REGIONAL COORDINATING UNIT
EAST ASIAN SEAS ACTION PLAN

UNEP UNITED NATIONS ENVIRONMENT PROGRAMME

PROCEEDINGS OF THE WORKSHOP ON SOFT-BOTTOM BENTHIC COMMUNITIES AS INDICATORS OF POLLUTANT-INDUCED CHANGES IN THE MARINE ENVIRONMENT

Edited by L.M. Chou

RCU/EAS TECHNICAL REPORTS SERIES NO. 7

Prepared in cooperation with:

NUS

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Bangkok, 1995

Note: This document is proceedings of the Workshop on Soft-bottom Benthic Communities as Indicators of Pollutant-induced Changes in the Marine Environment. The workshop was organized and convened during 20-29 March 1995 by the Department of Zoology of National University of Singapore (NUS) as one of the activities under the EAS-33 project "FP/ES/9101-94-66: Training workshop on the biological effects of pollutants: East Asian Seas region."

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PREFACE

This volume of the Regional Coordinating Unit for the East Asian Seas Action Plan (EAS/RCU) Technical Reports Series contains the proceedings of the Singapore Workshop on Soft-bottom Benthic Communities as Indicators of Pollutant-induced Changes in the Marine Environment. The workshop was convened as part of project EAS 33 (Biological Impacts of Pollutants), approved at the eleventh meeting of the Coordinating Body on the Seas of East Asia (COBSEA). It was organised by and held at the Department of Zoology, National University of Singapore (DZ/NUS) during 20-29 March 1995.

The main thrust of the Workshop, as perceived by the COBSEA, was essentially capacity-building in the form of training of scientists from countries of the region in methodologies and techniques for assessing soft-bottom benthic communities and their responses to pollution impacts in the marine environment. It was expected that these scientists will in turn impart their newly acquired skills to others back in their national laboratories and institutions. The workshop focused on marine soft-bottom benthic communities, how these can be surveyed and monitored, and how their response to environmental change caused by pollutants makes them useful as bioindicators at species and community levels.

The objectives of the Workshop were selected based on the recommendations of the 1993 Phuket Workshop on Biological Effects of Pollutants and emphasis was given to methods and techniques which do not necessarily demand sophisticated equipment and can be easily applied in most situations throughout the region. This should allow standardisation of monitoring programmes so that inter-comparability of data can result in enhanced understanding and effective management of coastal and marine areas across the region. A strong field component was incorporated to provide participants with a greater appreciation of the varied sources and range of human impacts as well as the management measures that can be effected. Field operation of equipment gave participants the understanding that unforseen difficulties could arise and how these may be resolved.

The scientific programme of the Workshop was developed by DZ/NUS in consultation with EAS/RCU and the Great Barrier Reef Marine Park Authority (GBRMPA, Australia) which will organise the next follow-up workshop of the project. The logistics for implementation of this Workshop was provided by DZ/NUS and the programme carried out by resource persons from DZ/NUS, National Institute of Education/Nanyang Technological University (NIE/NTU, Singapore) and Marine Science Institute/University of the Philippines (MSI/UP). In addition, the participation of the Australian scientific convenor for the follow-up workshop was essential for providing continuity to the training programme of the project.

Apart from the follow-up workshop to be organised in Australia by GBRMPA in August 1995, participants agreed to recommendations on further follow-up activities for consideration by the COBSEA. These will be presented to the next intergovernmental meeting of the Action Plan.

The final editing and compilation of this volume was done by L.M. Chou of DZ/NUS in consultation with the Regional Coordinating Unit for the East Asian Seas Action Plan.

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WELCOME ADDRESS

by Professor Lam Toong Jin
Head, Department of Zoology
National University of Singapore

Dr. Reza Amini, Coordinator of East Asian Seas Regional Coordinating Unit, UNEP

Overseas delegates

Ladies and gentlemen

It is indeed a great honour for the National University of Singapore to host this workshop as part of a series of workshops on the biological effects of pollutants, carried out as project EAS 33 by UNEP/COBSEA. I would like to extend a very warm welcome to everyone, and especially to the foreign participants representing the countries of COBSEA (Coordinating Body on the Seas of East Asia), some of whom are in Singapore for the first time.

