean abundance of 82.5 individuals m^{-2} and a mean biomass of 35 g m^{-2}. Two polychaetes, *Tharynx* sp and *Paraprionospio pinnatato*, were recorded as the most abundant species, in terms of number and biomass, of the benthic fauna at the site.

Another benthic grab survey, undertaken in December 1993 as part of the Fill Management Phase VI project (Binnie Consultants Ltd 1994a), involved six sampling stations. Of these, four were dump site stations (one each of previous and current, trailer and barge dumping areas) and two were reference stations. Very low abundances and biomasses were obtained from the dump site stations (five, zero, one and one animals $grab^{-1}$ recorded respectively, maximum recorded biomass 0.01 g m^{-2}). Higher abundances of 37 and 34 animals $grab^{-1}$ (308 and 208 animals m^{-2}) were recorded at the reference stations, although biomass levels of 1.4 and 0.2 g m^{-2}, respectively, were again low compared to those recorded by Shin and Thompson. Polychaetes were the dominant class recorded, with Nephytidae and Spionidae the most common families.

A REMOTS® survey undertaken in October 1993, again recorded polychaetes as being most abundant, both within and outside the disposal site. However, freshly deposited mud layers appeared to be devoid of macrofauna (SAIC 1994a). A second REMOTS® survey, undertaken in May 1994, was combined with a grab sampling programme for ground truthing. Twelve stations were surveyed, and a mixture of assemblages was found to be present within the disposal site. Areas of freshly deposited mud were again found to support few animals, whilst other stations supported a range of polychaetes and some echiuroids. One site, where considerable amounts of shell debris and mud clasts were present, was found to be exceptionally rich in invertebrates, and the three grabs yielded a total of 96 species and 965 individuals (SAIC 1994b).

An ROV survey undertaken in May 1995 provided incidental information on the benthos of the area (Binnie Consultants Ltd 1995a). Three different areas were surveyed: a mound of barge dumped clay (at -6 mPD), an apron of dumped material (at -15 mPD), and an area of recently consolidated (but previously fluid) mud (at -15 mPD). The mound contained numerous fish and invertebrate burrows, and several large tunicates and some gorgonian corals were attached to areas of harder sediment. The apron also supported several small gorgonians and soft corals, as well as at least one large bivalve mollusc. The recently consolidated mud contained low-medium densities of fish and invertebrate burrows.

A dive survey, carried out in May 1996, involved the use of 50 m SCUBA transects to quantify the extent of sediment recolonisation (Binnie Consultants Ltd 1995b). Again three areas were sampled: an area of consolidated mud near the centre of the disposal site (-16 mPD), an apron of barge-dumped spoil in the north-west of the site (-14 mPD) and a mound of disposed material in the northern portion of the site (-9 mPD). Results showed that although faunal assemblages were present throughout the disposal site, the heterogeneous nature of the site had resulted in considerable assemblage variation between the different areas sampled.

The consolidated mud, which had apparently flowed down from adjacent dumped material, supported the largest numbers of invertebrates, with a high density of stomatopod, chaetopterid and alpheid burrows present, together with smaller polychaetes and mollusc burrows. Gastropod trails and crab tracks were common on the mud, and several sea pens were present. The apron of barge-dumped spoil, which was mostly firm mud with some outcrops of more consolidated clays and patches of coarse material (including broken shells and debris), supported several small sea whips and similar burrows, although at a lower density, to those in the consolidated mud. The northern mound of disposed material comprised sticky clay with extensive areas of shell debris and some small rocks. Large burrows were present, although at the lowest density of any of the three sites, and the area had been sparsely colonised by gorgonians, gastropods, bivalves and crustaceans. Exposed rocks had been colonised by barnacles, bryozoans and the solitary hard coral *Balanophylia* spp.

5.2.4 *Sampling Station Selection*

Previous surveys of the seafloor in the Study area had shown the presence of two mounds within the footprint of disposed material (BGS 1995). Grab sampling effort was therefore designed to maximize the number of stations within each of five Study areas, namely the eastern and western disposal mounds (designated E and W), the aprons associated with each of these mounds (designated SE and SW) and a reference area to the east of the Sokos Islands (REF). Grab sample station locations for the Study site are shown in *Figure 5.2a.*

SPI samples, designed to collect information on sediment physical properties and processes influencing benthic community structure, were taken from two cross-shaped grids centred on the apexes of the disposal mounds. Additional samples were taken from random locations on dredged material layers adjacent to these topographic highs, within the gazetted disposal site boundaries. A northeast transect of stations heading toward Cheung Chau was taken to sample beyond the previously delineated dredged material footprint (BGS 1995), and reference samples were also taken from the REF area to the east of the Soko Islands. SPI sample station locations for the Study site are shown in *Figure 5.2a.*

5.3 *RESULTS*

5.3.1 *Grab Samples*

A total of 11,082 specimens, belonging to 70 families in seven phyla were recorded from the Study site. Polychaetes were the most abundant group present, representing 96 % of identified individuals, although only 33 % of the total biomass. By contrast, molluscs constituted less than 1 % of the identified individuals but provided 60 % of the total biomass recorded. The full dataset of taxa recorded in each grab sample is summarised in *Table 5.3a* below.

Table 5.3a ***Summary of Taxa Recorded from the South Cheung Chau Study Site***

Phylum	Total Number of Families Identified	Total Number of Individuals Recorded	Total Biomass (g)
Annelida	43	10,586	86.81
Arthropoda	17	291	16.22
Echinodermata	2	55	1.64
Hemichordata	1	1	0.72
Mollusca	6	57	143.20
Sipuncula	1	93	0.56
Nemertinea	>1	6	0.54
Unidentified	-	-	0.52
Total	> 71	11,082	250.21

Although most animals sampled were identified to family level, exceptions applied as described in *Section 2.4.1.*

Data from the grab sampling programme were analysed in terms of mean abundance, biomass, and taxonomic richness in each of the areas sampled. The results of the analysis are summarised in *Table 5.3b.*

Table 5.3b ***Summary of Benthic Grab Survey Results from the South Cheung Chau Site***

Study Area	Reference Area REF (n=8)	East Mound E (n=9)	South- East Apron SE (n=13)	West Mound W (n=10)	South-West Apron SW (n=16)
Mean Total Abundance (individuals grab^{-1} ± SD)	176 ± 70	179 ± 103	325 ± 480	297 ± 263	55 ± 35
Mean Total Biomass (g grab^{-1} ± SD)	2.9 ± 1.7	8.8 ± 11	7.0 ± 12	3.9 ± 3.5	1.1 ± 0.90
Mean Taxonomic Richness	22 ± 3.2	15 ± 3.0	15 ± 4.8	15 ± 3.5	10 ± 3.2

The overall mean abundance recorded from the Study site was high (200 animals grab^{-1}; 2,100 animals m^{-2}), as were mean abundances from all sample areas. Even the most depauperate area, the SW apron area, supported an average of 55 animals grab^{-1} (570 animals m^{-2}), a figure considerably higher than that recorded by Shin and Thompson in 1982 (101 animals m^{-2}).

Polychaetes (phylum Annelida) were the most common group present. Of the polychaetes, the most abundant family in the assemblages in each of the W mound, E mound and SE apron areas, were the Spionids which often represented over 80 % of the individuals. Mean abundances was highest in the SE and W areas (where Spionids were present at densities of up to 1,300 animals grab^{-1}), lower in the E mound and REF areas, and lowest in the depauperate SW apron area. Other polychaetes (especially Capitellids and Magelonids) also formed an important element of the assemblage in the SW apron and REF areas, and these areas, which did not support such high abundances of Spionids showed little between-station variation in abundance of major taxa.

The mean total abundance of animals recorded per grab in each area and their taxonomic composition is presented in *Figure 5.3a (i)*. The abundance of the numerically dominant families in each area is shown in *Figures 5.3a (ii)*.

Overall mean biomass levels recorded from the South Cheung Chau site were typical in waters of Hong Kong, at 4.7 g grab^{-1} or 48.9 g m^{-2} (Shin and Thompson recorded an average value of 35 g m^{-2} from Hong Kong waters in 1982). Biomass was highest in the E mound (8.8 g grab^{-1} or 91.5 g m^{-2}) and SE apron (7.0 g grab^{-1} or 72.8 g m^{-2}); lower from the W mound(3.9 g grab^{-1}, 40.6 g m^{-2}) and REF area (2.9 g grab^{-1} or 30.2 g m^{-2}); and lowest from the SW apron, where only 1.1 g grab^{-1} (11.4 g m^{-2}) was recorded.

Large numbers of low-weight Spionid polychaetes provided much of the biomass recorded from the disposal site stations, although biomass from the reference area was derived from a wider range of polychaete taxa. In addition to the Spionids present, the W mound also supported relatively high biomasses of Capitellid polychaetes and Pinnotherid crustaceans (pea crabs). The high biomasses recorded from the E mound and SE apron were largely due to the presence of a few heavy Venerid bivalves (weighing up to 15.1 g each) which represented over 90 % of the total biomass recorded at some stations. Other large specimens included a 0.72 g Hemichordate acorn-worm (SW apron), a 0.6 g pea-crab (SW apron), a 1.80 g Hoplocarid mantis shrimp (E mound), and two Terebellid polychaete worms weighing 1.70 g between them (SE apron). Within-area biomass variability was mostly due to the uneven distribution of the Venerid molluscs and, to a lesser extent, Spionid polychaetes. The mean wet biomass recorded in each area, and its taxonomic composition, is presented in *Figure 5.3b (i)*. The mean biomass of the gravimetrically dominant families recorded in each area are shown in *Figures 5.3b (ii)*.

Taxonomic richness varied between sample areas, with the REF area supporting the greatest mean number of families per station (22 families grab^{-1}). The E mound, W mound and SE apron all had similar levels of taxonomic richness (15 families grab^{-1}), whilst that of the SW apron was lowest at 10 families grab^{-1}. Although common polychaete taxa (eg Capitellidae, Cirratulidae, Pilargiidae and Spionidae) were present throughout most of the stations sampled, other families (eg Syllidae and Phascolionidae) were more frequently encountered in the W mound than other sites, and the Magelonidae and Paraonidae were most commonly present in the REF area.

5.3.2 *SPI Investigations*

Previous geophysical investigations concluded that dredged material was widely distributed both within and outside the South Cheung Chau disposal site boundaries (BGS 1995). The current SPI survey confirmed these results, and showed that all stations sampled (with the exception of the reference area) were located on deposits of dredged material which were thicker than the maximum prism penetration depth of 21 cm.

The majority of stations sampled throughout the Study site consisted of primarily fine-grained sediment, with a major mode of silt-clay (> 4 ϕ), although some disposal site stations contained high-reflectance, white or red consolidated clay clasts, indicative of their origins as dredged material (*Figure 5.3c*). At other disposal site stations sediment textures ranged from a smooth, consolidated sedimentary matrix (*Figure 5.3d*) to granular, pelletized surface layers with mud clasts of varying thicknesses at the sediment-water interface (for an example of this see *Figure 3.4d*).

Each of the designated mound apexes was found to have a fine-grained mud base overlain by sand or shell hash (for an example of this see *Figure 4.3e*). Prism penetration at these stations was minimal, but distinct boundaries could still be seen between the sand and mud layers (for an example of this see *Figure 4.3g*). Profiles taken from the north-east transect showed highly-fluid, low shear-strength sediments, possibly resulting from disposed trailer dredged material (*Figure 5.3e*). Many of these stations suffered from over-penetration of the camera prism, and therefore provided no information about the nature of the sediment-water interface.

5.3.3 *Sediment Characteristics*

Stations from the E mound, SE and SW aprons and reference area were all dominated by fines (smaller than 63 μm diameter), although REF stations had a higher percentage of sediment of 75 - 150 μm in diameter. Stations from the W mound contained more large grained sediment (over 700 μm diameter) and SPI images from this area showed that seven of the ten stations sampled had surface layers of medium to very coarse sand overlying the fine-grained mud base. Total Organic Carbon values across the Study site ranged from 0.6 % - 0.9 % (*Figure 5.3f*).

5.4 *DATA ANALYSIS RESULTS*

5.4.1 *Grab Samples*

Mean transformed measures of total abundance, total biomass and taxonomic richness from each Study area were compared through step-wise analyses using ANOVA and Scheffe's tests.. The initial analyses involved comparison of the two mounds (and aprons) from the eastern and western parts of the Study site to determine whether data could be validly pooled for further analysis. Where no significant differences were detected between these data sets, mean mound (or apron) values were then compared to other Study areas. Where significant differences were detected between east and west mounds (or aprons), the two areas were retained separately for analysis.

The two mound areas (E and W) were not found to differ significantly from each other in any of the parameters measured. Data were therefore combined for the subsequent analyses. The two apron areas (SE and SW) differed significantly from each other in taxonomic richness at a p - value of 0.05 (the SW area had a significantly lower mean value), although not in abundance or biomass. Taxonomic richness data were therefore retained separately for the subsequent analyses.

Combined mound data were found not to differ significantly from reference data for any of the parameters measured. The mound data also did not differ significantly from the two apron datasets in total abundance or biomass, although they did have a significantly higher taxonomic richness than the SW apron. There was no significant difference in taxonomic richness between the mounds and the SE apron. Both apron areas had significantly lower taxonomic richness than the reference area. These analyses are summarised in *Table 5.4*.

Table 5.4 ***Summary of Univariate Analysis and Multiple Comparison Test of Grab Sample Data***

Parameter	Outcome of ANOVA analysis (p value)	Comparison Between Stations (SNK Test)
Total Abundance	$p = 0.228$ (Not Sig)	ref < apron < mound
Total Biomass	$p = 0.257$ (Not Sig)	ref < apron < mound
Taxonomic Richness	$p = 0.029$ (Sig) $p = 0.009$ (Sig) $p = 0.000$ (Sig) $p = 1.000$ (Not Sig) $p = 0.002$ (Sig) $p = 0.270$ (Not Sig)	SW apron < SE apron SW apron < mound SW apron < ref SE apron = mound SE apron < ref mound < ref

Sig = significant at the $p < 0.05$ level. Values underlined are statistically significantly different.

The high mean abundance and biomass values recorded in some areas (see *Table 5.3a*) were greatly influenced by a few stations containing very high numbers of Spionid polychaetes or biomasses of Venerid molluscs. The effects of these values on group means became less important after data transformation, so not all apparent differences were statistically significant.

5.5 *DISCUSSION*

This section provides an interpretation of the data and analyses undertaken, as described in detail in *Section* 5.3 and *Section 5.4*. The significance of the results are considered in the light of both the overall and the specific aims of this Study.

5.5.1 *South Cheung Chau Site Characteristics*

SPI and sediment data revealed that all stations sampled within the South Cheung Chau disposal site were located on substantial deposits of dredged material. Sediment at most stations was composed of fine grained silt-clays (>4 ϕ), but a number of stations contained mud clasts of varying thickness. It was not possible to accurately distinguish the border between mound and apron areas, although the apexes of the mound sites were recognisable due to the high levels of sand or shell hash present. The additional SPI transect to the north-east of the disposal site recorded highly fluid, low shear strength sediments extending well beyond the previously delineated dredged material footprint. Such sediments are typical of trailer dredged material, and may have resulted from short dumping. Recorded apparent RPD depths ranged from 0 to 4.37 cm below the sediment water interface, with shallower depths, indicative of more recent disturbance, found near the mound apexes.

Values of TOC recorded throughout the South Cheung Chau Study site showed no relationship with grain size or assemblage composition, but were similar to those recorded elsewhere in Hong Kong waters (EPD 1996).

5.5.2 *Study Objective 1: Recolonisation of Sediments Within and Around the Disposal Site*

Grab and SPI data showed that all stations sampled within the South Cheung Chau disposal site support some benthic fauna, and none of the Study areas supported a benthic community that was significantly lower in abundance or biomass than the reference area. In fact, invertebrate abundances at the disposal site were considerably higher than those recorded from other surveyed areas throughout Hong Kong (eg Shin and Thompson 1982, Binnie Consultants Ltd 1994a).

The invertebrate assemblages sampled during the present Study at the disposal site may be explained in a number of ways. Stations may have been recolonised since the last local disposal event through an influx of young and adults from nearby areas, and/or the passive settling out of planktonic larvae (and some juveniles) from the water column. Previous studies have indicated that benthic recolonization proceeds quickly in Hong Kong waters, although recolonising assemblages often differ from those of undisturbed areas (ERM 1997d , ERM 1997e, Binnie Consultants Ltd 1995a). Opportunistic taxa such as Spionids and Capitellids are usually most abundant in recently disturbed areas, and were commonly recorded at the South Cheung Chau disposal site.

Alternatively, the dredged material disposed at the site may have retained some of its original benthic infauna. Taxa which are tolerant of physical disturbance and adaptable to (potential) local changes in the physio-chemical environment may have survived transportation to the disposal site. Although the biotic component of dredged material has not been studied, the numerically dominant Spionids recorded from disposal site areas are hardy, pollution tolerant species, which are often dominant within the organic-enriched sediments of Hong Kong harbour (SAIC 1996). The high biomass bivalves recorded from several disposal site stations are also unlikely to be recent colonisers as the species are relatively immobile, and take a considerable time to grow to the sizes recorded, therefore it is likely that these organisms may have been passively transported to the site in dredged material.

Finally, the fauna present may be remnants of the original fauna from the site. Many infaunal taxa have the ability to survive burial after storms or natural sediment slumping. The frequency of such events limits the potential for sediment recolonisation, and burial depth, burial time, deposited sediment properties, species affected and local water temperature are all important in determining the severity of such impacts (Rhoads *et al* 1978). Again no data are available as to survival of local benthic assemblages under disposal conditions, but hardy, or mobile, taxa may well survive from one disposal event to another.

5.5.3 *Study Objective 2: Differences in Recolonisation Patterns Between the New Mound, Old Mound, Apron and Reference Areas*

The most striking difference between disposal site Study areas was the low abundance and species richness present in the SW apron. This could be the result of a number of recolonisation scenarios, including:

- slumping of material from the western mound may have recently smothered the benthic assemblage present in the SW apron and insufficient time may have elapsed for sediment recolonisation from nearby areas;

- the apron may have been less recently affected by disposed material than other areas in the disposal site, which may now support assemblages dominated by species transported to the site with biotic dredged material; and,
- other factors not addressed by this Study may be operating in the vicinity of the SW apron.

The first hypothesis may be supported by the low taxonomic richness of the SW apron. Such reduced richness values have been recorded from other disposal site studies, and are believed to be indicative of an adverse impact, often anthropogenic in origin (eg Hall 1994). However, the absence of elevated Spionid abundances or Venerid biomasses in the reference area (despite its more diverse assemblage) may imply that such taxa have either been transported to the site in disposed material, or are somehow exploiting existing conditions within the site to a greater extent than other taxa. Neither hypothesis can be evaluated further without data on the faunal content of disposed material.

5.5.4 *Study Objective 3: Factors Structuring Infaunal Assemblages*

Sediment grain size, percent TOC and RPD depth were highly variable throughout the disposal site, and mean values showed no relationship with benthic assemblage structure. Reference stations tended to have intermediate values of grain size, percent TOC and RPD depth, but these characteristics were also present at disposal site stations. Samples from the mound apexes were found to have more shell lag than other stations, but SPI analysis indicated that a thick layer of dredged material was present throughout the disposal site, and transitional boundaries between mound and apron areas could not be accurately defined. None of the measured sediment characteristics appeared to be of overriding importance in determining area assemblage composition. The elapsed time since the last disposal event, and biotic content of the disposed material are likely to affect the benthic infaunal assemblage present.