This workshop focuses on marine soft-bottom benthic communities and how they can be used as indicators of environmental change caused by pollutants. Throughout the region, studies on soft-bottom benthic communities lag behind those of other coastal and marine habitats such as coral reefs and mangroves. But the situation is now improving as more useful information is gathered through increasing efforts and initiatives. The ASEAN members benefitted greatly through their involvement in the recently concluded 10-year monitoring programme of the ASEAN-Australia Living Coastal Resources Project and have created an enormous regional database that is valuable for regional analysis across large spatial scales. National programmes within ASEAN have additionally been strengthened. Much of the experience from the ASEAN-Australia LCR Project are being shared in this workshop. Member countries of COBSEA which are not members of ASEAN will no doubt have their own programmes on marine soft-benthic communities and the sharing of experiences will be important to this workshop.

Marine soft-bottom benthic communities are not readily seen and therefore impacts on the sea-floor caused by pollutants do not invoke much human sentiment no matter how drastic the effects maybe. Degraded mangroves and reefs are more visible and induce management interventions based on what is seen. Nevertheless, soft-bottom benthic communities are an important component of the marine environment and deserve proper management. It is hoped that this message can be conveyed to coastal managers and decision makers so that the marine environment as a whole can be effectively addressed.

The Department of Zoology of this University has an active on-going collaborative programme with the Ministry of the Environment on marine soft-bottom benthic communities. Dr. Chou Loke Ming and Ms. Maylene Loo are two members of the research team who will be contributing as resource persons. In addition, there are two resource scientists who will be contributing their expertise. They are Dr. Helen Yap from the Marine Science Institute, University of the Philippines, and Dr. Shirley Lim from the School of Science, National Institute of Education, Nanyang Technological University. Both of them have extensive experience with soft-bottom benthic communities and we are extremely glad that they could reschedule their heavy workloads to be at this workshop.

The outcome of this workshop will be important in giving future direction to the programme on the biological effects of pollutants in the marine environment. I trust that every participant will benefit from this meeting, through the two way process of receiving and contributing. To the overseas participants, I hope that you will enjoy your stay in Singapore. The workshop programme includes field work which allows you to see Singapore from a perspective that no ordinary tourist will ever get. But you do have some time, although limited, to see Singapore as a tourist.

PROPERTIES OF THE MARINE ENVIRONMENT

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INTRODUCTION

The oceans cover 70.8% (254 million km^2) of the earth's surface and has a large influence on climate as they control the distribution of heat on the planet (Ingmanson & Wallace, 1973). Water is a good absorber of heat, without itself increasing much in temperature. It is also the most abundant molecule in the liquid state on earth, 97% of which occurs in the oceans with the remaining 3% in rivers and lakes, snow and glaciers, and the atmosphere. Being a universal solvent, water has the unique ability to dissolve at least part of almost every substance and is essential for biological processes. The oceans form the largest reservoir of free water. Since a bit of almost every substance is present in dissolved form in the oceans, they are more likely to undergo chemical reactions compared to the gaseous or solid phases.

Topographical features differ between the continents and the ocean basins. Average elevation of land is 0.4km above present sea level. The highest land elevation represented by the peak of Mount Everest is 8.8km above sea level. In the marine environment, the deepest known location is the Challenger Deep in the Mariana Trench, 11km below sea level. Apart from the large areal extent, seawater occupies an enormous volume of 1.4 billion km^3 with depths averaging 4km.

Currents moving seawater about give the impression that the oceans are completely homogeneous. In reality, they are heterogeneous as a combination of factors operate to provide a large variety of marine ecosystems with different and unique characteristics, but still linked by water moved by currents. In shallow coastal waters, autotrophic and heterotrophic layers are in closer contact, and the constant influx of nutrients from land promote high productivity.

BIOGEOCHEMICAL PROCESSES

Water is an efficient transport agent and is itself transported between land, ocean and atmosphere through the hydrological cycle. As the largest reservoir of free water, the oceans are maintained in a steady state with loss through evaporation balanced by input from rivers and rainfall. Its density changes with temperature and salt concentration. Salt also increases its viscosity, conductivity and osmotic pressure. Many marine organisms maintain an internal salt content similar to that of seawater to minimise the amount of energy otherwise needed to keep an internal salt content different from seawater. Local variations in the rate of water transport through the hydrological cycle control salinity. Temporal variations in salinity are restricted to surface waters and coastal areas which are easily influenced by rainfall and river runoff.

Unlike the terrestrial environment where primary producers are often large, in the marine environment, they are mostly tiny. Phytoplankton have short lifespans but reproduce rapidly and therefore, have high turnover rates. They respond quickly to environmental changes. A sudden increase in nutrient input can trigger a phytoplankton bloom and affect higher trophic levels of food chains. In the marine environment, consumers occupying the higher trophic levels such as whales and large fishes, are the longest living species, while on land, the longest living organisms are trees, the primary producers (Steele *et al.*, 1989; Steele, 1991). Trees respond much more slowly to environmental changes than the sea's phytoplankton. Since marine primary producers have such high turnover rates, they and the higher trophic levels that they support become vulnerable to environmental fluctuations even of short duration.

The ocean is largely biogeochemically downstream from land and is considered as a biogeochemical sink. Chemicals in dissolved or particulate forms are transported from land to the ocean by rivers, and from the inner earth by hydrothermal vents. Undergoing chemical transformations in the ocean, most of these materials sink and get incorporated with bottom sediments. They are returned to the system by weathering when uplifted by geological processes. Marine sediments are an important reservoir of materials derived from weathered pieces of continental or oceanic crust transported to the oceans by rivers, glaciers, or winds, and the precipitation of solutes from seawater.

Particles of organismic origin most common in sediments are hard parts such as bone and shell, and are rich in calcium and silica. Organic matter alters the mechanical properties of the sediments and also provide food for the benthos. Living organisms in turn, have an impact on the physical, chemical and geological characteristics of the sediment. Burrowers for example, increase the supply of oxygen to the sediments. As particles sink in the water column, they are quickly coated by a film of organic matter which adsorbs metal ions and attract heterotrophic bacteria. In this way, particles transport metals from water to the sediment sink, while at the same time, promote biofouling.

Gases are important components of marine biogeochemical cycles. They diffuse across the air-sea interface until an equilibrium is reached with winds and temperature influencing the rate of flux. Elements of carbon, hydrogen, oxygen, nitrogen, phosphorous and sulphur form organic matter and are biologically active. Their transport is largely influenced by the biogeochemical cycle of organic matter. Those that are present in low quantities, such as nitrogen and phosphorous, but are important to life processes are referred to as biolimiting elements. Elements that are essential for the growth of plants are known as nutrients, and the distribution of nitrogen and phosphorous in the marine environment is important to primary productivity. Other elements such as carbon and sulphur are available in abundance and their distribution in the marine environment through the biogeochemical cycle of organic matter is not as crucial. Hydrogen and oxygen are present mostly as water. Trace metals such as iron, aluminium and silicon are present in small quantities as solutes in the water but are abundant in the earth's crust. Many are important to life, performing crucial roles in enzyme systems. Marine organisms concentrate metals in their bodies and lower forms are more efficient at this. The metals are resolubilised upon death of the organisms.

Autotrophs are responsible for synthesising organic matter from inorganic compounds and assimilating carbon, nitrogen, phosphorous and sulphur during photosynthesis. Phytoplankton produce most of the particulate organic matter (POM), much of which is then passed up the food chain. Excretion or death of organisms converts POM into detrital form. Decomposition or remineralisation of detrital POM is performed by heterotrophs. In the presence of oxygen, decomposition is aerobic where complete oxidation returns particulate nitrogen and phosphorous to the soluble form, making them available again as nutrients. The large amount of oxygen in the euphotic zone promotes aerobic decomposition of POM and regenerates nutrients. Still, a fraction sinks to the seafloor and is buried in the sediments.