The high abundances, in combination with low biomasses, may be attributable to a recruitment pulse for one or more of the dominant taxa (eg the Spionids). Results from the survey undertaken near the Soko Islands during the same period showed similar abundance: biomass relationships (ERM 1997e). If recruitment had occurred, the large numbers of low-weight larvae would be widely dispersed throughout the Study site, preventing other differences in assemblage structure between the disposal and reference areas from being detected. Alternatively, the Study area assemblages may be the result of some other form of anthropogenic disturbance, either physical (eg trawling) or chemical (eg organic enrichment). Such factors could stress assemblages, causing dominant taxa to be present at high abundances of low biomass individuals, and reducing overall taxonomic richness. This would be indistinguishable from recruitment effects on the data presented here, and could mask local effects resulting from disposal operations.

In the absence of further data on recruitment, biotic content of dredged material, and ongoing anthropogenic impacts in the area, it is, however, not possible to further evaluate the factors structuring the benthic community assemblages at the South Cheung Chau disposal site.

5.6 *SUMMARY*

In summary, this Study has shown that:

- mound and apron areas have been affected by dredged material deposition, which appears to have spread beyond the designated site boundaries;
- all areas of the disposal site support assemblages which are comparable in abundance and biomass to the far-field reference area;
- taxonomic richness at disposal site areas is less than that from the reference area, and richness at the SW apron is particularly low;
- assemblage composition also differs between disposal site areas and the reference area, with Spionids less dominant in the reference area;
- both disposal site and reference areas support high abundances of low biomass invertebrates;
- there are no clear relationships between assemblage composition, sediment size, TOC content or RPD depth at the disposal site; and,
- a number of factors, which cannot be fully evaluated given the data available, may be structuring local faunal assemblages including biotic content of disposed material; elapsed time since last disposal event; ongoing anthropogenic impacts and local recruitment events.

6 *SOUTH LAMMA*

6.1 *STUDY OBJECTIVES*

The South Lamma survey area was proposed as a reference area for the Seabed Ecology studies for the following reasons:

- it was thought unlikely to be affected by dredging and disposal activities (Note: following a reconnaissance geophysical survey it was actually shown that there was degraded dumped material within the area);
- it has been proposed by AFD for designation as a potential site for a marine park due to corals and gorgonians along the Sham Wan coastline and possible nesting grounds for green turtles on Sham Wan beach; and,
- the benthic ecology of the area has not been studied in detail previously, therefore this survey provides a useful opportunity to obtain baseline ecological information for the site.

The objectives of the Seabed Ecology studies at this site were:

- to characterise the soft bottom benthic community in an area of southern waters; and,
- to examine the benthic characteristics and features which structure the infaunal assemblages at the areas sampled.

6.2 *THE SOUTH LAMMA SITE*

6.2.1 *Site History*

The Study site is located in southern Hong Kong waters and stations are located between 200 m and 1.5 km from the South Lamma coastline. The area has been identified by AFD as a potential site for a marine park due partly to evidence that green turtles nest on Sham Wan beach and the presence of corals and gorgonians along the coastline. The southern portion of the site is currently a Dangerous Goods anchorage.

6.2.2 *Site Characteristics*

Hydrodynamic conditions to the south of Lamma Island are influenced by the oceanic environment of the South China Sea. Routine water quality monitoring conducted by EPD throughout Hong Kong waters includes a sample station (SM18) to the south of Lamma, although not within the Study site (approximately 6 km away), which is likely to reflect the general off-shore conditions in area (*Figure 6.2a*). Mean bottom salinities of 33.5 ppt, mean bottom dissolved oxygen saturation of 79.2 % and mean suspended solids of 9.2 mg L^{-1} (ranging from 1.7 to 17.3 mg L^{-1}), were recorded at station SM18, which reflect the oceanic conditions to the south of Lamma.

Due to the lack of existing geophysical information on the South Lamma Study site, a geophysical survey, comprising swath (multibeam) bathymetry, side scan sonar and benthic grab sampling was undertaken to fully assess the area (EGS 1997). Results indicated that the seabed South of Lamma is flat at a depth of - 20 mPD to -22 mPD. Within the sheltered Sham Wan Bay, depths decrease considerably to -10 mPD. The presence of anchor marks was detected within the dangerous goods anchorage site and trawl marks were identified in two areas, adjacent to the coast and further offshore in the dangerous goods anchorage. An area of degraded dumped material was reported at the mouth of Sham Wan Bay and some smaller areas along the Lamma coastline. The seabed was classified as sandy clay during grab sampling by EGS (EGS 1997) and silt clay in a Remote Ecological Monitoring of the Seafloor (REMOTS) survey conducted by Binnie Consultants in 1993 (SAIC and Binnie 1994).

6.2.3 *Previous Ecological Studies*

At the time of the Study, existing data on the benthic ecology of the south of Lamma area was sparse and restricted to one historical benthic grab Study (Shin and Thompson 1982), recent REMOTS (SAIC and Binnie 1994) survey of Hong Kong waters and dive surveys of the hard bottom communities in Hong Kong (Binnie Consultants Ltd 1995b).

Shin and Thompson used a Smith Macintyre benthic grab to sample Hong Kong waters, including several locations south of Lamma, (although none from within the current Study site) between November 1976 and January 1977. Results indicated that the fauna was dominated by polychaetes, with a mean abundance of 88.2 individuals m^{-2}, which was approximately average compared to other sites in Hong Kong waters. Two polychaetes, *Nephtys* sp and *Aglaophamus lyrochaeta*, were recorded as the major benthic fauna at the site, comprising 11.9 and 10.8 % of the total number of individuals collected.

A Hong Kong wide REMOTS survey conducted by Binnie Consultants Limited and SAIC in 1993 surveyed several sites south of Lamma (SAIC and Binnie 1994). Benthic habitat quality was generally high with mature undisturbed ecological communities observed. Prism penetration depths were uniformly high indicating unconsolidated sediments and apparent RPD depths of 3 cm or greater. The report interpreted these conditions as consistent with good habitat quality.

Recent underwater surveys focussed on the hardbottom communities of Hong Kong waters, including the Sham Wan coastline, were conducted between October 1991 and November 1994. Hard corals and fish were observed and the site was classified as being of high conservation value due its proximity to the turtle nesting area at Sham Wan beach (Binnie Consultants Ltd 1995b).

6.2.4 *Sampling Station Selection*

The sample stations and areas were located using the results of the geophysical survey of the South Lamma area conducted in February 1997 (EGS 1997). Samples were collected from within Sham Wan Bay (SHAM WAN), the dangerous goods anchorage (ANCH-IN and ANCH-OUT) area located south of Sham Wan Bay and the area of degraded dumped material (DDM-IN and DDM-OUT) located in the mouth of Sham Wan Bay. The sampling plan is shown in *Figure 6.2a*.

6.3 RESULTS

6.3.1 *Grab Samples*

A total of 6,457 specimens, belonging to 60 families in ten Phyla were recorded from the South Lamma site. Polychaetes (phylum Annelida) were the most common group present, representing 57 % of all identified individuals and 31 % of the total biomass. The data set summarised in *Table 6.3a*.

Table 6.3a ***Summary of Organisms Recorded from the South Lamma Study Site During the Grab Sampling Programme***

Phylum	Total Number of Families Identified	Total Number of Individuals Recorded	Total Biomass (g)
Annelida	38	3,664	37.01
Arthropoda	10	488	30.96
Cnidaria	1	4	5.31
Echinodermata	2	116	4.08
Hemichordata	1	38	10.18
Mollusca	4	1,648	16.05
Nematoda	1	376	0.37
Nemertinea	-	3	0.10
Sipuncula	1	23	0.09
Total	58	6,360	104.15

Some of the fauna collected were not identified beyond phylum level as detailed in *Section 2.4.1*.

The results of the grab sampling are presented in terms of mean abundance, biomass and taxonomic richness in each of the areas sampled. A summary of the results of the grab investigations is provided in *Table 6.3b*.

Table 6.3b ***Summary of the Grab Data from the South Lamma Sampling Areas***

	SHAM WAN (n=8)	DDM-IN (n=8)	DDM-OUT (n=8)	ANCH-IN (n=8)	ANCH-OUT (n=8)
Mean Total Abundance (individuals grab^{-1} ± SD)	320±337	333±206	67±43	41±16	30±7.5
Mean Total Biomass (g grab $^{-1}$ ± SD)	2.1±1.7	5.1±4.5	1.6±1.9	2.1±2.8	1.3±1.9
Mean Taxonomic Richness (Taxa grab^{-1} ± SD)	19±5.0	21±6.4	14±5.5	13±2.3	12±2.9

The overall mean abundance recorded from the South Lamma site was 161 individuals grab^{-1} or 1674 individuals m^{-2}, which was higher than the abundances observed previously at Eastern Waters (352 individuals m^{-2} (ERM 1997c)), Basalt Island (238 individuals m^{-2} (ERM 1997d)), East Sha Chau (468 individuals m^{-2} (ERM 1997e)) and East of Ninepins (291 individuals m^{-2} (ERM 1997a)) but lower than the mean abundance recorded at the Sokos (2168 individuals m^{-2} (ERM 1997b)), Tathong Channel (3130 individuals m^{2} (ERM 1997f)) and South Cheung Chau (2,100 individuals m^{-2} (ERM 1997g)). Abundances of 320 and 333 individuals grab^{-1} (3327 and 3462 individuals m^{-2}) were recorded at SHAM WAN and DDM-IN respectively, which was considerably higher than those recorded at the DDM-OUT (67 individuals grab^{-1} or 697 m^{-2}), ANCH-IN (41 individuals grab^{-1} or 426 m^{-2}) and ANCH-OUT (30 individuals grab^{-1} or 312 m^{-2}) areas.

Overall mean biomass levels recorded from the South Lamma Study site were 2.94 g grab^{-1} or 30.57 g m^{-2}, which was within the 0.58 to 4.7 g grab^{-1} range recorded at other sites in Hong Kong (ERM 1997a-g), but slightly lower than that recorded by Shin and Thompson in 1982 (35 g m^{-2}).

Polychaetes (phylum Annelida) were the most common group at all sites. Large numbers of the polychaetes Capitellidae, Spionidae, Pilargiidae, Pisionidae and Paraonidae and the arthropod Ampeliscidae were recorded at all sites and within the DDM-IN area high abundances of the mollusc Veneridae were also recorded.

The mean total abundance of animals recorded per grab in each sample area, and their composition by major taxonomic group, is presented in *Figure 6.3a (i)*. The mean abundance per grab of the numerically dominant families recorded in each area is shown in *Figure 6.3a (ii)*.

No one taxa was distinctly gravimetrically dominant within the South Lamma Study area as a whole, however, there were site specific characteristics. At SHAM-WAN and DDM-IN Annelids were gravimetrically dominant, at ANCH-OUT and DDM-OUT Arthropods were the heaviest taxa recorded and at ANCH-IN the 'other' group (comprising all recorded taxa other than molluscs, arthropods and annelids) recorded the highest biomass. The Pinnotherid crabs were recorded at high biomasses at all areas in the Study site.

The mean wet biomass recorded in each area, and its taxonomic composition, is presented in *Figure 6.3b (i)*. The mean biomass of the gravimetrically dominant families recorded in each area are shown in *Figure 6.3b (ii)*.

Taxonomic richness also varied between sampling areas, with SHAM-WAN and DDM-IN areas supporting a greater mean number of families per station (19 and 21 families grab^{-1}) than the DDM-OUT, ANCH-IN and ANCH-OUT areas (14, 13 and 12 families grab^{-1}, respectively).

6.3.2 SPI Investigations

Results from the SPI investigations showed a considerable difference in sediment characteristics within the sample stations in Sham Wan bay (SHAM-WAN, DDM-OUT and DDM-IN areas) and between these and those further offshore in the anchorage area (ANCH-IN and ANCH-OUT). The stations within the anchorage area recorded uniform fine grained sediments, with high water content and low shear strength.

Stations in the west of Sham Wan bay were dominated by coarser grained sediments of fine or medium sands while those on the east side of the bay were uniformly dominated by fine grained sediments (silt-clay, $\geq 4\ \Phi$). Within the SHAM-WAN bay area the distinct difference in sediment grain size observed is likely to be due to erosional forces operating in the west and depositional forces causing finer grained sediments in the east. Sand ripples indicating sea bottom transport were visible at stations in the west (*Figure 6.3c*), whereas soft grained sediments *(Figure 6.3d)* with the presence of coral at some stations (*Figure 6.3e)* were present in the east.

In the mouth of Sham Wan bay in the area of degraded dumped material (DDM-IN and DDM-OUT) an east to west gradient in sediment types was also observed. The seafloor in the east of the bay is dominated by fine grained muds with low-shear strengths that show evidence of deep biological reworking (*Figure 6.3f*), this type of sediment was also observed throughout the southern anchorage area. Within the degraded dumped material area three stations (L-15, L-16 and L-23) were located on fine-grained bottom with debris and rocks on the sediment surface (*Figure 6.3g*).

The variation in sediment grain size and biological reworking depth was reflected in the pattern of prism penetration depth. The shallower prism penetration values on the west side of the bay correspond to the presence of coarse grained sediment in this area. Prism penetration increased in the southern area of the bay as the percentage of fine grained sediments increased. Camera prism penetration was minimal on the eastern side of the bay mouth due to the presence of rocks, coral and debris. It is interesting to note that the stations with the highest camera prism penetration, located within the ANCH-IN, ANCH-OUT and DDM-OUT areas, also recorded the lowest abundance and biomass values in grab samples from the Study site. However, the SPI images show evidence of a biologically active community perhaps suggesting that this community exists within a deeper strata than that sampled by the grabs.

The depth of the apparent Redox Potential Discontinuity (RPD) was greatest at those stations dominated by fine grained sediments and intense biological reworking. Evidence of deposit-feeding taxa and well oxidised sediment layers was observed at most stations which is indicative of a healthy benthic community.

Within the ANCH-IN and ANCH-OUT areas uniformly high (>15 cm) prism penetration was recorded which is consistent with the heterogeneous silt clay sediments observed in these areas.

6.3.3 *Sediment Characteristics*

The laboratory data support the grain size determinations compiled from SPI image analysis. Eighty-eight percent of the stations were dominated by silt-clay sediments. The stations along the western coast of the SHAM WAN area (L-1, L-3, L-6 and L-8) had much coarser sediments than at other stations with only 2 % to 16 % silt-clay. Grain size and TOC from the stations at South Lamma are summarised in *Table 6.3c* and presented *Figure 6.3h.*

Table 6.3c ***Summary of Sediment Characteristics from the South Lamma Site***

Parameter	**SHAM WAN Stations**	**DDM-IN Stations**	**DDM-OUT Stations**	**ANCH-IN Stations**	**ANCH-OUT Stations**
% Fines (<63μm) (Mean % by weight ±SE)	35.60± 10.34	71.01±5.73	97.50±0.73	89.48± 0.74	91.15±1.06
Total Organic Carbon (% ± SE)	1.81± 0.36	1.47±0.51	1.17±0.23	0.97± 0.19	0.98±0.10

Sediment TOC values were highest at the stations in the north of the Study area, (ie SHAM WAN, DDM-IN and DDM-OUT) and lower in the off-shore anchorage area (ie ANCH-IN and ANCH-OUT). TOC values at the stations in SHAM WAN, DDM-IN and DDM-OUT areas in the north of the Study site were higher than the average (1 %) for marine sediments (Tyson and Pearson 1991) and higher than the range (0.47 to 1.17 %) recorded previously in Hong Kong waters (ERM 1997a - g).

6.4 *DATA ANALYSIS RESULTS*

6.4.1 *Grab Samples*

Measures of total abundance, total biomass and taxonomic richness from the five Study areas were compared using ANOVA and Student-Newman-Keuls (SNK) post-hoc multiple range test. If the results of the ANOVA indicated that the means were not equal in the five Study areas, the multiple range test was employed to identify where the differences lay. The data were evaluated using graphical display for adherence to the parametric statistical model assumptions of approximate normality and equal variances. Non-normal distributions were observed for total abundance and total biomass and a log transformation was performed to allow parametric analyses. Taxonomic richness data had an approximately normal distribution and did not need transformation prior to parametric analysis. All test were performed to the $\alpha = 0.05$ level. These analyses are summarised in *Table 6.4*.

Table 6.4 ***Summary of Univariate Analysis and Multiple Comparison Test of Grab Sample Data***

Parameter	**Outcome of ANOVA analysis (p value)**	**Outcome of SNK Multiple Comparison Test**
Total Abundance	$p = 0.00$ (***)	SW DDM-IN DDM-OUT ANCH-IN ANCH-OUT
Total Biomass	$p = 0.056$ (NS)	
Taxonomic Richness	$p = 0.001$ (***)	DDM-IN SW DDM-OUT ANCH-IN ANCH-OUT

Note: *** = $p < 0.01$
NS= Not Significant
SNK Multiple comparison tests: Areas underlined are not statistically significant. Areas on the left side of the column recorded the highest values and those on the right the lowest.

These tests indicate the following trends:

- Significantly higher abundances were recorded at the SHAM WAN and DDM-IN areas compared to ANCH-IN, ANCH-OUT and DDM-OUT;
- Total biomass was not significantly different between the five Study areas in the South Lamma Study site; and,
- ANCH-IN, ANCH-OUT and DDM-OUT recorded similar (not significantly different) family level taxonomic richness, however these values were significantly lower than taxonomic richness recorded at the DDM-IN station.

6.5 DISCUSSION

This section provides an interpretation of the data and analyses undertaken, as described in detail in *Section 6.3* and *Section 6.4*. The results are considered in the light of both the overall and the specific aims of this Study.

6.5.1 *South Lamma Site Characteristics*

All sample stations in the Lamma Study site were dominated by silt-clay except for four stations along the west coast of Sham Wan bay (L-1, L-3, L-6 & L-8) where the sediments were of predominantly medium to fine sand. Mean TOC values in the anchorage area were 0.97 and 0.98 % which is close to the average for TOC in marine sediments (1 %) (Tyson and Pearson 1991). However, in the areas closer to the shore mean TOC values were 1.87 % (SHAM WAN), 1.47 % (DDM-IN) and (DDM-OUT) 1.17 % which was considerably higher than average. This pattern is unusual as higher TOC levels are generally found in soft sediment depositional environments such as those outside Shan Wan Bay, with lower TOC levels in coarser grained sediments. In this case, these high TOC levels are likely to be caused by organic matter washing into the sea from the land, due to the close proximity of these stations to Lamma island.

The overall mean infuanal abundance recorded in the South Lamma Study site was 1674 individuals m^{-2} which was considerably higher than that recorded by Shin and Thompson in 1982 (88 individuals m^{-2}). However, the mean abundance recorded at the South Lamma Study site was lower than those recorded at the Sokos, South Cheung Chau and Tathong Channel, all in southern waters, but higher than that recorded at other sites in Hong Kong waters.

6.5.2 *Study Objective 1: Patterns in Infaunal Communities*

Within the South Lamma Study site, the mean total abundance was significantly higher at the SHAM WAN and DDM-IN areas compared to DDM-OUT and both of the anchorage areas. In addition, taxonomic richness was lower within the anchorage areas and DDM-OUT than at DDM-IN. Taxonomic richness at SHAM WAN was not statistically significantly different from any other area. No significant difference in mean biomass was recorded across the Study site.