Oxygen undersaturation is pronounced below the euphotic zone, particularly in the thermocline where water is relatively stagnant and a large flux of POM is received. POM continually accumulates in deep water masses. Without oxygen, some microorganisms are capable of using nitrate and sulphate for respiration. In sediments and coastal upwelling areas, oxygen deficiency can result when the amount of POM is greater than that of oxygen. Dissolved organic matter (DOM) forms a large pool of carbon in seawater. Produced by degradation of detrital POM, most is quickly assimilated by bacteria. Dissolved inorganic nitrogen is necessary for the growth of marine plants. Nutrient and light availability control the proliferation of autotrophs. Coastal waters have the highest productivity because of the nitrogen input from rivers and of nitrogen fixation in shallow environments.

As is the same for nitrogen, the marine biogeochemical cycle of carbon is controlled mainly by biologically mediated processes. The equatorial Pacific is thought to be the largest natural source of atmospheric carbon dioxide, with the magnitude of the flux varying inter-annually under the influence of the El Nino-Southern Oscillation cycle. Equatorial upwelling bring up sediments rich in organic carbon, but new primary production has not been found to match the relative concentrations of new nutrients (Barber *et al.*, 1994). This may be due to efficient biological recycling of nutrients and carbon dioxide in near-surface waters. The important role of small grazers (microzooplankton) is increasingly being recognised. As primary production increases, grazing also increases proportionally. Carbon export is therefore not as high as originally believed but dense aggregations of large oceanic diatoms do make important local contributions to carbon exports.

Organic compounds are also important to life as they initiate physiological responses. Apart from being the main food source for heterotrophs, some function as toxins to discourage competitors or predators. Others have the ability to neutralise the toxic effects of heavy metals, or to attract mates. Organisms degrade organic compounds to obtain chemical energy and the numerous species-specific anabolic and catabolic pathways result in a great variety of biologically-synthesised organic compounds.

LATITUDINAL VARIATIONS

In deep waters of the higher latitudes, seasonal changes in climate create convective currents that bring the stratified bottom waters together with trapped nutrients to the surface. Nearer the tropics where atmospheric temperature remains constant throughout the year, deep waters remain at the bottom and sinking materials stay trapped permanently at the bottom (except in areas of upwelling). Surface salinity also varies with latitude because of differences in the rate of water loss through evaporation and gain from precipitation. Surface water salinities are greatest at mid-latitudes where net loss of water through evaporation is greatest.

In the high latitudes, limited light availability results in one plankton bloom annually. In mid latitudes, shifts in nutrient and light availability result in a large plankton bloom in spring and a smaller one in the fall, together with accompanying increase in consumers. Nearer the equator, bottom nutrients remain trapped because of the absence of convective mixing and plankton blooms occur only in shallow or upwelling areas.

AN OPEN AND INTERCONNECTED ENVIRONMENT

The marine environment is three-dimensional and life exists throughout all depths from surface waters that receive maximum sunlight to the deep ocean trenches devoid of light. Most organisms exploit the density of seawater to swim, float and be transported across large distances. Life styles categorise marine organisms into three general groups: those that drift, those that swim and those that remain attached. Those that drift include the tiny plants and animals (plankton) whose transport depends almost totally on currents. Swimmers, particularly strong ones like turtles, fishes, whales are largely independent of currents, and are referred to as nekton. Bottom dwelling organisms (benthos) remain closely associated with the substratum and can be attached, move about on the bottom or burrow into the substratum.

Seawater links organisms and processes in and on the seafloor with those in the water column. In addition, benthic areas spaced apart are connected by the flow of seawater between them. Benthic sessile organisms are completely dependent on currents to supply food and nutrients. At the same time, benthic communities 10km (for example) downstream will be more easily affected by pollutants introduced into the water column upstream compared to the terrestrial environment. The marine environment has to be considered as an open and interconnected system where the effects of activities in neighbouring areas are easily transported across large distances to affect other marine areas.

Marine organisms make use of the open and interconnected properties of the marine environment to their advantage. Many species have external fertilisation, permitting currents to transport and disperse gametes and larvae over large distances. This strategy reduces overcrowding in vicinity of parent populations, ensures survival should the habitat of parent population be destroyed, reduces potential for inbreeding, and increases range of habitats for settlement. Many marine species have a planktonic life history.

Seawater is an excellent medium for the transport of food, nutrients and gases needed by marine organisms (particularly sessile ones) to grow and survive. Many marine organisms are well adapted to surviving on low concentrations of nutrients characteristic of most marine environments, but currents allow these limited quantities to be more evenly distributed among the marine communities. The transporting property of currents is about the most important factor linking different marine areas. Shallow coastal areas are linked with deeper offshore systems by currents. Fast currents can disperse living and non-living materials over wide areas. The larvae of many shallow water invertebrates are commonly found hundreds of kms from the nearest shallow water. Occasionally, juvenile reef fish have been found up to 800km from shore. It is therefore important to understand the scale associated with currents and other hydrodynamic features in order to determine the spatial scale needed for marine protection planning and management.

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IMPACTS ON THE MARINE ENVIRONMENT

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INTRODUCTION

Impacts on the marine environment come from natural and anthropogenic sources. While marine ecosystems are known to recover fully from natural hazards, they are seldom known to do so from human impacts. Impacts caused by humans can be grouped into over-exploitation, alteration of the physical environment, and pollution. Thus, apart from causing physical damage, human activity frequently results in introduction of foreign substances to the marine environment, and is the main cause of marine pollution. All of these impacts cause changes to natural biogeochemical processes to varying degrees. This paper focuses on anthropogenic impacts on the marine environment.

Human impacts are often greater in coastal waters than the open seas, but are not necessarily confined to shallow waters as the environment dealt with is an open and interconnected system. Impacts can be transported over great distances. Management of these impacts is of great environmental concern, particularly with the growing trend of increasing populations in member countries of the Coordinating Body on the Seas of East Asia (Table 1).

TABLE 1 Population size and growth of member countries of UNEP's East Asian Seas Action Plan (WRI, 1994).

Country	Population (in millions)		
	1950	1995	2025
Australia	8.22	18.34	25.21
Cambodia	4.35	9.45	16.72
China	554.76	238.32	1539.76
Indonesia	79.54	201.48	283.32
Korea (S)	20.36	45.18	50.29
Malaysia	6.11	20.13	31.27
Philippines	20.99	69.26	105.15
Singapore	1.02	2.85	3.31
Thailand	20.01	58.27	72.26
Vietnam	29.95	73.81	116.96
Total	745.31	1737.09	2244.25

An estimated 70% of the population live in the coastal area. Fast growing coastal cities, many without adequate sewage treatment contribute to the degradation of coastal waters and shallow marine habitats. Open drainage canals keep pouring raw effluents and industrial wastes directly into coastal waters. The majority of rivers in developing countries are so polluted with wastes, including raw sewage, that they are considered biologically dead. Case studies of coastal pollution have been highlighted by Hinrichsen (1990). Factors contributing to the degradation of the marine environment have been identified to be mostly from human activities (GESAMP, 1990) and reviews of the situation in Southeast Asia are provided by Gomez *et al.*, (1990) and Chou (1994).

TYPES OF IMPACT

Humans damage the marine environment and marine life in many ways. Norse (1993) identified 5 major ways by which harm is caused to the marine environment by humans:

1. overexploitation of living things
2. alteration of physical environment
3. pollution of the sea
4. introduction of alien species
5. addition of substances to the atmosphere that increase ultraviolet radiation and alter climate.

These impacts can be grouped into direct or indirect use of resources (Table 2). All of them, whether extractive or not, alter the natural biogeochemical processes to varying degrees. Non-sustainable removal of species or introduction of alien species will interfere with biologically mediated transport and transformation of substances, leading to imbalance between source and sink and inefficient cycling of materials. Breakdown of ecosystem integrity through physical alteration of habitats causes drastic changes to the entire biogeochemical cycle that make it impossible for the remaining species to survive. Dredging of seabed releases chemical pollutants locked in benthic substrata back into the water column and also resuspends fine particles that reduce sunlight penetration resulting in suppressed photosynthetic activity, and affects respiratory processes of marine animals.