Largely the same families were collected within each Study area, therefore stations were separated primarily due to differences in abundance of the common families. However, the sandy stations located in the west of Sham Wan Bay had consistently high total abundance, with Spionid polychaetes dominating. Stations on the eastern shore of Sham Wan Bay were very variable and were characterised by either very low abundance, or very high abundance, the presence of most of the dominant taxa and Tellinidae clams. Within the mouth of Sham Wan Bay the communities were dominated by Veneridae clams, however this did not appear to be linked to sediment grain size or TOC.

In general, the benthic communities sampled in the South Lamma Study site separate into two groups. Those in close proximity to the shoreline (SHAM WAN and DDM-IN) recorded benthic communities with higher abundance, biomass and taxonomic richness, higher sediment TOC and larger sediment grain size than at all other stations. Stations in the anchorage area and DDM-OUT, further offshore, recorded highly heterogeneous silt clay sediment and benthic communities with lower mean abundance, biomass and taxonomic richness than was recorded in all other areas.

6.5.3 *Study Objective 2: Factors Structuring Infaunal Communities*

There was no widespread evidence of physical disturbance and sediment transport within the Study site and with the exception of the four sandy stations on the west coast of Sham Wan Bay the entire area appears to be primarily a low-energy depositional regime. Therefore, the major variations in the physical environment which may influence the benthic assemblages are the differences in sediment grain size and TOC content of the sediment. Benthic communities within the South Lamma Study site can be loosely linked to both these variables as the high abundance and family level taxonomic richness observed in SHAM WAN and DDM-IN correlates with the high TOC levels and larger sediment grain size in these areas. Correspondingly the lower abundances and taxonomic richness in the ANCH-IN, ANCH-OUT and DDM-OUT areas can be correlated with the comparatively lower TOC levels, smaller sediment grain size and higher sediment water content at these locations.

The larger grain size at the four sandy stations in the west of Sham Wan Bay may explain the distinctness of the benthic communities at these stations. Within this cluster of stations, the highest abundance and highest taxonomic richness was observed at station L-2, which is likely to be due to the proximity of this station to the shore and the heterogeneity in grain size distribution in this area. Large variations in grain size within a sediment provides a larger number of niches for colonisation by benthic fauna than are present in heterogeneous sediments. High sediment TOC content also indicates that community growth is not limited by food supply. Both these factors contribute to the high abundance, biomass and taxonomic richness found in the SHAM WAN and DDM-IN areas.

The reason for the high energy environment along the western side of Sham Wan Bay and the lower energy environment on the opposite east coast could be linked to the predominantly easterly winds which exist in this area. The east wind causes waves and swells which would impact the west (east facing) coast, whilst the east (west facing) coast would be in the lea of the wind in a lower energy environment. However, if this is the case one would expect to observe a similar high energy environment (to that in the west of the Bay) and evidence of bottom sediment transport at the mouth of Sham Wan Bay. These conditions were not observed at the mouth of Sham Wan Bay indicating that this hypothesis may not be correct.

6.6 *SUMMARY*

In summary, this Study has shown that:

- stations on the west side of Sham Wan Bay are located in a high kinetic energy regime where bedload transport and erosion occur. The medium to coarse sand bottom in this area is distinct from the fine grained silt clay sediments found throughout the rest of the Study site;
- the benthic communities within SHAM WAN and DDM-IN areas were significantly more abundant than those found at all other areas;
- the benthic communities within the anchorage area were uniform and showed significantly lower abundance than SHAM WAN and DDM-IN, significantly lower taxonomic richness than DDM-IN, but were not significantly different from those at DDM-OUT;

- the distinctness of the benthic communities within the SHAM WAN and DDM-IN areas is likely to be due to the higher sediment heterogeneity and higher sediment TOC levels recorded in these areas; and,
- the dominant families within the Study site were Ampeliscidae, Capitellidae, Cirratulidae, Pilargiidae, Spionidae and Veneridae.

7 *TATHONG CHANNEL*

7.1 *STUDY OBJECTIVES*

A general objective of the Seabed Ecology Studies at Tathong Channel was to determine the impact of dredging operations on local benthic assemblages, using some of the approaches described in *Section* 2.

The objectives of the Seabed Ecology Studies at this site were threefold:

- to examine recolonization by infaunal taxa of sediments within the MBA pit;
- to examine differences between the assemblages of the MBA pit, the lip and a far-field reference area; and,
- to examine the benthic characteristics and features which structure the infaunal assemblages at the areas sampled.

7.2 *THE TATHONG CHANNEL SITE*

7.2.1 *Site History*

The Tathong Channel marine borrow area (MBA) is located to the east of Hong Kong Island, and comprises an area of approximately 11.8 km^2 between Fat Tong Chau, Po Toi and Cape d'Aguilar. This site is a mosaic of allocated borrow areas, which have been dredged for sand at different times, including some which have not yet been dredged. The earliest dredging took place in allocation 2, located east of Tung Lung Chau, between December 1990 and September 1991. The most recent dredging took place from April 1993 to June 1994 due south of Tung Lung Chau. The LIP stations were located adjacent to the PIT area. Dredging in these areas was completed in March and April 1994, therefore these areas have been undisturbed for a slightly longer period of time than the PIT stations.

7.2.2 *Site Characteristics*

Hydrodynamic conditions in the Tathong Channel are influenced by both tidal currents and oceanic water movements. Current speeds are highest in the narrow northern channel and water velocities drop as the channel widens to the south. Water quality data from the Environmental Protection Department's (EPD) routine water quality monitoring stations located within Tathong Channel (EPD 1996) recorded mean bottom salinities of 33.2 ppt, mean bottom dissolved oxygen saturation of 84.4 % and mean suspended solids of 6.1 mg L^{-1} (ranging from 1.9 to 15.7 mg L^{-1}), which reflect the oceanic influence.

The natural seabed around the Tathong Channel MBAs varies between depths of -13 mPD in the north western section, near Victoria Harbour, to approximately -30 mPD in the south east, south of Tung Lung Chau. The MBAs are at depths ranging between -30 mPD and -40 mPD. Sediments within the MBAs are dominated by silts and clays. Fluid mud and angular mud clasts were also noted both within and outside the MBA (SAIC and Binnie 1994a).

7.2.3 *Previous Ecological Studies*

There has been little ecological data collected previously from the Tathong Channel site. The two most recent studies have utilised the Remote Ecological Monitoring of the Seafloor (REMOTS) system, whilst a historical Hong Kong-wide Study of benthic communities conducted by Shin and Thompson utilised benthic grabs (Shin and Thompson 1982).

Shin and Thompson used a Smith-Macintyre benthic grab to sample several locations in Tathong Channel between November 1976 and January 1977 (Shin and Thompson 1982). These stations were classified as typical of scoured tidal channels in Hong Kong and results indicated that the fauna was dominated by polychaetes and molluscs, with a mean abundance of 182.6 individuals m^{-2}. The mean abundance recorded in these scoured tidal channels was higher than at any other area in Hong Kong waters. The mollusc *Tapes philippinarum* was recorded as the most abundant species at these sites.

Two REMOTS surveys were conducted in Tathong Channel by SAIC and Binnie Consultants Limited, in 1993 and 1994. The first of these studies surveyed sites throughout Hong Kong waters, in addition to Tathong Channel. Within the northern part of Tathong Channel there was evidence of organic loading which was thought to be due to the close proximity of this area to pollution sources in Victoria Harbour and the Chai Wan sewage outfall (SAIC and Binnie 1994b).

A subsequent REMOTS survey conducted in May and June 1994 surveyed Tathong Channel and the surrounding seabed to examine the recolonisation of previously dredged areas. The Study concluded that since the termination of dredging, the borrow pits have undergone some colonisation, however, there were several stations where there was little prism penetration due to consolidated clay substratum. As it is unlikely that sediments consolidated to the extent that they prevent prism penetration would encourage colonisation of benthic organisms, it was assumed these sediments contained uncolonised sediments (SAIC and Binnie 1994a).

7.2.4 *Sampling Station Selection*

The sampling design was to sample from within the pit (PIT), the pit lip (LIP) area and one reference (REF) area located southwest of the pit lip. The PIT stations were located on the allocations which have been dredged most recently (16 and 17). LIP stations were located on allocations 14 and 15 which have been dredged less recently and are located adjacent to the PIT. REF stations were located close to the dredged areas but on sediments which have not been dredged. The sampling plan is shown in *Figure 7.2a*.

7.3 *RESULTS*

7.3.1 *Grab Samples*

A total of 13,550 specimens, belonging to 67 families in eight phyla were recorded from the Tathong Channel site. Polychaetes (Annelida) were the most abundant group present, representing 82.7 % of the identified individuals and 56.4 % of the total biomass. The data is summarised in *Table 7.3a*.

Table 7.3a ***Summary of Organisms Recorded from the Tathong Channel Study Site During the Grab Sampling Programme***

Phylum	**Total Number of Families Identified**	**Total Number of Individuals Recorded**	**Total Biomass (g)**
Annelida	43	11,211	85.77
Arthropoda	12	313	18.15
Echinodermata	3	173	28.89
Echiura	1	1	7.07
Mollusca	5	1,731	8.38
Nemertinea	-	5	0.41
Sipuncula	1	110	1.55
Total	65	13, 544	150.22

Some of the fauna collected were not identified beyond phylum level as described in *Section 2.4.1.*

Data from the sampling programme were analysed in terms of mean abundance, biomass and taxonomic richness in each of the areas sampled. A summary of the results of the grab investigations is provided in *Table 7.3b.*

Table 7.3b ***Summary of the Grab Data from the Tathong Channel Sampling Areas***

	PIT (n=16)	LIP (n=15)	REF (n=14)
Mean Total Abundance (individuals grab^{-1} ± SD)	239±282	242±126	433±361
Mean Total Biomass (g grab $^{-1}$ ± SD)	2.3±2.0	3.9±2.8	3.7±3.5
Mean Taxonomic Richness (Taxa grab^{-1} ± SD)	19±6.1	24±3.9	23±4.2

The overall mean abundance recorded from the Tathong Channel Study site was 301 individuals grab^{-1} or 3130 individuals m^{-2}, which was high compared to other locations in Hong Kong waters (ERM 1997b, ERM 1997g, ERM 1997a, ERM 1997d). A mean abundance of 433 individuals grab^{-1} was recorded at the REF area which was nearly twice the densities present in the PIT and LIP areas (239 and 242 individuals grab^{-1}, respectively). Overall mean biomass levels recorded from Tathong Channel were typical of waters in the Territory, at 3.4 g grab^{-1} or 35 g m^{-2}. Shin and Thompson recorded an average value of 35 g m^{-2} from Hong Kong waters in 1982. Mean biomass was lower at the PIT (2.3 g grab^{-1}) than the LIP and REF areas (3.9 and 3.7 g grab^{-1}).

Polychaetes (phylum Annelida) were the most common group present during the survey, comprising 83 % of all individuals captured. Large numbers of Capitellidae, Cirratulidae and Spionidae were recorded at all sites and within the PIT high abundances of the mollusc Veneridae were also recorded. Three annelid species, *Parheteromastus tenuis, Prionospio queenslandica* and *Cirriformia filigera,* were abundant at many stations and were present in numbers >100 grab^{-1} at several stations.

The mean total number of individuals recorded per grab in each sample area, and their composition by major taxonomic group, is presented in *Figure 7.3a (i)*. The mean abundance per grab of the numerically dominant families recorded in each area is shown in *Figure 7.3a (ii)*.

As well as being numerically dominant, polychaetes were gravimetrically dominant throughout the Tathong Channel Study site. There was a general paucity of large organisms; the largest individual recorded was the burrowing echiurian *Ochetostoma erythrogrammon* weighing 7.07 g. Within the REF area Spionidae were gravimetrically dominant, at the LIP Spionidae and Schizasteridae were recorded in the highest biomasses and in the PIT, Echiuridae were recorded in the largest biomasses.

The mean wet biomass recorded in each area, and its taxonomic composition, is presented in *Figure 7.3b (i)*. The mean biomass of the gravimetrically dominant families recorded in each area are shown in *Figure 7.3b (ii)*.

Taxonomic richness also varied between sampling areas, with LIP and REF areas supporting a greater mean number of families per station than the PIT area (24, 23 and 19 families grab^{-1} respectively).

7.3.2 *SPI Investigations*

Results from the SPI investigations showed a substantial overlap in sediment characteristics between the three survey areas. In general, images were taken at a depth of between -26 and -28 mPD. Most stations sampled exhibited fine grained (ie silt-clay) sediments, however, several of those stations closest to shore in both the PIT (T-46) and REF (T-51 and T-52) areas were primarily coarse sand.

Images from the PIT stations showed predominantly fine grained silt clay sediments, however north of the PIT (T-47) a hard sea-bottom, and the presence of coral, was observed (for an example of this see *Figure 6.3e*). Many of the stations in this area had a high moisture content (*Section 7.3.3)*, and these highly fluid muds had low shear strengths and bearing capacity which accounts for the frequent occurrence of camera prism over penetration in the PIT area (for an example of this see *Figure 5.3e*). Another station within the PIT (T-12) consisted silt clay with a small amount of sand at the surface (for an example of this see *Figure 4.3g*). Spatial variation in relative shear strengths and corresponding camera over penetration within Tathong Channel Study site can be observed, with the highest frequency of over penetration occurring within the PIT and the southeastern area of the LIP.

Sediments within the REF area were characterised by firm silt clays with surface sand layers. Station T-54, located near to the shore in the REF area had sediments with a distinct surface layer of shells and coarse sand (for an example of this see *Figure 4.3e*), and all other stations within the REF area, had surface sand layers that were fairly distinct (for an example of this see *Figure 6.3a*) or were reworked into the upper sediment layers by bioturbation (*Figure 7.3c*). There were no occurrences of prism overpenetration in this area.

Sediments in the LIP area were transitional between those in the PIT and those in the REF area. Some stations showed highly fluid muds with camera prism overpenetration while others were firmer silt clays with surface sand layers (for an example of this see *Figure 4.3d*). The major distinguishing differences between the PIT and REF areas were the frequency of stations with high water content (see *Section* 7.3.3) and high frequency of camera overpenetration in the PIT and the presence of a fine to medium sand layer at the sediment surface at all stations in the REF area.

There was evidence of deposit feeding taxa at many of the predominantly silt clay stations, however, those stations with surface sand layers appeared to be characterised by a richer diversity of fauna, possibly due to the heterogeneity in grain size and thus available habitat niche. An example of an SPI image indicating the presence of polychaetes is illustrated in *Figure 3.4c*.

Although a wide range of Redox Potential Discontinuity (RPD) depths were recorded, the range was consistent among the three areas. There were no stations with high sediment oxygen demand or overlying hypoxic or anoxic waters which would cause low RPD values (<1 cm). The depth of the oxygenated surface layer of sediments ranges between 1.2 to 3.8 cm across all stations, indicative of fairly healthy communities with active biological reworking. RPD values could not be obtained at several stations within the PIT and LIP areas due to the frequency of camera prism overpenetration in these areas.

7.3.3 ***Sediment Characteristics***

The laboratory data support the grain size determinations compiled from SPI image analysis that percent fines was largest in the PIT, smallest at the REF area and intermediate at the LIP. Grain size data, TOC and moisture content from the stations at Tathong Channel are summarised in *Table 7.3c*. Sediment grain size data is presented in *Figure 7.3d*.

Table 7.3c ***Summary of Sediment Characteristics from the Tathong Channel Site***

Parameter	PIT Stations	LIP Stations	REF Stations
% Fines (<63μm) (Mean % by weight±SE)	75.43 ± 5.81	56.45 ± 10.60	37.74 ± 6.51
Total Organic Carbon (% ± SE)	0.85 ± 0.08	0.56 ± 0.19	0.47 ± 0.10
% Moisture Content	46.04 ± 2.38	38.90 ± 6.01	32.01 ± 1.89

Overall 91 % of the stations were dominated by silt-clay (< 63μm) with this fraction contributing between 33 and 100 % of the total weight. The stations in the LIP and REF areas had lower % fines and a higher fraction of sand than stations in the PIT. Six of the fourteen REF stations had sediments with a grain size in the coarse (+ 710 μm) to fine (+ 150 μm) size range. Percent fines were greater at the LIP than the REF stations but lower at the LIP than the PIT.

A wide range in sediment moisture content was observed in the Study site with many of the stations in the PIT and two in the LIP recording highly fluid muds with a water content in excess of 50 %. In general, moisture content was highest at the silt-clay dominated PIT stations, lowest in the REF area and intermediate in the LIP.

Sediment TOC was highest in the PIT which corresponds with the smaller grain sediment grain size recorded in this location. TOC was lowest in the REF area and intermediate at the LIP. Seventy one percent of the stations in the Tathong Channel Study site had TOC values below 1.0 %. This is below the average (1 %)

for marine sediments (Tyson and Pearson 1991)) but within the range recorded at other sites in Hong Kong waters (ERM 1997a, ERM 1997b, ERM 1997d, ERM 1997e, ERM 1997g).

7.4 *DATA ANALYSIS RESULTS*

7.4.1 *Grab Samples*

Measures of total abundance, total biomass and taxonomic richness as well as the abundance of the five most numerically dominant families from the three Study areas, were compared using an ANOVA and Student-Newman-Keuls (SNK) post-hoc multiple range test. If the results of the ANOVA indicated that the means were not equal in the three Study areas, the multiple range test was employed to identify where the differences lay. The data were evaluated using graphical display for adherence to the parametric statistical model assumptions of approximate normality and equal variances. Non-normal distributions were observed for total biomass and total abundance as well as the abundance of four of the five dominant families. A log transformation was performed on these data to allow parametric analyses. Taxonomic richness and Capitellidae abundance data had approximately normal distributions and did not need transformation prior to parametric analyses. All tests were performed at the $\alpha = 0.05$ level. These analyses are summarised in *Table 7.4*.

Table 7.4 ***Summary of Univariate Analysis and Multiple Comparison test of Grab Sample Data.***

Parameter	Outcome of ANOVA analysis (p value)	Outcome of SNK Multiple Comparison Test
Community-based hypotheses		
Total Abundance	$p = 0.015$ (**)	PIT LIP REF
Total Biomass	$p = 0.046$ (**)	PIT REF LIP
Taxonomic Richness	$p = 0.009$ (***)	PIT LIP REF
Taxonomic-based hypothesis		
Cirratulidae Abundance	$p = 0.031$ (**)	PIT LIP REF
Capitellidae Abundance	$p = 0.072$ (NS)	
Spionidae Abundance	$p = 0.015$ (**)	PIT LIP REF
Veneridae Abundance	$p = 0.911$ (NS)	

Parameter	Outcome of ANOVA analysis (p value)	Outcome of SNK Multiple Comparison Test
Pilargiidae Abundance	$p = 0.006$ (***)	PIT LIP REF

Note: ** = $p < 0.05$
*** = $p < 0.01$
NS= Not Significant
SNK Multiple comparison tests: Areas underlined are not statistically significant. Areas on the left side of the column recorded the lowest values and those on the right the highest.

These tests indicate the following trends:

- PIT stations recorded significantly lower total abundance and family level taxonomic richness than the REF area and significantly lower mean biomass and richness than LIP stations;
- The abundance of Veneridae and Capitellidae were not significantly different among areas; and,
- The abundance of Cirratulidae, Spionidae and Pilargiidae were significantly lower at the PIT than the REF area, and the average abundance of Pilargiidae was also lower at the PIT than the LIP.

The biomass at the two sandy stations within the REF area was considerably lower than at all other REF stations. These stations with low biomass values reduced the mean biomass grab^{-1} of the REF area considerably resulting in no significant difference between the mean biomass at the REF and the lower mean biomass at the PIT. Removal of the sandy stations from the dataset and subsequent statistical analysis resulted in a significantly greater biomass at the REF and PIT area.

7.5 *DISCUSSION*

This section provides an interpretation of the data and analyses undertaken, as described in detail in *Section 7.3* and *Section 7.4*. The results are considered in the light of both the overall and the specific aims of this Study.

7.5.1 *Tathong Channel Site Characteristics*

Sediment grain size for all stations ranged from coarse sand to silt-clay material. Most of the stations with fine-grained sediments (>80 % fines) were found in the PIT, while most of the sandy stations (<30 % fines) were found in the REF area. The moisture and TOC content of the sediments showed a positive relationship with the percent fines. TOC values within the Study site were low indicating that the area is not heavily influenced by organic loading from Victoria Harbour and the Chai Wan sewage outfall.

The overall mean infaunal abundance recorded in the Tathong Channel Study site was very high (3130 individuals m^{-2}), compared to that recorded by Shin and Thompson in 1982 (101 individuals m^{-2}). However, the overall mean biomass value for the Study site (35 g m^{-2}) was identical to that reported by Shin and Thompson, indicating that benthic communities in the area are dominated by large numbers of individuals with biomass approximately average for Hong

Kong waters. The discrepancy observed between these two datasets could be due to temporal or spatial variances between the two surveys.

7.5.2 *Study Objective 1: Recolonisation of Sediments Within and Surrounding the MBA*

Within the Tathong Channel Study site, the PIT and LIP areas showed evidence of recolonisation. Infaunal population densities in these two areas ranged from low (135 m^{-2} at Station T13) to very high (9,400 m^{-2} at Station T12), with an average station population density of approximately 2,500 individuals m^{2} and an average biomass of 32 g m^{-2}. Benthic communities within the PIT and LIP were characterised by the same common families as those at the REF stations. These data indicate that sediments within and surrounding the PIT have been recolonised or are in the process of being recolonised.

7.5.3 *Study Objective 2: Differences in Benthic Communities Between PIT, LIP and REF Areas*

The mean total abundance and taxonomic richness were significantly lower within the PIT than at the REF area. In addition, total biomass and taxonomic richness were also significantly lower at the PIT than the adjacent LIP area. No significant differences between the benthic communities at the REF area and the LIP were detected.

7.5.4 *Study Objective 3: Factors Structuring Infaunal Assemblages*

Variations in the benthic assemblages within the Tathong Channel Study site can be linked to variations in sediment characteristics. Depth gradients across all stations vary by only 2 metres and there is no evidence of erosion or transport in the SPI images. Therefore, these factors are unlikely to greatly influence the benthic communities. The low abundance, biomass and family-level taxonomic richness observed within the PIT (compared to the REF and LIP area) shows a relationship with the high frequency of stations with fluid mud (>50 % water content) and a high silt-clay content in this area. Correspondingly, the higher abundance, biomass and family-level taxonomic richness in the REF area, compared to the PIT, shows a relationship with a higher mean sediment grain size and lower sediment water content.

A possible reason for the distinct communities within the REF area, compared to the PIT and the LIP, is that the larger variety in sediment grain size and the presence of a surface sand layer at these stations created a more heterogeneous benthic environment and a larger number of niches for benthic fauna. The surface sand layer present on the seabed in the REF area and at some of the LIP stations could be due to the sand borrowing activities which have occurred at the adjacent marine borrow areas or may represent a naturally occurring geological feature of the area.

The low abundance, biomass and richness within the PIT is likely to be a response to the highly fluid nature of the sediment. Fluid mud has a low density and limited ability to support organisms (Rhoads 1974) and large individuals may find it difficult to find sufficient physical support to prevent sinking into the substrate. Reduced biomass of organisms is a frequent adaptation of organisms to this type of environment (Stanley 1970), and would explain the low biomass recorded at this site. In addition, this sub-optimal habitat is expected to also result in lower abundances and taxonomic richness. The fluid muds in this area could be attributed to high organic inputs from Victoria harbour and the Chai Wan sewage outfall, however the low TOC values reported during this survey discount this as a potential source of the fluidised sediments. Another possible explanation could be near bottom sediment transport, which has been shown to occur in other areas in the east of Hong Kong (ERM 1997c). This, however, is also unlikely as there was no evidence of bottom sediment transport in the SPI images collected within the Tathong Channel area. It is possible that the fluid mud observed within the PIT is due to overflow of fine sediment with a high water content back into the water column during the dredging process. However, this is unlikely, since dredging in the PIT was completed almost 3 years prior to this survey and any fluid mud which collected within the PIT during the dredging process is likely to have become consolidated in the low velocity conditions within the dredged pit.

7.6 *SUMMARY*

In summary, this Study has shown that:

- The benthic assemblage in the Tathong Channel area, as sampled in April 1997, is characterised by very high abundances and intermediate biomass and is dominated by polychaetes;
- Recolonisation has occurred within the PIT with abundance, taxonomic richness and biomass values comparable to those reported in previous Hong Kong wide benthic surveys;
- The PIT stations have lower mean total abundance and richness than REF stations and lower mean biomass and richness than the LIP area;
- The biological community is similar in taxonomic composition throughout the site, with variation in abundance by taxa among stations.
- The dominant families in the Tathong Channel Study site were Cirratulidae, Capitellidae, Spionidae, Veneridae and Pilargiidae;
- Approximately half the stations sampled in the PIT area recorded fluid muds, (water content in excess of 50 %); and it is possible that this is responsible for the lower abundance, taxonomic richness and biomass recorded in this area; and,
- The presence of coarse sand on the surface of the sediment in the REF area and at some stations in the LIP, appears to have increased the habitat heterogeneity and may result in higher faunal abundances in these areas.

8 *EAST OF NINEPINS*

8.1 *STUDY OBJECTIVES*

A general objective of the Seabed Ecology Studies at East of Ninepins was to determine the impact of disposal operations within the area on local benthic assemblages, using some of the approaches listed. This Study also expanded on previous work in the area, which is described below in *Section* 2.2.3.

The East of Ninepins disposal site lies approximately 1.5 km to the east of the Ninepin Island Group, in the eastern waters of Hong Kong (*Figure 1.1a*). The site has been used as an open water disposal site for uncontaminated dredged material since 1981 (see *Section 2.2.1*) and dumping operations are ongoing. Recent (1995) geophysical surveys of the site have identified three geophysically distinct areas; the mound, the mound apron and a mass flow area to the northwest of the mound, which was formed by mound slope failure (see *Section* 3 for a definition of terms).

The objectives of the Seabed Ecology Studies at this site were fourfold:

- to examine recolonization by infaunal taxa of sediments within the disposal site;
- to examine differences in recolonization between the mound, apron and far-field reference areas (to the south (RS) and north (RN) of the site);
- to examine differences in assemblage structure between years or seasons, by comparison of the results of this Study with previous data, including data from the same reference stations (RS and RN) (Binnie 1994b; Binnie 1996a); and,
- to examine the benthic characteristics and features which structure infaunal assemblages.

8.2 *THE EAST OF NINEPINS SITE*

8.2.1 *Site History*

The East of Ninepins disposal site comprises an area of approximately 2.7 km^2 lying 1.5 km east of East Ninepin Island and 3.2 kms east of the main Ninepin Group. The site was first gazetted for "General Purpose" disposal in 1981 and more recently has been used as an open water disposal site for uncontaminated dredged material. The position at which vessels dispose within the site is determined by the Fill Management Committee (FMC) and is changed every 1 to 3 months to avoid the formation of a hazard to navigation. Since 1993, an average of 24 barge loads day^{-1} (= 20,000 m^3 day^{-1} of disposed material) and 3.6 trailer dredger loads day^{-1} (= 30,000 m^3 day^{-1} of disposed material) have been disposed. There are also reports of previous unpermitted disposal of construction waste and other debris in the vicinity of the site and indications of intensive trawling in the area.

8.2.2 *Site Characteristics*

The natural seabed in this area is generally flat and gently slopes such that depth increases westward toward the Ninepin Island Group. Prior to dumping the seabed was at a depth of approximately -27m. Periodic bathymetric surveys indicate that in recent years (1991 to 1994), two large mounds have formed in the western portion of the site and two north-south ridges have developed in the central and eastern portions of the site. Due to slope failures, possibly caused by storm events, an apron of material has formed to the west and southwest of the site. A mass flow area, where the mound slope has failed, lies at the northwest boundary of the site. Impact rings, indicating discrete disposal events, exist throughout the site. A recent bathymetric survey (1996) has updated the precise locations of all the above features of the East of Ninepins disposal site.

8.2.3 *Previous Ecological Studies*

Previous ecological studies in the area comprise the following:

- Sediment profile imagery investigations of the Ninepins disposal site (SAIC 1994);
- grab sampling adjacent to the Ninepin Islands undertaken in December 1993 and January 1994 (Binnie 1994b); and,
- grab sampling undertaken in June 1995 in the RS and RN stations (Binnie 1996a).

Sediment profile imagery stations in and around the disposal site were sampled in May 1994. These images indicated a post-depositional density flow of fluid mud from the centre toward the edges of the disposal site. The report concluded that the benthic infauna are apparently well-adapted for physical bottom disturbance as, based on the sediment images, the presence of dredged material had not affected the infaunal assemblage.

Grab samples were collected at several stations around the Ninepins Group between December 1993 and January 1994. Five replicate samples were taken at each station, using a Ponar grab (dimensions 333 x 365 x 215 mm; thus sampling area = 0.12 m^2 and volume = 26.1 L), the grab samples were sieved, identified to family level and wet biomass measured. At the two stations nearest the disposal site, the infauna were dominated by polychaetes and the stations ranked moderate to high in abundance and diversity. These results coincide with those of a previous Study, undertaken throughout Hong Kong waters in 1976 and 1977, (Shin and Thompson 1982) which also identified polychaetes as the dominant fauna in the eastern waters.

The RS and RN stations sampled during this Study were first sampled in June 1995 (Binnie 1996a) using a Van Veen grab. The results of this Study indicate that at the RS and RN stations, polychaetes, particularly the Capitellidae, were dominant.

8.2.4 *Sampling Station Selection*

For the benthic grab samples, sampling effort was allocated to maximize the number of stations within different impact zones. SPI stations were located along known physical topographic gradients, to collect information on physical sedimentary properties and processes influencing the benthic community structure. The sampling locations for grab and SPI stations are indicated in *Figure 8.2a*.

8.3 RESULTS

8.3.1 Grab Samples

A total of 51 grab samples were taken from the East of Ninepins site. Seven stations in the RN area and 9 stations from the mound were not sampled owing to rough sea conditions and the proximity of vessels undertaking disposal operations, respectively. A total of 1442 specimens belonging to 73 families were collected from the 51 grabs, as shown in *Table 8.3a*.

Table 8.3a Organisms sampled in the Grab Sampling Programme at East of Ninepins

Phylum	Total Number of Identified Families	Total Number of Individuals Recorded	Total Biomass (g)
Annelida	28	961	8.67
Arthropoda	20	385	8.10
Cnidaria	2	4	9.77
Echinodermata	3	56	3.57
Echiura	1	32	0.09
Mollusca	19	42	30.55
Total	73	1,480	60.75

In addition to these, several other phyla were collected, but were not identified to family level, for reasons described in *Section 2.4.1.*

For the purpose of this Study, the three stations located in the mass flow area (N21, N22 and N23) were treated as mound stations as these stations were located on top of disposed material and were indistinguishable from the mound. The total abundance and composition of the benthic assemblage by major taxonomic group (Polychaete, Mollusc, Crustacea, Cnidaria and Others) is presented in *Figure 8.3a (i)*. The abundances of the dominant families identified at each area are presented in *Figure 8.3a (ii)*. These figures indicate that of the four areas, the north reference (RN) and MOUND contained the highest total abundance of organisms, dominated by polychaetes. The lowest abundances were recorded from the APRON and RS stations, with polychaetes and 'other' major taxa being dominant. At the family taxonomic level, the Nemertinea and Pilargiidae dominated RN, APRON and RS stations and the Spionidae polychaetes were clearly dominant in the MOUND stations.

The total biomass and composition of the benthic assemblage by major taxonomic group is presented in *Figure 8.3b (i)*. Unlike the pattern shown in abundance, the RS stations had the highest mean biomass values, with a clear dominance by Molluscs. The lowest biomass was found in the MOUND and APRON stations, where crustacea were gravimetrically dominant. The biomass of the dominant families identified at each area are presented in *Figure 8.3b (ii)* and indicate that at the family level, the Arcidae (bivalve molluscs) dominated the RS stations, while dominance at the other stations was shown by the Sternaspidae polychaetes (RN) and the decapod crustacea Goneplacidae (MOUND and APRON).

A summary of the results of the benthic grab investigations is provided below in *Table 8.3b*.

Table 8.3b ***Summary of Grab Data from the East of Ninepins Sampling Areas***

Parameter	RN (n=9)	RS (n=16)	MOUND (n=10)	APRON (n=16)
Mean Total Abundance (individuals grab^{-1}±SD)	36.7±14.1	22.4±9.1	38.9±19.6	21.8±11.0
Mean Total Biomass (g grab^{-1}±SD)	1.1±1.1	2.9±4040	0.3±0.3	0.3±0.2
Mean Taxonomic Richness	16.3±4.5	11.1±2.6	7.7±2.5	11.6±4.2

8.3.2 *SPI Investigations*

SPI images were obtained from 46 stations; rough sea conditions inhibited camera operation at the remaining 5 stations.

The RN and RS stations showed similar sediment profiles typical of the ambient sea floor in Hong Kong territorial waters (uniform fine-grained sediment, low boundary roughness, well-developed redox layers, and evidence of deposit feeders). The average depth of the apparent RPD ranged from 1.42 to 6.07 cm at these two areas (the mean for both RS and RN was 3.28 cm)

In contrast, the MOUND stations exhibited heterogeneity in sediment grain-size, high boundary roughness, and lower average RPD values. The average RPD depth at the MOUND stations was notably lower, ranging from 0.45 to 4.15 cm (mean RPD depth for all MOUND stations was 1.77 cm). In addition to the mud clast sediment texture that has been previously described in Hong Kong sediment profile images (eg Binnie 1995a), there were four distinct facies (two with primarily silt-clay, two with primarily sand) that were recognizable in the sediment profile images from the dredged material mound. These facies were characterised as follows:

- Facies 1 = a sand component (ranging in size from very fine to medium sand) which formed a distinct surface layer
- Facies 2 = a sand component (ranging in size from very fine to medium sand) in which the sand was poorly sorted and dispersed throughout the mud matrix
- Facies 3 = silt-clay as the grain-size major mode and consolidated clumps of mud at the surface; and,
- Facies 4 = silt-clay as the grain-size major mode and uniform textures.

Station N37 showed clear evidence of non-native material at the surface in the form of cobble that had been transported from shallower water, as indicated by the presence of barnacles encrusting the cobble surface (*Figure 8.3c*).

The SPI transect and APRON stations to the west of the disposal mound (N17 to N21, N41, N45, N53) did not show evidence of dredged material present. Three of the stations (N41, N45, and N53) confirmed the earlier results from the interpretation of the side-scan sonar results performed by the British Geological Survey (BGS 1995) of no dredged material present at these locations. Stations N17, N18 and N19 were in an area that had not been characterized by either side-scan or CHIRP sonar (BGS 1995) and did not have a distinct dredged material signature. While Stations N18 and N19 did show the presence of the mud clast layer (for an illustration of mud clasts see *Figure 3.4d*) and were located on fine-grained bottom, Station N17 (near the Ninepin Islands) was on the hard bottom as evidenced by the camera's minimal prism penetration and the presence of a coral colony in the sediment profile image (*Figure 8.3d*).

8.3.3 *Sediment Characteristics*

Grain size data and TOC content from the stations at East of Ninepins are summarised in *Figure 8.3e*. The laboratory data support the grain size determinations compiled from SPI image analysis: the RN and RS stations comprised mostly fine sediment, with over 84 % smaller than 63 μm particle sizes. MOUND sediments were more heterogeneous than the reference areas, with larger particle sizes (>63 μm) comprising over approximately 25 % of the sediments. APRON stations had a high fine sediment content, however the remaining sediments were composed of large particle sizes. In terms of TOC, RS exhibited the highest TOC content, at 1.09 ± 0.11 % (SE). In the other stations, mean TOC was between 0.69 and 0.84 %.

8.4 *DATA ANALYSIS RESULTS*

8.4.1 *East of Ninepins Disposal Site Characteristic*

Univariate analyses were employed to investigate the differences between the RN, RS, MOUND and APRON areas in terms of total abundance, total biomass, and taxonomic richness. As the data were found to be non-normal and variances heterogeneous, parametric statistics (one-way ANOVA followed by SNK multiple comparison test) were inappropriate. A nonparametric equivalent to one-way ANOVA, the Kruskal Wallis test (based on ranks) and an SNK range test were applied to test the significance of similarities between areas, and to identify where the differences lie. The outcome of these tests is summarised in *Table 8.4a*.

Table 8.4a ***Summary of Univariate Analysis and Multiple Comparison Test of Grab Sample Data***

Parameter	**Outcome of ANOVA analysis (p value)**	**Outcome of SNK Multiple Comparison Test**
Total Abundance	$p = 0.005$ (Sig)	RN & MOUND > RS & APRON
Total Biomass	$p = 0.038$ (Sig)	RS > RN, MOUND & APRON
Taxonomic Richness	$p = 0.001$ (Sig)	RN > RS & APRON > MOUND

Notes: Sig = significant at the $p < 0.05$ level
> = "is significantly different from" at the $p < 0.05$ level

The outcome indicates that significant differences were observed for all three parameters investigated. Specifically, these are:

- the abundances recorded from the RN and MOUND stations, as shown in *Figure 8.3a* were significantly higher (significance level $\alpha = 0.05$) than those recorded from the RS and APRON stations;
- the biomass recorded from RS stations was significantly higher ($\alpha = 0.05$) than all other stations; and,
- The RN stations contained significantly more taxa than all other stations, and MOUND stations contained significantly less taxa than all other stations (RS, and APRON stations were not significantly different from each other).

8.4.2 ***Comparison with Previous Data***

As described in *Section 8.2.3*, two previous studies have collected benthic grab samples from in and around the East of Ninepins site (Binnie 1994b, 1996a). The first of these studies was undertaken in December 1993 and January 1994, and sampled 11 sites around the Ninepin Islands. Data from 5 stations in the Binnie Study (ie, Stations 15, 17, 18, 20 and 21) were excluded from statistical comparison with RS and RN stations sampled under this Study, as they were located within areas impacted by dredging or disposal operations. To enable the comparison of data from the two studies, each replicate taken in the Binnie Study was treated as an independent sample. The data were also scaled to account for differences in grab size between the two studies. Statistical comparison of both total abundance and taxonomic richness (family level) data was made using a Kruskal Wallis and a non-parametric multiple comparison test, (as described above in *Section 8.4.1*). The datasets compared were as follows:

- the RS dataset sampled under this Study;
- the RN dataset sampled under this Study; and,
- the 6 stations (with 5 replicates) sampled by Binnie in 1994 (the B94 dataset).