TABLE 2 Direct and indirect uses of the marine environment.

Direct uses (dependent on existence of resource)	Indirect uses (not dependent on existence of resource)
Fishing	Shipping (transport)
Collection of living resources other than fish, for food, curios, or other uses	Discharge of thermal outfall from power generating plants
Non-living resource extraction	Sewage outfalls
Research	Mariculture
Desalination of seawater	Construction
Marine tourism	

Destruction or alteration of marine benthic communities by heated power plant effluent is greatest in the tropics because unlike temperate organisms, tropical species are known to live at temperatures only a few degrees below their upper lethal limit. Lethal or sublethal effects are thus likely to be induced by small temperature elevations. Numerous tropical marine organisms belonging to a widely divergent group of plants and animals all begin to reduce their metabolic rates between 28 - 30^{0}C and begin to die at about

33^0C and above (Gomez & Junio, 1982). Thus, any artificial rise in water temperature poses a greater threat to the natural communities in the tropics. Once eradicated, they are difficult to replace as there are few replacement species which are able to colonise such environments, blue-green algae being an exception (Zieman & Wood, 1975).

Humans have increased the rate of introduction of terrestrial particles into the marine environment. Soil is eroded through deforestation, agriculture and poor land management. Toxic substances and excessive nutrients contaminate or over-nourish many coastal ecosystems resulting in plankton blooms that affect other marine life. The increasing frequency of toxic red tide occurrences in the region is suspected to be triggered by agricultural pesticides. Discharge of untreated human sewage into the sea has greatly increased the organic matter of some coastal sediments and waters, and caused episodes of anoxia (Libes, 1992).

Human activities cause significant alterations to biogeochemical processes. An example is a change in fluxes of nitrogen as increasing amounts of nitrogen are being fixed by industrial processes than is provided for in nature. Fertiliser runoff, sewage dumping, and soil erosion have increased the anthropogenic input of nitrogen so as to overwhelm the natural riverine nitrogen flux of some estuaries. Nitrogen dioxide emissions have increased the rate of nitrogen input to the atmosphere which then enters the ocean by diffusing across the air-sea interface or by rainfall. These human impacts can significantly alter marine productivity and biodiversity.

While many of these impacts are more obvious in shallow coastal waters within the immediate time frame, they are not necessarily confined to these areas. Pollutants are readily transferred throughout food webs through bioaccumulation and biomagnification. They can then be transmitted to the open ocean by marine organisms such as pelagic fish. Marshall (1986) showed that the Chesapeake Bay plumes continually seeded the waters of the continental shelf with a mixture of estuarine and coastal species as they moved across the shelf. Many of these species now appear more common over the shelf indicating the possibility of increasing shelf eutrophication. These processes will transfer impacts over the long term to the rest of the marine environment and marine biodiversity can be affected through selection against certain genetic attributes, elimination of populations, extinction of species, and destruction or fragmentation of ecosystems.

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POLLUTION AND THE MARINE ENVIRONMENT

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INTRODUCTION

The Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) was formed in 1969. **Marine pollution**, as defined by GESAMP is the **introduction by man, directly or indirectly, of substances or energy to the marine environment resulting in deleterious effects such as: hazards to human health; hindrance of marine activities, including fishing; impairment of the quality for the use of seawater; and the reduction of amenities**.

The emphasis, therefore, is on man-made inputs and the damaging effects of wastes, rather than natural inputs to the sea. Most examples of pollution have been cited based on how the deleterious effects relate to human interests in the sea. Thus in practical terms, pollution can be seen as an example of how one set of human interests such as those of industrial and commercial concerns (e.g. the burning of coal, the transportation of oil, the generation of electricity, the disposal of waste products) conflicts with other human interests such as health, fisheries, amenities and scientific interests.