Comparisons between stations in terms of biomass were not made as biomass data for the B94 set were not available.

Results of the comparison are presented in *Table 8.4b.*

Table 8.4b ***Summary of Univariate Analysis and Multiple Comparison Test of Grab Sample Data***

Parameter	Outcome of ANOVA analysis (p value)	Outcome of SNK Multiple Comparison Test
Total Abundance	$p = 0.023$ (Sig)	RN > B94
Taxonomic Richness	$p = 0.023$ (Sig)	RN > B94 & RS

Notes: Sig = significant difference at the $p < 0.05$ level
> = "is significantly different from" at the $p < 0.05$ level

The results indicate that:

- in terms of total abundance, differences between studies were significant ie higher / lower; and,
- the taxonomic richness of B94 was significantly lower, at 10.63±0.99 taxa per grab, than RN (16.3±4.5) but not RS (11.6±2.6) stations.

Similar comparisons were also undertaken between grab sample data collected at the same location as the RS and RN stations, in June 1995 (sites labelled VRCS and VRCN, respectively; Binnie 1996a) as described in *Section 8.2.3*. As for this Study, the Binnie (1996; B96) samples involved a single Van Veen grab at each station. Statistical comparison of both total abundance and taxonomic richness (family level) data was made using a Kruskal Wallis test (as described above in *Section 8.4.1*) as follows:

- data from VRCN sampled by Binnie in June 1995 were compared with data from RN stations sampled during this Study; and,
- data from VRCS sampled by Binnie in June 1995 were compared with data from RS stations sampled during this Study.

Results of the analyses are presented in *Table 8.4c.*

Table 8.4c ***Comparison between Seabed Ecology Studies and Binnie (1996a)***

Stations	Parameter	Outcome of ANOVA analysis (p value)
VRCN/RN	Total Abundance	$p = 0.57$ (NS)
	Taxonomic Richness	$p = 0.90$ (NS)
VRCS/RS	Total Abundance	$p = 0.79$ (NS)
	Taxonomic Richness	$p = 0.94$ (NS)

Notes: NS = not significant at the $p < 0.05$ level

This indicates that in terms of total abundance and taxonomic richness, the benthic assemblage at the two references areas is similar between samples taken in June 1995 and August 1996.

8.5 *DISCUSSION*

The Seabed Ecology Studies provide an opportunity to combine traditional benthic community analyses, sediment grain-size and TOC measurements, with SPI technology at the same sampling locations. The importance of the findings of the Study with respect to the Study objectives as defined in *Section 8.1* is discussed below.

8.5.1 *Study Objectives 1 and 2: Recolonisation of Sediments Within the Disposal Site*

A broad objective of the Seabed Ecology Studies was to examine impacts to the marine environment resulting from dredging and disposal activities, and a key component was the investigation of recolonization of disturbed sediments. This Study was designed to facilitate comparisons between impacted (MOUND and APRON) and far field reference areas (RN and RS) to examine differences in both the physical and biological characteristics of the site.

The results indicated that the far field reference areas, which represent areas not disturbed by dredging or disposal activities, are generally characterised by fine sediments and high RPD values, indicating a well-oxygenated upper sediment layer. The dominant major taxonomic groups were polychaetes and crustacea, which is similar to findings of previous studies (Shin and Thompson 1982). At the family or species level, however, the assemblages are different from the previous Study. Shin and Thompson (1982) record a dominance of the family Phyllodocida in eastern waters, whereas the Nemertinea and Pilargiidae were dominant in this Study. Total abundance and total biomass differed between RS and RN in this Study, with RN having a higher total abundance but lower biomass than RS owing to the presence of several molluscs at RS which were not recorded at RN. In addition, despite a smaller sample size at RN, significantly more taxa were recorded here than RS. This pattern of total abundance and taxonomic richness between RS and RN was also observed when these areas were sampled in 1995 (Binnie 1996a).

The physical characteristics of the mound were found to be distinct from the surrounding seabed in that the sediments comprised a larger proportion of coarse grained material and had low RPD values, indicating a low level of oxygenation of the surface sediments. The benthic assemblage on the mound was dominated by the Spionidae, which are opportunistic polychaetes recorded in high abundance from disturbed sediments and have been observed as dominating the benthos in other parts of Hong Kong waters (Shin and Thompson 1982; SAIC 1996; ERM 1996). Significantly fewer taxa were recorded from the mound than the RN, RS and APRON stations.

The apron is an area where sediments have moved off the mound as a result of natural forces, eg storm events. Sediments in this area were not distinct from the ambient seabed. The apron assemblage was dominated by the Nemertinea and Pilargiidae, and shared many similarities with the RS reference area (eg in abundance and richness). However, significantly lower biomass was recorded from the APRON stations than from the RS reference stations.

The results indicate that areas directly impacted by disposal operations (MOUND stations) have a biological assemblage which is different from the surrounding seabed in composition (ie the types of taxa present), and in richness and abundance. There are several possible explanations for the origin of the assemblages in the mound. These explanations can be grouped under one of two hypotheses regarding the original condition of the disposed material, ie whether the dredged material originally contained organisms or was abiotic.

Hypothesis - Abiotic Disposed Material

If it is assumed that the disposed material is abiotic, then the current assemblage must have formed by recolonization through processes such as settlement of juveniles or movement of adults from surrounding areas (Santos and Simon 1984). Such recolonization processes are also assumed to be unhindered by ongoing disposal operations. Using data from the Fill Management Committee (FMC) on the allocation of dumping locations within the site (as described in *Section 2.2.1*) and disposed volumes at the site, the following information on the frequency of disposal was collected:

- prior to this Study, the section of the mound which was sampled by this Study was allocated as the disposal location in January 1995 (for 3 months); and,

- the average disposal rate for the period January to March 1995 was 62,000 m^3 day^{-1}, corresponding to 25 dumps day^{-1} by barge and 5 dumps day^{-1} by trailer dredger.

Given this information, and making the assumption of abiotic disposed material, it may be deduced that the assemblage observed has colonised the mound during the 17 months since disposal in that sector ceased.

Hypothesis - Biotic Disposed Material

The alternative hypothesis to that described above is that the disposed material retains the benthic infauna present before the material was dredged, and at least part of the assemblage survives dredging, transportation and disposal. The assemblage that was sampled during this Study would then be comprised of the following:

- original pre-dredging organisms which have survived transportation off-site and are tolerant of physical disturbance to the benthic habitat and potentially different physical conditions between the original site and the disposal site (eg salinity); and,

- organisms which have moved into the disposed material from surrounding sediments or colonised from the water column in the 17 months since disposal, as described above.

The biotic component of dredged material prior to disposal has not been studied, therefore it is not possible to ascertain the degree to which organisms may survive the dredging and transportation process. It is noteworthy, however, that the dominant taxa recorded from the MOUND stations are the Spionidae polychaetes. These are hardy, pollution tolerant and opportunistic taxa which have been recorded as dominating sediments within the organic-enriched waters of Hong Kong harbour (SAIC 1996). The Spionidae also occur in other parts of Hong Kong although they comprise a smaller proportion of the assemblage (Binnie 1996c).

8.5.2 *Study Objective 3: Comparison with Previous Data*

Comparisons with Previous Studies Near the Ninepins Islands

Comparisons between data collected in this Study for the RS and RN stations and data collected previously in near the Ninepins (Binnie 1994b, 1996a) were made to provide an insight into possible spatial and temporal changes in the abundance and richness of benthos. Comparisons between the three studies indicated both similarities and differences in the assemblages sampled, suggesting that temporal variation in benthic assemblage parameters occurs. This is further supported by examination of the composition of the benthos: each Study recorded different numerically dominant taxa. It is not yet possible to determine the cause of these differences, or the possible time scale over which changes in the benthic assemblage have occurred.

Comparisons with Previous Studies of Recolonisation

In order to provide further insight into relevant recolonization processes a similar Study undertaken in the eastern waters of Hong Kong in December 1995 is reviewed. The previous Study used sediment profile imagery and grab sampling to examine recolonization of the South Mirs Bay disposal site (Binnie 1996c). The Site is located approximately 20 km to the north of the East of Ninepins site near the mouth of the Tolo Harbour and was used for the disposal of surplus, uncontaminated dredged material and assorted construction waste until 1993, when disposal operations ceased. In contrast to the mound at the East of Ninepins disposal site, this site is comprised of a relatively flat area of the seabed upon which a thin surface deposit is located. Discreet, small mounds of material are also present.

The Study revealed that the disposal site comprised more heterogeneous sediments than the surrounding seabed, and consequently retained a markedly different benthic assemblage with a higher abundance and diversity of organisms. The composition of the disposal site assemblage was also different, with some families being located exclusively in the disposal site (eg Corophid and Ampeliscid amphipods), and others in the surrounding seabed (eg the Nephtyid polychaetes) but absent from the disposal site assemblage.

Comparison between the South Mirs Bay Study and this Study indicates the following:

- the abundances recorded during this Study are considerably lower than those recorded from South Mirs Bay;
- similar patterns in the benthic assemblage structure (ie numbers of different types of taxa) observed at South Mirs Bay are emerging at East of Ninepins (eg a generally higher polychaete abundance in the MOUND stations); and,
- differences in the dominant polychaetes of reference and mound areas were recorded from South Mirs Bay and a similar pattern has also been observed at the East of Ninepins site.

It has not been possible to address possible temporal variations in benthic assemblage composition of the two disposal sites as the two studies were undertaken in different seasons and years. The physical attributes of the South Mirs Bay and East of Ninepins sites are similar in terms of sediment heterogeneity and it is reasonable to assume that similar recolonization processes occur at the two sites. Therefore, it would be expected that once disposal operations at East of Ninepins cease, the coarser sediments of the mound will continue to be colonised by a different suite of organisms that those occurring in the surrounding seabed. The mound is also less likely to be disturbed by other activities such as trawling, which may influence the development of the recolonized assemblage (Morton *et al*, 1983). The mound assemblage may, however, comprise different taxa, and be structured differently in terms of abundances and biomass, than the assemblage of the South Mirs Bay Disposal site.

The results of these two studies highlight the need for sequential studies of sites in order to address temporal variation in the benthos and rates of recolonization of sediments.

8.5.3 Study Objective 4: Identifying Factors Structuring Infaunal Assemblages

Relationships between physical environmental factors (eg grain size, TOC, RPD) and biological assemblage parameters (abundance, biomass) were examined using cluster analyses. This exploratory technique identified that MOUND stations are both physically and biologically distinct from the surrounding apron and seabed, having a greater coarse sediment component and a dominance by the Spionidae polychaetes. No clear geographical pattern in either biological and physical parameters across the RS, RN and APRON stations was shown.

8.6 SUMMARY

In summary, this Study has shown that:

- the benthic assemblage in the East of Ninepins area when sampled during the wet season, is generally dominated by polychaetes;
- the mound stations are physically distinct from the surrounding areas, being characterised by heterogeneous sediments and a low RPD;
- the mound stations are also biologically distinct from the surrounding areas, with the opportunistic Spionidae polychaetes being numerically dominant;
- compared with generally undisturbed conditions of the surrounding areas, the mound stations are in a moderately disturbed condition;
- the apron stations were found to be indistinguishable from surrounding areas in both physical and biological parameters; and,
- differences were detected between current and previous studies, suggesting a temporally dynamic assemblage.

9 *EASTERN WATERS*

9.1 *STUDY OBJECTIVES*

A general objective of the Seabed Ecology Studies at Eastern Waters was to describe the benthic assemblages and identify temporal and spatial variation in the benthic communities. The Study also provided further baseline ecological information on the site, to compliment that obtained from previous studies.

The objectives of the Seabed Ecology Studies for this site were threefold:

- to examine whether differences in benthic community patterns exist between the proposed marine borrow area (MBA) and the reference south (RS) area.
- to examine the benthic characteristics and features which may structure the infaunal assemblages at the areas sampled; and,
- to examine the temporal and spatial variations in the benthic communities by comparisons between this survey, the survey undertaken in June 1995 (Binnie Consultants Ltd 1996a) and data from the reference areas surveyed under the Seabed Ecology Studies at East of Ninepins (ERM 1997a).

Due to adverse weather conditions during this sampling cruise, sampling had to be curtailed and no samples could be collected from the reference north area of the Study site. ERM undertook the following additional analyses to compensate for the absence of these data, and further assist in the assessment of the above objectives:

- analysis of mean body size of dominant families in the Study;
- a comparison of the SPIs collected during this Study and the REMOTS images from the Binnie Consultants Ltd, June 1995 survey; and,
- a Remotely operated vehicle (ROV) survey of the south Lamma site (reported separately in the South Lamma Report of the Seabed Ecology Studies).

9.2 *THE EASTERN WATERS SITE*

9.2.1 *Site History*

The presence of sand deposits in the Eastern Waters area, adjacent to Victor Rock, were first identified through seismic data collected in early 1993. Since this time further geotechnical and environmental data collection has been carried out in support of a proposal to dredge sand from the area and, once completed, backfill the disused pits with uncontaminated dredged material. The original proposal involved dredging a 145 Mm^3 sand reserve located west, east and south of Victor Rock. The current proposal consists of dredging 36 Mm^3 from an area south of Victor Rock. However, sand dredging operations have not yet been initiated.

9.2.2 *Physical Site Characteristics*

Hydrodynamic conditions at the Study site are influenced by the oceanic environment of the South China Sea. During the dry season the dominant ocean currents are from the northeast and during the wet season they are from the southwest. Data from routine water quality monitoring stations in the Victor Rock area (EPD 1996) recorded mean bottom salinities of 34.0 ppt, mean bottom dissolved oxygen saturation of 92.0 % and mean suspended solids of 6.7 mg L^{-1} (ranging from 2.2 to 14.6 mg L^{-1}), which reflect the oceanic influence. The area is exposed and influenced by the strong winds associated with the north-east monsoon.

The seabed in the area is flat at a depth of -25 to -28 mPD except for Victor Rock, an isolated underwater pinnacle formation consisting of 3 separate outcrops reaching as high as -7 mPD. The seabed is composed of a layer 8 to 10 m thick, comprised of silt-clay with generally less than 10 % sand, which overlays sand deposits. TOC levels in the area are uniform, ranging from 0.5 % to 0.9 % (Binnie Consultants Ltd 1996a) which is slightly lower than the 1 % TOC considered average for marine sediments (Tyson and Pearson 1991) and within the range recorded at other areas in Hong Kong (ERM 1997b, ERM 1997d, ERM 1997e).

9.2.3 *Previous Ecological Studies*

A number of different benthic invertebrate surveys have been undertaken at the proposed MBA. These have included quantitative benthic grab and dive surveys and qualitative surveys using the Remote Ecological Monitoring of the Seafloor (REMOTS® system).

The earliest grab sampling in the area was undertaken between July 1976 and January 1977 as part of a Territory-wide survey of infaunal benthos, and used a Smith Macintyre benthic grab to sample several sites in eastern areas near the Ninepins (Shin and Thompson 1982). Results indicated that the fauna was dominated by polychaetes, with a mean abundance of 72.5 individuals m^{-2}. Two polychaetes, *Nephtys* spp and *Aglaophamus lyrochaeta*, were recorded as dominating the benthic fauna at the site, where they comprised 11.9 and 10.8 % of the total number of individuals collected.

A combined benthic grab and REMOTS® survey, undertaken in June 1995 as part of the Fill Management Phase VI project (Binnie Consultants Ltd 1996a), sampled stations at three areas around Victor Rock and two reference areas, one southeast of Victor Rock, and one northeast of Basalt Island. All five areas sampled showed similar relative abundance of major taxonomic groups, with polychaetes numerically dominant in all areas, comprising between 61 % and 72 % of all organisms recorded. The most common families were Capitellidae, Sipunculida and Nemertinea. Significantly higher abundances of 42.3 individuals $grab^{-1}$ were recorded at reference north area near Basalt Island compared to mean abundances of 18.8 to 26.9 per $grab^{-1}$ at all other areas sampled. These abundances were high compared to those recorded by Shin and Thompson.

The reference south and reference north areas sampled by Binnie in 1995, and the east of Ninepins Disposal site were surveyed by ERM in August 1996, as a component of the Seabed Ecology Studies (ERM 1997a). Mean taxonomic richness (16.3 families $grab^{-1}$) and mean total abundance (36.7 $grab^{-1}$) were significantly higher at reference north stations and mean total biomass (2857 mg $grab^{-1}$) was significantly highest at reference south. Communities were dominated by molluscs at reference south and by polychaetes at reference north. Additional information on the ecological communities which are present in the Study site is presented below:

A sidescan sonar survey at Victor Rock concluded that the seabed within a 250 to 300 m radius of Victor Rock showed no mud clasts and little evidence of trawling compared to the surrounding area (Selby and Evans 1997). It is therefore likely trawling will exert an effect on the benthic communities sampled during the current survey. These conclusions were used to conduct further analyses of the grab and REMOTS images collected by Binnie Consultants Ltd, during June 1995, to assess the effects of trawling on the benthic communities around Victor Rock (Binnie Consultants Ltd 1996b). No differences in the physical or biological communities between trawled and "untrawled" areas could be detected.

A dive survey, carried out in April 1995, obtained detailed information on the hardbottom communities at the site (Binnie Consultants Ltd 1995c). Results showed that the soft coral, gorgonian and *Tubastrea* spp populations at Victor Rock were some of the richest in Hong Kong in both diversity and abundance. Reef building corals were rare which was thought to be due to both the scouring action of waves and the depth of the rocks.

9.2.4 Sampling Station Selection

The location of the benthic grab and REMOTS sampling stations for this Study, was based as closely as possible on the sampling design used by Binnie Consultants Ltd during their survey of benthic communities in Eastern Waters in June 1995 (Binnie Consultants Ltd 1996a). In the ERM survey, samples were collected from the Victor Rock south and the reference south areas sampled by Binnie Consultants Ltd in 1995. The stations to the east of Victor Rock were not sampled as this area is not currently being considered for dredging. This sampling design facilitates a direct comparison between the results from current survey and the June 1995 Study by Binnie Consultants Ltd. Grab sample station locations for the Study site are shown in *Figure 9.2a.*

SPI samples, designed to collect information on sediment physical properties and processes influencing benthic community structure, were taken from two cross-shaped transects centred on the middle of the proposed marine borrow area. Additional SPI samples were taken from random locations within the gazetted marine borrow area boundaries, and match those previously sampled by Binnie in June 1995. Reference SPI samples were also taken from the RS area to the southeast of Victor Rock. SPI sample station locations for the Study site are shown in *Figure 9.2a.*

9.3 RESULTS

9.3.1 Grab Samples

A total of 1,086 specimens, belonging to 48 families in nine phyla were recorded from the Study site. Polychaetes (Annelida) were the most abundant group present, representing 74 % of the identified individuals, although only 10 % of the total biomass. By contrast, molluscs constituted only 5 % of the identified individuals but provided 74 % of the total biomass recorded. The data of taxa recorded in each grab sample is summarised in *Table 9.3a* below.

Table 9.3a ***Summary of Taxa Recorded from the Eastern Waters Study Site (MBA & RS).***

Phylum	Total Number of Families Identified	Total Number of Individuals Recorded	Total Biomass (g)
Annelida	30	806	9.09
Arthropoda	9	76	7.79
Cnidaria	1	1	0.49
Echinodermata	2	53	3.61
Hemichordata	1	1	0.19
Mollusca	3	56	64.04
Nemertinea	-	2	0.11
Sipuncula	1	88	0.76
Total	47	1083	86.08

Although most animals sampled were identified to family level exceptions applied as described in *Section 2.4.1.*

Data from the grab sampling programme were analysed in terms of mean abundance, biomass, and taxonomic richness in each of the areas sampled. The results of the analysis are summarised in *Table 9.3b.*

Table 9.3b ***Summary of Benthic Grab Survey Results from the Eastern Waters Site***

Study Area	Reference South (RS) (n=16)	Marine Borrow Area (MBA) (n=16)
Mean Total Abundance (individuals grab^{-1}± SD)	33.9 ± 14.5	33.6 ± 13.7
Mean Total Biomass (g grab^{-1} ± SD)	2.2 ± 2.6	3.2 ± 4.2
Mean Taxonomic Richness (no. of families grab ± SD)	11.5 ± 2.4	11.7 ± 2.3

The overall mean abundance recorded from the Study site was low to moderate (34 animals grab^{-1}; 352 animals m^{-2}) compared to other sites in Hong Kong waters. Mean abundance grab^{-1} was the same in each area and was higher than that recorded previously at sites near Victor Rock, by Binnie Consultants Ltd in 1995 (245 individuals m^{2} at the MBA and 285 individuals m^{-2} at RS) and Shin and Thompson in 1982 (72.5 individuals m^{-2}).

Mean total abundance was virtually the same in each area, however the average biomass per station was higher at the MBA than the RS. This was due to the presence of a fewer number of molluscs which nevertheless had higher biomasses in this area. The abundance of benthic fauna in the RS area shows an area of relatively high densities (greater than 40 individuals grab^{-1}) in the east of the area. At the MBA there is a central area of low abundance stations (less than 20 individuals grab^{-1}) surrounded by stations with increasingly higher abundance.

The mean total abundance of animals recorded per grab in each area and their taxonomic composition is presented in *Figure 9.3a (i)*. The abundance of the numerically dominant families in each area is shown in *Figures 9.3a (ii)*.

Polychaetes (phylum Annelida) were the most common group present during the survey, comprising 71 % of all individuals captured. Capitellidae dominated the assemblage at both the MBA and RS area, however mean abundances were low (9.0 and 7.1 animals grab^{-1}, respectively). Other annelids (especially Cirratulidae, Spionidae and Paraonidae) also formed an important element of the assemblage in both areas. Only one species, the polychaete, *Heteromastus filiformis* was recorded at moderate total abundances (>10 animals grab^{-1}) at more than one station.

The mean wet biomass recorded in each area, and its taxonomic composition, is presented in *Figure 9.3b (i)*. The mean biomass of the gravimetrically dominant families recorded in each area are shown in *Figures 9.3b (ii)*.

Most animals captured weighed less than 0.1 g but a few relatively large individuals were present and contributed a substantial proportion of the total biomass. The eighteen heaviest individuals (1.7 % of the total number of individuals), which were all Arcidae molluscs, contributed 72.9 % of the total biomass (63.51 g). The higher biomass at the MBA was largely attributable to the presence of larger molluscs at this site (41.49 g total mollusc biomass, 25 individuals) than in the RS area (22.54 g, 31 individuals). In addition to the Arcidae present in the Study site, low biomasses of Capitellid and Trichobranchid polychaetes and four species of Arthropoda (Amphiuridae, Upogebiidae, Pinnotheridae and Grapsidae) were recorded at both sites.

There was little variation in taxonomic richness between sample areas, with the RS area supporting 11.5 families grab^{-1} and the MBA supporting 11.7 families grab^{-1} (*Table 9.3b*).

9.3.2 SPI Investigations

The results from the SPI investigations showed generally uniform sediment grain size within the Study site. In general, sediments were composed of very soft and fine grained silt-clay and sandy muds with low shear strengths. The majority of the sediments showed mottled tan to grey colouring, due to the mixing of sand with silt-clay. The sediments show evidence of intensive physical reworking and the presence of mud clasts which may be attributed to disturbance due to wave action or trawling (Selby and Evans 1997). The majority of these clasts were rounded (see *Figure 3.4d* for an example of this) although some were angular in shape (see *Figure 3.4f* for and example of this). Disturbance of the bottom sediments can cause sediment resuspension followed by redeposition which produces a poorly compacted, high water content sediment. During compaction expulsion of excess pore water takes place through pore spaces. This process can be observed in sediment profiles illustrated in *Figure 9.3c*.

Over penetration of the camera prism occurred at 7 of the 16 stations sampled, therefore providing no information on the nature of the sediment-water interface. This over penetration was likely to be due to the highly fluid nature of the mud and the rough sea conditions encountered during sampling.

Due to the over penetration of the camera, apparent redox penetration depths (RPD) could only be measured at eight stations in the RS area and one at the

MBA. In general, RPD values would be expected to increase as sediment shear strengths reduce and camera penetration depths increase. At RS, a thinning of the apparent RPD in a north to south direction (3.4 cm to 1.0 cm, respectively) was observed. During the survey at RS in June 1995 (Binnie Consultants Ltd 1996a) half of the stations sampled recorded apparent RPD depths of less than 1 cm. The small sample size of both datasets precludes any definite conclusions, however the larger RPD values recorded during this survey may be due to physical resuspension and aeration of the bottom as a result of the rough weather encountered during sampling.

9.3.3 *Sediment Characteristics*

All of the stations sampled were dominated by silt-clay (≥4 ϕ or <62.5 μm) with this fraction contributing between 77 and 95 % of the total weight. The stations at the MBA and RS showed no large gradients in sediment grain size. Total Organic Carbon (TOC) values across the Study site ranged from 0.9 to 1.0 % at RS and 0.62 to 1.60 % within the MBA. No correlation between TOC content and sediment grain size was observed. Grain size data and TOC content values are summarised in *Table 9.3c* and presented in *Figure 9.3d.*

Table 9.3c ***Summary of Sediment Characteristics from the Eastern Waters Study Site***

Parameter	Reference South (RS) (n=16)	Marine Borrow Area (MBA) (n=16)
Mean Fine Sediment (≥4ϕ) (%± SE)	87.84 ± 1.18	90.53 ± 0.56
Mean TOC (% ± SE)	0.94 ± 0.01	1.17 ± 0.08

9.4 *DATA ANALYSIS RESULTS*

9.4.1 *Grab Samples*

Measures of total abundance, total biomass and taxonomic richness as well as the abundance of the five most numerically dominant families from the two Study areas, were compared in a two-tailed t-test. The data were evaluated using graphical display for adherence to the parametric statistical model assumptions of approximate normality and equal variances. Non-normal distributions were observed for total biomass and abundance of the dominant families; these data were skewed with high values recorded at several stations. A log (x+1) transformation was used on the dominant family abundances, and the "rankit" transformation on the total biomass data to allow parametric analyses. The total abundance and taxonomic richness data had approximately normal distributions and common variances and did not need transformation prior to parametric analyses. All tests were performed at the α=0.05 level.

The two areas (MBA and RS) were not found to differ significantly from each other in any of the parameters measured. These analyses are summarised in *Table 9.4a*.

Table 9.4a ***Summary of Univariate Analysis and Multiple Comparison Test of Grab Sample Data***

Parameter	**Outcome of ANOVA analysis (p value)**
Community-based hypotheses	
Total abundance	$p= 0.97$ (Not Sig)
Total biomass	$p = 0.63$ (Not Sig)
Taxonomic richness	$p = 0.83$ (Not Sig)
Taxonomic-based hypotheses	
Capitellidae abundance	$p = 0.36$ (Not Sig)
Phascolionidae abundance	$p = 0.80$ (Not Sig)
Spionidae abundance	$p = 0.83$ (Not Sig)
Cirratulidae abundance	$p = 0.77$ (Not Sig)
Pilargiidae abundance	$p = 0.85$ (Not Sig)

9.4.2 *Temporal and Spatial Variation in Benthic Assemblage*

Three separate surveys have been conducted at locations in the Eastern Waters: June 1995 (Binnie Consultants Ltd 1996a), August 1996 (ERM 1997) and the April 1997 survey presented in this report. The areas sampled in each of these separate surveys (*Figure 9.4a)* are as follows:

- the MBA (sampled in June 1995 and April 1997);
- the RS (sampled in June 1995, August 1996 and April 1997); and,
- a reference north (RN) area northeast of Basalt Island (sampled in June 1995 and August 1996).

A summary of the benthic community data from the present survey and the two previous surveys is given in *Table 9.4b*. As abundance data are available for all sites during all survey seasons, spatial and temporal differences in abundances were tested statistically. Identification and statistical testing of patterns in biomass and taxonomic richness are limited by the lack of biomass data from the June 1995 surveys at all sites and the incompatibility of the June 1995 richness data with those collected in other seasons. Therefore, differences in biomass and taxonomic richness were not tested statistically.

Table 9.4b ***Summary of Abundance Data for the Eastern Waters Area***

	MBA		**RS**			**RN**	
	June 1995 (n=12)	April 1997 (n=16)	June 1995 (n=15)	August 1996 (n=16)	April 1997 (n=16)	June 1995 (n=15)	August 1996 (n=9)
Mean Total Abundance (individuals $m^{-2} \pm$ SD)	245 ±125	351 ±150	285 ±152	224 ±96	353 ±151	528 ±226	381 ±147
Mean Total Biomass ($g\ m^{-2} \pm$ SD)	na	32.9 ±45.0	na	29.5 ±42.2	23.0 ±27.1	na	10.9 ±11.4

	MBA		RS			RN	
	June 1995 (n=12)	April 1997 (n=16)	June 1995 (n=15)	August 1996 (n=16)	April 1997 (n=16)	June 1995 (n=15)	August 1996 (n=9)
Mean Taxonomic Richness (families grab^{-1} ± SD)	nc	12 ±2.3	nc	11 ±2.6	12 ±2.4	nc	17 ±4.7

na = Not available. Biomass not measured for the June 1995 survey.
nc = Not comparable. A smaller Van Veen sampler was used in the June 1995 survey. Unlike abundance, richness is not expected to be a linear function of area sampled, and is therefore not easily converted to standard units (per square metre).

9.4.3 *Hypothesis Testing*

The data for total abundance, and abundance of the five dominant families (calculated as the most abundant families across all three surveys, ie Capitellidae, Spionidae, Amphiuridae, Paraonidae and Pilargiidae) were analysed using ANOVA techniques to determine whether the temporal and spatial differences observed were significant. Prior to analysis, these data were evaluated for normality and homogeneity of variance using graphical displays. Total abundance was found to meet the assumptions of the model without any transformation, Capitellidae abundance required a "rankit" transformation, Spionidae and Amphiuridae required a log (x+1) transformation and Paraonidae and Pilargiidae required a fourth-root transformation to achieve the necessary distributional assumptions for the parametric ANOVA.

Due to the unbalanced design inherent in comparing data within a dataset for which not every location was sampled in every season, separate ANOVA tests (and where appropriate multiple comparison tests) were conducted for the following:

- 2-way ANOVA between location (MBA and RS) and time (June 95 and April 97)
- 2-way ANOVA between location (RS and RN) and time (June 95 and August 96);
- 1-way ANOVA for the RS location for time (June 95, August 96 and April 1997); and,
- 1-way ANOVA for the time June 95 for location (MBA, RS and RN).

These tests were conducted for total abundance and for the five most abundant families across all surveys. The interaction between time and location was tested for each and was non significant. The results are discussed below.

Differences Between MBA and RS in June 1995 and April 1997

Only two of the datasets tested showed significant differences under this structured comparison. The analysis of total abundance showed that while no significant differences were detected between the MBA and RS locations, total abundance was significantly greater in April 1997 than in June 1995. This same pattern was apparent in the abundance data for the family Amphiuridae.

Differences Between RS and RN in June 95 and August 96

The results of this ANOVA showed significant differences both in location and time. For total abundance data, both factors were significant: total abundances were higher in June 1995 than in August 1996 and total abundances at RN were higher than at RS. This pattern was repeated for either location or time (but not both) in four of the five families tested. Capitellidae and Spionidae abundances were significantly higher in June 1995 than in August 1996, whereas for Amphiuridae and Pilargiidae abundances were significantly higher at RN than at RS.

Differences At RS in June 1995, August 1996 and April 1997

This test compared survey location RS over time and found significant differences in three of six datasets tested. Total abundances were found to be significantly greater in April 1997 than at other survey times. Similar significant patterns were found in the Capitellidae and Spionidae where abundances in April 1997 and June 1995 were similar but significantly higher than abundances in August 1996.

Differences At MBA, RS and RN in June 1995

Significant differences in total abundance were found between RN and other survey locations, with RN stations showing a significantly higher total abundance and abundance of the polychaete family Amphiuridae. In addition, abundance of Pilargiidae was significantly higher at RN than RS.

Summary of Significant Results

From the results presented above several general conclusions can be drawn regarding spatial and temporal variation in the Eastern Waters Study site. Although the structure of the dataset limits the number of valid comparisons between location and time components, the following trends appear to hold:

- RN area shows greater abundances than either RS or MBA areas (*Figure 9.4b*);
- Highest abundances were generally encountered in April 1997 and lowest abundances in August 1996. Abundances in June 1995 were intermediate and were, during different survey times, not significantly different to either April 1997 or August 1996 abundances (*Figure 9.4b*);

Community Family Composition

In general, the community compositions of the three Study areas displayed noticeable temporal and spatial variations. In August 1996, Capitellid and Spionid abundances were very low in comparison to June 1995 and April 1997. In contrast, Nemertinea abundances in August 1996 were the highest of any taxa recorded, and were considerably higher than Nemertinea abundances in the June 1995 and April 1997 surveys.

The northern reference area differed from the other two areas due to higher Amphiurid, Paraonid and Pilargiid densities. The community compositions of the proposed MBA and the RS were comparable.

In addition to the variability in dominant families between surveys, the families present in each survey varied considerably. Large changes in community composition were observed with many entire families disappearing and reappearing within periods of less than one year. A possible explanation for these community changes is the transient loss of habitat stability due to physical disturbance. This could be due to wave action causing sediment resuspension and/or the effect of trawling. A recent study on fishing operations in Hong Kong waters has shown that trawling operations occurs very frequently in this area and is likely to be a major contribution o the disturbance (ERM 1998). In addition, the timing of the survey relative to the last major disturbance event is likely to strongly influence the benthic assemblage sampled.

Mean Body Size

Differences in the mean body size of individuals at different locations and times can indicate differences in the elapsed time since recruitment and/or in food supply. For these reasons, differences in mean body size of the five numerically abundant, and the five gravimetrically dominant families were explored for the MBA and RS sites in April 1997. For comparison, mean body size of organisms collected at the RS site in August 1996 is also presented in *Figure 9.4c* and listed below in *Table 9.4c*. Comparisons can only be made within the April 1997 data (MBA and RS) and within the data from RS (August 1996 and April 1997). The April 1997 data from the MBA and the August 1996 data from RS are not directly comparable as the data are not constant in space or time.

Table 9.4c ***Mean Body Size of Dominant Families Captured at the Eastern Waters Area***

Family		**Mean Body Size (g ±SE)**	
	MBA (April 1997)	**RS (April 1997)**	**RS(August 1996)**
Phascolionidae[1]	0.0076± 0.0021	0.0102± 0.0025	N/A
Pilargiidae[1]	0.0061± 0.0012	0.0074± 0.0023	0.0009± 0.0002
Cirratulidae[1]	0.0048± 0.0007	0.0091± 0.0037	0.0038 ± 0.0008
Spionidae[1&2]	0.0045 ± 0.0007	0.0176± 0.0105	0.0010± 0.0001
Capitellidae[1&2]	0.0046± 0.0009	0.0064± 0.0012	0.0032 ± 0.0017
Amphiuridae[2]	0.0633± 0.0188	0.0618± 0.0222	0.0249 ± 0.0058
Arcidae[2]	3.1243± 0.5676	3.4380± 0.7234	3.1342 ± 1.2742
Pinnotheridae[2]	0.0837± 0.0238	0.3190 ± 0.1728	N/A

1 Numerically Dominant Family 2 Gravimetrically Dominant Family
N/A Mean body size not calculated as family collected at fewer than 4 stations in the survey.
underlined families - Significant differences in mean body size detected.

Mean body size of the polychaete family Pilargiidae was significantly larger at RS in the April 1997 survey than at the same location in August 1996. This could be due to variations in physical processes affecting this family, food supply variation between sites or surveys, or may be indicative of the timing of larval recruitment of this family.

The graphical presentation of mean body size illustrates a general trend of larger mean body size of the most gravimetrically and numerically abundant families at RS than the MBA in the April 1997 survey (Phascolionidae was 134 %, Capitellidae 139 %, Pinnotheridae was 381 % larger at RS than the MBA) and larger individuals at RS in April 1997 compared to individuals at the same location in August 1996 (Spionidae were 1760 % larger, Pilargiidae were 822 % larger, Amphiuridae 248 % and Capitellidae 200 % larger at RS in April 1997 compared to the same site in August 1996). However, these differences were not significant due to the large amount of variability of mean body size in the dataset.

9.5 *DISCUSSION*

This section provides an interpretation of the data and analyses described in detail in *Section 9.3* and *Section 9.4*. The results are considered in the light of both the overall and the specific aims of this Study.

9.5.1 *Eastern Waters Site Characteristics*

Sediments at all stations within the Eastern waters Study site were dominated by fine grained silt-clays (>4 ϕ), and TOC values which were approximately average for marine sediments (1 %) (Tyson and Pearson 1991) and within the range recorded at other areas in Hong Kong (ERM 1997b, ERM 1997d, ERM 1997e). Bottom sediments showed high fluidity, as demonstrated by high apparent RPD depths and over penetration of the SPI camera at many of the stations sampled. This fluidity, in conjunction with the detection of mud clasts at all stations, indicates the Study site is subject to a high degree of seabed turbulence caused by wave action and/or trawling activity in the area. This disturbance likely results in physical resuspension of the seabed and promotes uniformity in the benthic community.

9.5.2 *Study Objective 1: Differences in Benthic Communities Between the Proposed MBA and the RS Area*

The proposed MBA and RS areas were generally similar in abundance, biomass and family-level taxonomic richness. Although differences in the mean body size of the most abundant and gravimetrically dominant families can be observed (*Figure 9.4c)* these differences were not statistically significant due to high variation in the dataset. For all but one family, mean body size appeared to be larger at the RS area than at the MBA. This observation could potentially be due to differences in food supply, physical disturbance and /or recruitment processes in the two areas.

9.5.3 *Study Objective 2: Identify Factors Structuring Infaunal Communities*

The presence of mud clasts and fluidised sediment at the surface of all Eastern Waters stations sampled in April indicates a physically disturbed environment. This is likely to be due to disturbance caused by bottom trawling and bottom shear stresses related to wave induced turbulence. The turbulence results in resuspension of uncompacted sediment on the seabed and reworking of more cohesive sediment on the seabed to form mud aggregates. Intensive bottom resuspension is likely to contribute to the relative uniformity of sediment grain size and benthic communities throughout the areas surveyed.

This uniformity of the physical environment is manifested in the comparatively homogeneous faunal distributions (abundance, biomass and family-level richness) observed in the April 1997 survey. This result could be explained by one or more of the factors described below:

- the abundance and family richness recorded during this survey is very low compared to other areas of the world;
- selective mortality is occurring in which physical disturbance causes greater mortality to shallow living, small biomass species while deeper living, large-bodied individuals are less affected; or

- the communities in the Eastern waters Study site are limited by environmental conditions such that sediment nutrient levels may be too low to support a deposit feeding environment and the water column may provide too little food to accommodate a large suspension feeding community.

9.5.4 *Study Objective 3: Examine the Temporal and Spatial Variation in the Benthic Community Structure by Comparison Within this Survey and Between this and Previous Surveys*

Although temporal and spatial differences between the present survey, the August 1996 survey (ERM 1997a) and the June 1995 survey (Binnie Consultants Ltd 1996a) can be detected, it is difficult to draw conclusions as to yearly or seasonal changes, given the unbalanced nature of the data and the limited number of surveys (see Section 9.4.2). However the following significant trends in the data were observed:

- The RN area showed greater abundances than either the RS or MBA areas;
- Highest abundances were generally encountered in April 1997 and lowest abundances in August 1996. Abundances in June 1995 were intermediate and were not statistically different to either April 1997 or August 1996 abundances depending on survey location; and,
- Mean body size of the polychaete family Pilargiidae were significantly larger (822 %) at RS in April 1997 than at the same location in August 1996.

9.6 *SUMMARY*

In summary, this Study (conducted in April 1997) has shown that:

- the proposed MBA at Eastern Waters is similar in abundance, biomass and richness to the southern reference (RS) area;
- the sediment characteristics and benthic community composition are consistent at both sites;
- the seabed in the Study site is primarily composed of fine-grained sediment with low shear strength which appears to be frequently subjected to physical disturbance events caused by wave action and/or bottom trawling; and,
- although limited by inconsistencies in the dataset, statistical testing revealed that the RN area has significantly higher abundances than MBA and RS areas, and that August 1996 surveys recorded the lowest abundances, some of which were significantly lower than both June 1995 and April 1997 surveys.

10 *BASALT ISLAND*

10.1 *STUDY OBJECTIVES*

As Basalt Island lies in the eastern waters of Hong Kong, and has been shown to be unaffected by dredging and disposal activities in the area (see *Section 10.2.3*), it was included in the Seabed Ecology Studies as a reference area.

The objectives of the Seabed Ecology Studies at this site were as follows:

- to characterise the soft bottom benthic community in an undisturbed area of eastern waters for comparison with other Study areas; and,
- to determine the benthic characteristics and features which affect the structure of infaunal communities.

10.2 *THE BASALT ISLAND SITE*

10.2.1 *Site History*

Basalt and the other small islands adjacent to it are uninhabited, and formerly served as a target for artillery practice. Although dredging and backfilling operations have not been undertaken near the site, and the site represents relatively undisturbed habitat, the site may have been subject to disturbance through artillery shells, illegal dumping and/or trawling operations (Selby and Evans 1997).

10.2.2 *Site Characteristics*

As it lies in the eastern waters of Hong Kong, the Basalt Island site is largely removed from the influence of the Pearl River, (to the west of Hong Kong) and therefore, unlike the western parts of Hong Kong experiences more oceanic than estuarine conditions. In winter, the dominant current is the Guangdong Coastal Current, which sets to the south-west. In summer, the Hainan current dominates, setting to the north east. Reversals occur, especially during the transition periods. Salinity fluctuates on a seasonal cycle, between 22 ‰ and 34 ‰(EPD 1994). Admiralty charts indicate that within a radius of one nautical mile of Basalt Island, the seabed reaches a maximum depth of -27 m (range -20 to -27 m) and is comprised of sand or mud.

10.2.3 *Previous Ecological Studies*

A Study of the spatial distribution of the infaunal benthos of Hong Kong (Shin and Thompson 1982) sampled areas near Basalt Island. Grab sampling techniques were used to survey the seabed from the north east of the territory through to the south western regions. In eastern waters, eighty one sites were sampled using a Smith Macintyre grab, between November 1975 and January 1977. Two sites in the vicinity of Basalt Island were surveyed, one lying to the south and the other to the south east of the Basalt Island at a distance of approximately 1.5 km. This area was found to be composed of fine sediments, with over 90 % silt-clay, and less than 2 % organic carbon in the sediments. As with most other regions in Hong Kong, polychaetes were the most abundant animals.

An Underwater Dive Survey of the hard bottom adjacent to the south and west of Basalt Island was performed in April, 1992 (Binnie Consultants Ltd, January 1995a). No anthropogenic disturbance was evident and abundant coral and associated organisms were reported.

10.2.4 Sampling Station Selection

For the benthic grab samples, sampling effort was allocated to maximize the number of stations within different impact zones. SPI stations were located along known physical topographic gradients, to collect information on physical sedimentary properties and processes influencing the benthic community structure. The sampling locations for grab and SPI stations are indicated in *Figure 10.2a*. They comprise 16 stations sampled with SPI and grabs within a radius of 1 nautical mile of Basalt Island. The stations were located randomly within this zone.

10.3 RESULTS

10.3.1 Grab Samples

A total of 365 specimens were collected from the grabs, belonging to 41 families as shown in *Table 10.3a*.

Table 10.3a Organisms sampled in the Grab Sampling Programme at Basalt Island

Phylum	Total Number of Identified Families	Total Number of Individuals Recorded	Total Biomass (g)
Annelida	28	252	2.19
Arthropoda	9	22	1.60
Chordata	2	2	0.81
Echinodermata	1	19	1.31
Mollusca	1	1	0.02
Total	41	296	5.92

In addition to these, several other phyla were collected, but were not identified to family level, for the reasons described in *Section 2.4.1*.

The composition of the benthic assemblage in terms of numerical abundance is presented in *Figure 10.3a (i)* and *(ii)*. *Figure 10.3a (i)* indicates that the mean total abundance was 23 organisms grab^{-1}, and polychaetes were the most abundant of the major taxonomic groups. When broken down into families, however, numerical dominance was not apparent, as indicated by the narrow range of abundances and high variability (standard error) between stations, in *Figure 10.3a (ii)*. Where more than 6 individuals belonging to a single family were identified in a grab, further classification to species level was undertaken. This occurred in 4 polychaete families from 6 stations, as indicated below in *Table 10.3b*. In each case, the family was represented by one species.

Table 10.3b ***Species Which Were Identified at Abundances > 6 Individuals Grab^{-1}***

Phylum	Class	Order	Family	Species	No. of stations where n>6*
Annelida	Polychaeta	Capitellida	Maldanidae	*Euclymene lombricoides*	2
Annelida	Polychaeta	Spionida	Spionidae	*Prionospio malmgreni*	2
Annelida	Polychaeta	Terebellida	Trichobranchidae	*Terebellides stroemii*	1
Annelida	Polychaeta	Phyllodocida	Pilargiidae	*Sigambra bassi*	1

Note: *n=number of individuals per grab

The composition of the benthic assemblage in terms of biomass is presented in *Figure 10.3b (i)* and *(ii)*. *Figure 10.3b (i)* indicates that the mean total biomass was 580 mg grab^{-1}, and mirrors the pattern shown by abundance, ie that polychaetes were the major family. Biomass data did not, however, indicate the dominance of a particular taxa at the family level, and variability between stations was occasionally high, as indicated by the standard error bars in *Figure 10.3b (ii)*, (eg in Nemertinea). The biomass recorded for the family Taenioididae (fish) arises from a single individual, hence this family was not recorded as numerically dominant. Although not generally targeted by grab sampling techniques, the Taenioididae are benthic dwelling fish which comprise a component of the benthic infauna and were thus retained in the dataset for this Study. A summary of the results of the benthic grab investigations is provided below in *Table 10.3c*.

Table 10.3c ***Summary of Grab Data from the Basalt Island area***

Parameter	Mean±SE
Total Abundance (number grab^{-1}±SD)	22.9±3.8
Total Biomass (g grab^{-1}±SD)	0.6±0.2
Total Biomass (g m^{-2}±SD)	6.1±1.7
Taxonomic Richness*	12.75±4.5

Note: *Taxonomic richness is defined as the number of taxa (families) identified in each sample.

10.3.2 *SPI Investigations*

Owing to rough seas during the latter part of the sampling programme at Basalt Island, SPI images were collected successfully from 13 of the 16 stations. Seventeen of the 48 images were missed as the camera was either triggered prematurely or was dislodged from the seafloor before the image had been taken.

The seabed in the vicinity of Basalt Island is composed of primarily fine-grain sediments with a major mode of silt-clay (> 4 ϕ). Three of the stations sampled on the west side of the island (B1, B2 and B4) had sand as a major component. Four stations (B6, B8, B12, B16) showed a layer of mud clasts at the surface which is probably a result of trawling activities in the area (Selby and Evans 1997). None of the stations showed any evidence of dredged material deposits.

The average depth of the apparent redox potential discontinuity (RPD) at all stations sampled was 3.57 cm. Values varied between stations with no distinguishing spatial pattern, and ranged between 1.28 cm at Station B1 and 5.31 cm at Station B12. Although biological parameters were not measured in the SPI images, there was frequent evidence of deposit feeding taxa, in the form of feeding voids, at each station irrespective of the sediment type (for an example of this see *Figure 3.4g*).

10.3.3 *Sediment Characteristics*

Data on grain size analyses and TOC content from the stations at Basalt Island are presented in *Figure 10.3c*. Rock and dumped construction waste (boulders and granitic gravel) were observed in the grab samples from two stations (B10 and B12). Repeated grabs (3) were taken at B10 but a representative sample was not obtained and the station was relocated by moving 100m to the south of the original station.

10.4 *DATA ANALYSIS RESULTS*

As noted above, the benthic assemblage of the Basalt Island site is generally dominated by polychaetes, although high variability was exhibited in all assemblage parameters.

The cluster analysis on physical characteristics (measured sediment parameters) was used to examine habitat similarities among stations and to evaluate whether or not differences in physical sediment parameters explained some of the observed differences in benthic community structure. For this analysis, only laboratory measurements of sediment grain size (percent silt-clay) and total organic carbon (TOC) content were used owing to an incomplete SPI dataset.

The Basalt Island stations loosely cluster into three primary groups which are characterized by low (<0.62), moderate (<0.82), and high (>0.82) percent TOC levels. The station groups in the dendrogram are ordered by increasing TOC concentrations from left to right (*Figure 10.4a*). These groupings could also be described by an increasing percent fine sediment fraction, due to the strong correlation between this parameter and TOC content (r^2=0.73, p = <0.001; *Figure 10.4b*). The site is spatially heterogeneous, as illustrated by the variation in grain size and TOC between adjacent locations. Other than the three stations on the western side of Basalt Island with higher sand and lower TOC content, there does not appear to be any clear spatial pattern associated with the grain size/TOC station clusters.

The relevance of the observed physical differences between stations was evaluated using a cluster analysis on the benthic abundance data. If the patterns from the biological data mirror the patterns from the physical data, then a hypothesis about the dependence of the biological community on the physical habitat can be investigated. Based on a Bray-Curtis distance matrix of the family abundances, a cluster analysis showed that several pairs of stations were similar (eg, B1 and B10; B3 and B9; B7 and B16) with one, station B5, dissimilar from others (*Figure 10.4c*). Distinct, large scale groupings were not apparent.

A comparison between these clusters and that of the sediment parameters, does not reveal strong evidence for the hypothesis that physical parameters are the prime structuring factor of benthic assemblages at this site.

Several stations are grouped similarly for both sets of parameters, as follows:

- Stations B1 and B10 are two of the five stations which have a sandy, low TOC habitat; the common features of the biological community in these two stations are high numbers of individuals in the Cirratulidae, Maldanidae, and Spionidae families; and,

- Stations B6 and B8 share the common phenomenon of the mud clast layer present in the SPI images, as well as similar taxonomic profiles;

Several stations are grouped differently by biological parameters, when compared with groupings by sediment parameters.

- Stations B7 and B16 are different in terms of percent fine sediment and TOC, but similar in terms of family abundances;

- Stations with similar sediment characteristics (ie B2, B4 and B8, with low clay/silt fractions and TOC values) were dissimilar in biological parameters. These stations lacked the families common to other stations with these sediment characteristics (ie, B1 and B10); and,

- Station B5 is not clustered in the biological parameters, due to the absences of the Nemertinea and Pilargiidae families which are present at all but one other station.

10.5 DISCUSSION

As described in *Section 10.1*, the objectives of the Seabed Ecology Studies at Basalt Island were to characterise the benthic assemblage of a site which has not been disturbed by dredging related activities.

The overall structure of the benthic community at Basalt Island is generally similar to that previously reported for Hong Kong territorial waters, with low abundances recorded and a numerical dominance of polychaetes (Shin and Thompson 1982). At approximately 6 g m^{-2}, the average biomass of the benthic community at Basalt Island is considerably lower than historical reports, for example Shin and Thompson (1982) record a territory-wide average of 35.2 g m^{-2} and an eastern waters regional average of 22.5 g m^{-2}. It should be noted, however, that both this and the previous studies have not accounted for possible temporal (eg seasonal) variations in benthic assemblage structure.

Given the high variability of both sediment characteristics and assemblage parameters in the Basalt Island site, in addition to the effects of disturbance from anthropogenic sources (dumping of construction waste and trawling), a clear relationship between the physical environment and the benthic assemblage has not been observed.

11 *COMPARISONS BETWEEN STUDY SITES*

11.1 *INTRODUCTION*

The Seabed Ecology Studies were envisaged as a collection of individual, one-time surveys of eight different sites in Hong Kong waters. The sampling design reflected this philosophy in the sequential, rather than simultaneous sampling programme (sites sampled in August 1996, November/December 1996 and April 1997) and the lack of temporal replication (each site sampled only once, with the exception of a reference site (Reference South) which was sampled both in August 1996 (East of Ninepins study site) and April 1997 (Eastern Waters study site)). As a result of these study objectives, the original reporting schedule called for separate reports for each of the eight study sites to provide a "snapshot" of present conditions.

Subsequent to completion of the eighth final report, the usefulness of compiling the results of all eight sites in a single volume to provide a composite reference document was identified. As the format of such a report would also serve to facilitate comparisons between sites, a section discussing any observed patterns between sites was also suggested. Although further statistical analyses were contemplated, meta-statistical analyses (pooling data across stations and seasons) for surveys which were not designed with this purpose in mind were expected to be highly constrained and therefore of limited usefulness.

As a result, the following sub-sections provide a largely qualitative discussion of comparisons between sites in terms of abundance, biomass, taxonomic richness and physical characteristics of the sediments. These comparisons are structured around the factors of region, season and site history. All data from each study site (ie all of the sub-areas within each site) were combined in order to portray the overall site characteristics for the regional and seasonal comparisons (*Sections 11.2* and *11.3*). This approach was adopted due to the observed variability within sub-areas of study sites (eg between DDM-IN and DDM-OUT at South Lamma, and between the two Apron sites at South Cheung Chau) which made partitioning of study sites by sub-areas for this assessment inadvisable. However, the site history comparisons (*Section 11.4*) reference sub-area data, as site history was the factor that led to the attempted sub-area delineation in the first place. This section thus refers to sub-areas but notes the possible confounding influence of sub-area variability in the preface.

11.2 *OBSERVED SIMILARITIES BETWEEN SITES BY REGION*

One of the most important structuring forces in Hong Kong's marine environment is the influence of the Pearl River and the resulting variation in salinity, sediment and organic matter from west to east (Morton et al 1996, Shin and Thompson 1982). While it is thus clear that differences between western and eastern study sites may be expected, the existence of a gradient of influence between these two areas creates difficulties in assigning sites within southern waters to either region.

For the purposes of this assessment, the eastern region was defined as comprising the Basalt, East of Ninepins, Eastern Waters and Tathong Channel study sites. The western region was considered to include only the East Sha Chau study site;

a comparative assessment of sites within this region is thus not possible. The study sites at the Sokos, South Cheung Chau and South Lamma were grouped as a southern region due to their proximity to each other. Although it may be expected that the Sokos site, and to a lesser extent, the South Cheung Chau site, may be more greatly influenced by the effects of the Pearl River than the South Lamma site, the sampling at the Sokos and South Cheung Chau occurred in the dry season (November/December 1996) when freshwater discharge, and thus the influence of the Pearl River, is relatively low. Comparison of sites within the eastern and southern regions are provided below.

11.2.1 *Eastern Region*

The sites in the eastern region displayed a somewhat consistent pattern in the biological benthic parameters of abundance, biomass and richness. Study sites at Basalt, East of Ninepins and Eastern Waters sites ranked as the lowest three sites surveyed in terms of average total abundance (*Table 11.2a*): Average abundance values ranged from 240 individuals m^{-2} at Basalt to 294 individuals m^{-2} at East of Ninepins to 352 individuals m^{-2} at Eastern Waters. In contrast, the Tathong channel site ranked first of the eight sites with an average abundance of 3,130 individuals m^{-2}.

Examination of the data in terms of the average weight per individual at these four study sites reveals a similar, but opposite, pattern (*Table 11.2a*). The Eastern Waters (94 mg), East of Ninepins (44 mg) and Basalt Island sites (26 mg) contained the largest individuals and the Tathong Channel site (12 mg) contained the smallest individuals. Despite the large sizes of organisms encountered at Basalt and East of Ninepins, these sites ranked relatively low in terms of overall biomass (8th and 6th, respectively) perhaps due to the low abundances. Although the Eastern Waters study site also had low abundances (ranked 6th overall), its relatively large average biomass per individual (which was more than double that of other sites) resulted in a ranking of fourth overall for biomass. This high average biomass value at Eastern Waters is attributed to the presence of large molluscs at the study site, which contributed 74% of the recorded biomass, but only 5% of the recorded abundance.

Taxonomic richness was relatively low at Basalt, East of Ninepins and Eastern Waters (ranked 5th through 7th overall; values range from 12 to 13 taxa per grab) and relatively high at Tathong Channel (ranked 1st with a value of 22 taxa per grab) (*Table 11.2a*). However, the pattern of similarities between Basalt, East of Ninepins and Eastern Waters sites breaks down somewhat when sediment characteristics (percent TOC and fine-grained sediments) are examined as the values do not confirm any similarities between sites in this regard (*Table 11.2a*). These data, however, further indicate the distinctive features of the Tathong Channel site which had both the lowest percent TOC and the second lowest percent fines of the eight study sites.

Of the four eastern region sites, the species assemblages are generally similar with polychaetes (mainly Capitellidae and Spionidae) numerically dominant and low abundance/high biomass molluscs influencing the biomass patterns. An exception to this is found at the Basalt site where very few molluscs were found, Nemertinea had a stronger than usual presence and Pilargiidae were the most common polychaetes. This characteristic of the site may be due to its heterogeneity of sediment types (ie very low percent fines at some sites) although correlations between particular biological and sediment characteristics within the study site were not identified (see *Section 10*).

Table 11.2a Comparison Between Study Sites

	Study Site							
Comparative Note	**East Sha Chau**	**Basalt**	**East of Ninepins**	**Sokos**	**South Cheung Chau**	**Eastern Waters**	**Tathong Channel**	**South Lamma**
Total Abundance (no. m^{-2})	468	240	294	2,187	2,080	352	3,130	1,674
Rank Abundance	(5)	(8)	(7)	(2)	(3)	(6)	(1)	(4)
Total Biomass (gm^{-2})	7.5	6.1	12.8	35.7	47.2	32.9	35.7	30.6
Rank Biomass	(7)	(8)	(6)	(2)	(1)	(4)	(2)	(5)
Total Richness ($grab^{-1}$)	7	13	12	21	15	12	22	16
Rank Richness	(8)	(5)	(6)	(2)	(4)	(6)	(1)	(3)
Total Organic Carbon (%)	0.84	0.70	0.88	0.66	0.78	1.05	0.64	1.28
Rank Total Organic Carbon	(4)	(6)	(3)	(7)	(5)	(2)	(8)	(1)
Fine Grained Sediment (%)	91.3	76.7	86.9	45.3	65.7	89.2	57.4	76.9
Rank Fine Sediment	(1)	(5)	(3)	(8)	(6)	(2)	(7)	(4)
Average Weight per Individual	0.016	0.026	0.044	0.017	0.023	0.094	0.012	0.019
(Total g m^{-2}/ total no. m^{-2})	(7)	(3)	(2)	(6)	(4)	(1)	(8)	(5)

11.2.2 *Southern Region*

The study sites in the southern region (Sokos, South Cheung Chau and South Lamma) rank second, third and fourth (behind Tathong Channel) in terms of overall abundance of organisms. These average abundances, which range from 1674 individuals m^{-2} at South Lamma, to 2080 individuals m^{-2} at South Cheung Chau, to 2187 individuals m^{-2} at the Sokos, are nearly an order of magnitude higher than abundances observed at some of the eastern region sites (excluding Tathong Channel).

Also in contrast to the eastern region sites (excluding Tathong Channel), the average weight per individual at Sokos, South Cheung Chau and South Lamma is both more consistent (17-23 mg) and lower. However, because of the much greater abundances at the southern region sites as compared to Basalt, East of Ninepins and Eastern Waters, the overall biomass tends to be higher. South Cheung Chau had the highest overall biomass at 47.2 g m^{-2}. The Sokos study site tied for the second rank with the Tathong Channel site (at 35.7 g m^{-2}) and the South Lamma site ranked fifth (at 30.6 g m^{-2}).

In terms of taxonomic richness, the southern region sites rank second, third and fourth behind Tathong Channel. The southern region sites exhibit generally similar benthic communities which are numerically dominated by Annelida (mainly spionids) but supplemented by large numbers of Veneridae molluscs at the South Lamma site.

Although there do not appear to be strong regional similarities in the southern sites' percent TOC or percent fines values, it is interesting to note that the Sokos and Tathong Channel sites have the lowest percent fines and lowest TOC values. This particular characteristic is likely due to the fact that both sites were former sand borrow areas and thus may still contain more sandy sediments than other areas. It is also interesting to consider this feature in light of the very high abundance, biomass and taxonomic richness statistics for these sites. This combination of hetergeneous habitat and high abundance and diversity was also observed in a study of recolonisation of a former dredged material disposal site in Mirs Bay (BCL 1996). The Mirs Bay study concluded that the coarser sediment texture and greater variety of sediment types may provide opportunities for a greater number of species' niches and a more erosion-resistant and physically stable environment.

11.2.3 *Discussion of Regional Patterns*

When evaluating apparent similarities between eastern region sites (Basalt, East of Ninepins and Eastern Waters), it must be acknowledged that seasonal factors (Basalt and East of Ninepins both sampled in August 1996) and site history factors (both Basalt and Eastern Waters are undisturbed sites) may be exerting a confounding influence. An analogous caution applies to the apparent similarities observed between the Sokos, South Cheung Chau and South Lamma sites in that both the Sokos and South Cheung Chau sites were sampled in the same season (November/December 1996). Seasonal patterns are discussed below in *Section 11.3*.

Tathong Channel was initially considered as an eastern region site due to its geographic location. However, as the Tathong Channel study site lies at the eastern end of Victoria Harbour and contains a formerly used sand borrow area it is likely to exhibit characteristics of a disturbed site. In this respect it might thus be expected to show greater similarities to the southern region sites of the Sokos (former sand borrow area), South Cheung Chau (dredged material disposal site) and South Lamma (shows evidence of dredged material disposal and anchorage activities). Similarities due to site history, such as these and the Basalt and Eastern Waters similarities mentioned above, will be discussed in *Section 11.4* below.

The apparent regional patterns in some aspects mirror the findings of Shin and Thompson 1982. In the previous study benthic communities were found to show distinct characteristics following a salinity gradient from west to east. Eastern waters sites (defined as ranging from northern Mirs Bay to Po Toi) were classified as having similar benthic communities, as also found in the this Study. However Shin and Thompson noted evidence of several different communities occurring in the southern region between the Sokos and South Lamma. This finding does not agree with the apparent similarities in southern region communities observed in this Study. Finally, Shin and Thompson noted distinct communities, which had the highest abundance and biomass values of their five identified groups, in scoured tidal channels such as those in Tathong Channel. This finding may assist in explaining the extreme values for abundance and biomass determined in this Study for the Tathong Channel site.

11.3 OBSERVED SIMILARITIES BETWEEN SITES BY SEASON

Oceanic seasons in Hong Kong can be generally delineated into the wet season, which is generally thought to encompass mid-April to early October, and the dry season which includes the period from mid-October through early April. The transitional season is loosely defined as a six week period surrounding the change from wet to dry and dry to wet seasonal conditions. It is thus considered that the eight surveys can be categorized as occurring within the wet season (August 1996, three surveys), the dry season (November/December 1996, two surveys) and the transitional season (April 1997, three surveys). Potential seasonal patterns observed at the eight study sites are described below.

11.3.1 The August 1996 Sampling Period

Sites sampled within the wet season in August 1996 included East Sha Chau, Basalt, and East of Ninepins. Observed average abundances at these sites were generally low relative to other sites with East Sha Chau (468 individuals m^{-2}) ranked 5th, Basalt (240 individuals m^{-2}) ranked 8th, and East of Ninepins (294 individuals m^{-2}) ranked 7th. Average biomass was also relatively low with East Sha Chau (7.5 g m^{-2}) ranked 7th, Basalt (6.1 g m^{-2}) ranked 8th, and East of Ninepins (12.8 g m^{-2}) tied for ranks 6th and 7th. Taxonomic richness values follow the same pattern with relatively low rankings (8th, tied for ranks 6th and 7th, and 5th) for East Sha Chau, Basalt and East of Ninepins study sites, respectively. The August 1996 study sites show no apparent patterns in percent fines or TOC, or in average weight per individual.

The similarities between wet season study sites in terms of abundance, biomass and richness show a weak pattern of relatively low values and thus may reflect the influence of a seasonal factor. However, the similarity of the values for the Eastern Waters study sites to these wet season study site values, highlights that regional factors (described above) may be confounding apparent seasonal similarities between Basalt and East of Ninepins study sites. Furthermore, since seasonal effects in the wet season, eg greater discharge from the Pearl River Delta, would be expected to exert differential influences on western (East Sha Chau) and eastern sites (Basalt and East of Ninepins), any observed similarities between sites might argue against seasonal effects.

11.3.2 The November/December 1996 Sampling Period

The study sites sampled in the dry season in November/December 1996 include Sokos and South Cheung Chau. Despite the fact that these two sites represent an exhausted sand borrow pit and an open water dredged material disposal site, respectively, the apparently strong similarities between the two sites have been discussed in *Section 11.2.2.*

At initial reporting of the high average abundance values for the Sokos and South Cheung Chau study sites (see *Sections 4* and *5*) it was speculated that both sites may have been sampled during a recruitment pulse for one or more of the dominant taxa (eg the Spionids). However, subsequent reports identified that even higher abundances at the Tathong Channel site which was sampled in the transition season (April 1997). While this does not necessarily refute the seasonal recruitment pulse theory, particularly in light of Shin and Thompson's finding of very high abundances in the Tathong area, it further caveats this hypothesis.

11.3.3 The April 1997 Sampling Period

The transition season is highly variable since it represents a period of potentially rapidly reversing oceanic currents from dry (southwesterly flowing) to wet (northeasterly flowing) seasonal conditions. The study sites sampled during this period, ie Eastern Waters, Tathong and South Lamma, showed no apparent similarities in any of the examined parameters (*Table 11.2a*). Recorded average abundance values ranged from the highest recorded value at Tathong Channel (3,130 individuals m^{-2}), to a moderate value at South Lamma (1,674 individuals m^{-2}), to one of the lowest recorded values at Eastern Waters (352 individuals m^{-2}). Total biomass, total richness, average weight per individual, percent TOC, and percent fines were also variable. In addition to falling within one of two yearly oceanic transitional periods, the month of April was also identified by Shin and Thompson 1982 as lying within the most variable period of the year (ie February to May) for Hong Kong benthic communities. For these reasons, strong seasonal patterns between sites sampled in the transitional season are not expected.

11.3.4 Discussion of Seasonal Patterns

From the discussion above, it appears that seasonal factors do not appear to exert a discernable influence on benthic community patterns observed at the eight study sites. The only potential pattern was that of a possible seasonal recruitment pulse during November/December at the Sokos and South Cheung Chau study sites.

It is interesting to note that Shin and Thompson dismiss seasonal variation as factor in their assessment, although they point out that their survey avoided the variable February to May period. The lack of any obvious seasonal patterns in this Study is thus consistent with previous findings.

11.4 *OBSERVED SIMILARITIES BETWEEN SITES BY SITE HISTORY*

The primary purpose of the Seabed Ecology Studies was to explore the status of benthic communities at a variety of anthropogenically disturbed sites and to gain insight into the factors structuring the assemblage. The surveys included a capped pit (East Sha Chau), two open water dredged material disposal sites (East of Ninepins and South Cheung Chau), two exhausted marine borrow areas (Sokos and Tathong Channel, and three reference sites (Basalt, Eastern Waters and South Lamma), all of which showed evidence of trawling, anchorage and/or disposed debris. A discussion of observed patterns by these categories of site history is provided below.

It should be noted that this discussion is based on delineation of pit, lip, apron, mound and reference areas based on information existing prior to initiation of the individual site surveys. As the characteristics of these sub-areas were not always uniform, due either to delineation which did not accurately reflect actual habitat characteristics or to inherent small-scale variability within a coherent habitat type, comparisons must be drawn cautiously. The following discussion is designed to avoid conclusions based on data which may be confounded by high sub-area variability.

11.4.1 *Dredged Material Disposal Sites and Capped Pits*

It is often postulated that frequency, duration and type of disturbance is a major structuring force in ecological communities. This concept is particularly relevant to Hong Kong waters where most areas of the seabed are subjected to trawl disturbance (Selby and Evans 1997, Morton 1996), and many other areas have served as authorized or unauthorized sites for disposal of dredged material and/ or construction waste. In this Study, examination of recolonization following disturbance due to dredged material disposal was conducted at East Sha Chau, East of Ninepins, and South Cheung Chau study sites.

Comparison between the three disposal sites is most relevant for specific sub-areas within the sites designated to represent the direct effects of disposal operations. However, these comparison must account for the fact that the elapsed time between the most recent disposal (or capping) event and sampling at the study sites varied. At the East Sha Chau Pit stations, the mud cap was completed in January 1994, approximately 30 months prior to sampling. According to dumping allocation records, the East of Ninepins Mound stations last received dredged material in March 1995, approximately 16 months prior to sampling. It was not possible to precisely determine when the most recent disposal event occurred at the South Cheung Chau Mound stations although due to an allocation system which directs disposal away from existing mounds, it is likely that a year or more had elapsed between disposal and sampling at this site.

The Pit stations at the East Sha Chau site were found to demonstrate evidence of recolonization processes, despite the fact that observed abundance, biomass and taxonomic richness values were lower than those of a farfield reference site. Pit stations also exhibited a benthic assemblage which was mainly composed of polychaetes and was distinct from those in surrounding areas.

The Mound stations at the East of Ninepins site exhibited the highest abundance and lowest taxonomic richness of all sub-areas sampled including the two reference sites. The physical characteristics of the mound were found to be distinct from the surrounding seabed in that the sediments comprised a larger proportion of coarse grained material and had low RPD values, indicating a low level of oxygenation of the surface sediments. The benthic assemblage on the mound was dominated by opportunistic Spionid polychaetes which have been recorded at high abundances in disturbed sediments. These characteristics of the Mound stations could either be a result of recolonisation of disposed material or of survival of individuals transported from the dredging site during disposal operations. Given that uncontaminated mud in Hong Kong is usually dredged from depths greater than 2 metres below the surface of the seabed, and such sediments are unlikely to host substantial numbers of benthic organisms, recolonisation of the uncontaminated dredged material mound at the East of Ninepins site is the more probable explanation for the observed community.

At the South Cheung Chau disposal site fewer differences between mound and reference sites were apparent. All mound and reference stations were similar in terms of abundance and biomass and all areas within the disposal site were dominated by Spionid polychaetes. Differences in particle size, TOC content and RPD depth were not apparent within the disposal site and it was hypothesized that a recruitment pulse of Spionid polychaetes may have further contributed to the relatively uniform benthic community observed.

11.4.2 *Exhausted Sand Borrow Areas*

Sand borrow areas, which have been disturbed through the removal of sand deposits and remain as pits in the seabed, were the subject of study at the Sokos and Tathong Channel. As discussed in *Section 11.2.2*, the Sokos and Tathong Channel study sites rank lowest in both percent fine-grained sediment (45.3% and 57.4%, respectively) and percent TOC (0.66% and 0.64%, respectively), and highest (ie within the top three ranks) for abundance, biomass and taxonomic richness. It has been postulated by this and other studies that habitat heterogeneity and a low fine-grained sediment content leads to more diverse and mature assemblages. The extent to which these characteristics are related to site history at the Sokos and Tathong Channel study sites is explored below.

At the Sokos, both the Pit and Lip stations were found to lie within an area of highly heterogeneous seabed. The presence of numerous bedforms and cross-bedding planes indicated that a dynamic hydraulic regime influences the site although it was suggested that this factor may be compounded by the previous dredging activities. Even though the sediment characteristics of the Reference station were found to be very different (ie homogeneous fine-grained sediments), benthic communities were indistinguishable from those observed at Pit and Lip stations. Given the differences in the physical environment, it was postulated that a recruitment pulse of Capitellid, Spionid and Magelonid polychaetes, or another factor, determined the biological characteristics of the site. Therefore, it was not clear at this study site that habitat heterogeneity was responsible for the high abundance, biomass and taxonomic richness values observed.

Results of sampling at the Tathong Channel site did not parallel those at the Sokos site. Like the Sokos site, the Tathong Channel site recorded high abundances of organisms, but unlike the situation at the Sokos, the Tathong Channel site showed significant variation between Pit, Lip and Reference areas. Pit stations exhibited lower abundance and taxonomic richness values than Reference stations and lower biomass values than for the Lip stations. This was attributed to the presence of fluid mud at approximately half of the stations within the pit. It appears that strong currents at the Sokos prevent the pooling of fluid mud in the pit, whereas at the Tathong site, currents may scour areas at the level of the natural seabed (eg surficial sand was observed at some stations in the Reference area) but do not extend to the bottom of the marine borrow pit. These findings are thus consistent with those of Shin and Thompson, which observed the highest abundance and biomass values in scoured tidal channels in the Tathong area, and support the habitat heterogeneity hypothesis formulated by BCL 1996.

11.4.3 Other Sites

Study sites at Basalt, Eastern Waters, and South Lamma were originally designed to serve as undisturbed reference areas from which baseline data could be compiled. However, further investigation of the sites through swath bathymetry and sidescan sonar surveys at the South Lamma site, and through SPI and grab sampling at all three sites, revealed evidence of disturbance at each site.

At Basalt, the impacts of trawling were inferred from the presence of mud clasts at four stations, and rock and disposed construction waste were observed in grab samples from two stations. The evidence for anthropogenic disturbance was not as clear at the Eastern Waters site. Nevertheless, sediments showed high fluidity, as evidenced by high apparent RPD depths and overpenetration of the SPI camera at many stations, which indicates the site is subject to a high degree of seabed turbulence caused by wave action and/or trawling activity in the area. The reconnaissance survey conducted at South Lamma indicated the presence of anchor and trawl scars adjacent to the southern coast and further offshore in the anchorage area. In addition, an area of degraded dumped material was reported at the mouth of Sham Wan Bay and some smaller areas along the south Lamma coastline.

These results indicate the ubiquity of potential anthropogenic impacts to Hong Kong's seabed. Although further comparison of these "other" sites is constrained by the lack of a common site history, it is evident from this Study that it is highly unlikely that any site in Hong Kong waters can be considered completely undisturbed.

11.4.4 Discussion of Site History Patterns

The main site history pattern observed was that of opportunistic, colonizing organisms present on capped pits and at disposal mounds. The presence of these organisms indicates that either the disposed (or placed) sediments have been recolonised by individuals from the surrounding communities or that organisms present at the source site of the dredged material have survived transport to the disposal site. Such opportunistic species were also observed at sites which exhibited strong seabed currents (the Sokos) and substantial quantities of fluid mud (Tathong Channel). Given the observations of anthropogenic or wave-derived disturbance at each of the reference site, it is inferred that most of Hong Kong's seabed is subject to one or more types of disturbance on a regular basis. It is therefore not surprising that the benthic community observed in this Study is characterised by rapidly colonizing and/or disturbance-resistant species.

11.5 CONCLUSION

While the Seabed Ecology Studies' survey design was not intended to facilitate comparisons between sites, the foregoing discussion has qualitatively explored potential patterns by region, season and site history, and highlighted several findings of interest. These findings include:

- Sites in the eastern waters of Hong Kong (Basalt Island, East of Ninepins and Eastern Waters study sites) showed a consistent pattern of benthic community parameters with abundance, biomass and taxonomic richness values relatively lower than other sites. However, no consistent patterns were observed in the sediment parameters. These results support the findings of Shin and Thompson 1982 which suggested that benthic communities from Mirs Bay to Po Toi shared similar characteristics.

- Sites in the southern waters of Hong Kong (Sokos, South Cheung Chau and South Lamma) were also found to be consistent with relatively higher abundance, biomass and taxonomic richness, but relatively lower average weight per individual. These findings differ from Shin and Thompson 1982 which found significant differences in benthic communities between Lamma Island and the Sokos.

- The Tathong Channel study site had the highest abundance, biomass and taxonomic richness of any study site and it was postulated that habitat heterogeneity observed at the site contributed to the rich benthic assemblage. Shin and Thompson 1982 also noted distinct communities with high abundance and biomass in scoured tidal channels such as the Tathong Channel.

- Observed seasonal patterns were limited to a possible seasonal recruitment pulse noted during November/December at the Sokos and South Cheung Chau study sites.

- Opportunistic, colonising species were present on capped pits and at disposal mounds indicating recovery of the benthic community after placement of dredged material.

- Both exhausted sand borrow areas (Sokos and Tathong Channel) showed high abundance, biomass and richness values indicating, as in BCL 1996, that heterogeneous substrate may be one of the factors promoting a diverse and mature assemblage at these sites.

- Evidence of seabed trawl scour, the presence of disposed construction waste, or anchor scars was observed at one or more of the reference sites suggesting the ubiquity of anthropogenic impacts to Hong Kong's seabed.

Confirmation of any of the patterns described above would require focused research and robust hypothesis testing. Nevertheless, by presenting the individual summaries and this synthesis of results, the Seabed Ecology Studies can not only characterise conditions at the eight study sites but also provide the impetus for further exploration of Hong Kong's benthic environment.

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