It is important to strike a balance between these conflicting interests. Generally, a threat to human health is usually given the highest priority for control. Often, it is rather difficult to make decisions on the priorities. It is only a straightforward decision when only two interests conflict and both are commercial. For example, in 1967 when the oil tanker *Torrey Canyon* ran aground off the Cornish coast in 1967, a decision had to be made with regards to the treatment of the oil spill. At that time, chemical dispersants were very toxic to marine organisms and their use would have meant a serious risk of great damage to the local fishing industry. However, if the oil is left untreated the tourist industry would be seriously affected. The fishing industry then was estimated to be £6 million per annum while the tourist industry was worth £60 million! As a result, it was a rather obvious choice and the beaches were cleaned. Fortunately, the fishing industry was not noticeably affected. Generally, however, issues are not so clear cut and the decision-making is often difficult. A great deal of information is usually required before decisions can be made.

TYPES OF POLLUTION AND THEIR IMPACTS

Since the late 1960s, there has been a growing environmental concern in western nations. This is fuelled by reaction to a number of incidents of acute pollution such as Minamata disease in Japan and the *Torrey Canyon* disaster in the English Channel. The rest of this paper focuses on some major types of marine pollution, their associated respective disasters and the impacts on the marine environment.

1. <u>OIL SPILLS</u>

(a) *Torrey Canyon* disaster

On March 18, 1967, the tanker *Torrey Canyon* bound for Milford Haven from the Persian Gulf, carrying 117,000 tonnes of Kuwait crude oil, struck a reef and ran aground off Land's End. Six of her tanks were torn apart by the impact and oil began to escape from the ruptured tanks immediately after stranding. By Monday, March 20, some 30,000 tonnes had been discharged into the sea with the main oil slick 18 to 20 miles long and moving south.

By the following week, (24-26 March), it was estimated that some 48,000 tonnes of oil had issued from the *Torrey Canyon* and most of the early release had moved southwards to inflict damaging pollution upon parts of the Brittany coast. It was evident that the oil release was developing to an unprecedented scale and that it was necessary to either remove the oil at its source or disperse it from the surface of the sea. As mentioned earlier, conflicting interests of tourism versus fisheries were easily resolved based on the revenue that each of them brought to the country. By March 27, the *Torrey Canyon* was considered to be beyond hope of salvage and she was bombed.

Rocky shores are high-energy beaches and stranded oil is quickly removed from the intertidal region by wave action and water movement. However, this is not necessarily an advantage if fresh oil is then redeposited on other beaches, repeating the damage elsewhere! Large amounts of stranded oil may kill animals by smothering them.

However, the conspicuous damage on some Cornish beaches following the wreck was, ironically, not due so much to the stranded oil, but to the very toxic oil-spill dispersants (then in use) which were mistakenly poured in concentrated form over the beaches! The dispersant or the mixture of dispersant and oil, proved more lethal than the oil alone and most organisms on the affected beaches were killed. Most importantly, limpets (*Patella*) were killed and in the absence of these herbivores, diatoms and algae colonised the rocks. The algal succession continued unchecked during the summer resulting in a dense stand of *Fucus*. The presence of *Fucus* inhibited the settlement of limpets or barnacles the following season. The change from a community dominated by *Balanus* and *Patella* to one dominated by algae was rather longlived. It was only after some 4 to 5 years that *Patella* became re-established and were able to graze down the *Fucus*. More than 10 years after the spill, the barnacle domination of the rocky shore community was restored but the associated fauna still appeared to be less rich and varied than before.

As a result of the dramatic changes observed on some rocky shore beaches following the wreck of the *Torrey Canyon*, public attention was drawn to the great impact that a very large oil spill could have. It caused concern for the effect of pollution in general on the health of the oceans, and stimulated a large research effort in marine pollution in the following years.

(b) *Amoco Cadiz* disaster

On the night of March 16, 1978, the supertanker, *Amoco Cadiz* ran aground 1.5 nautical miles from the shore at Portsall, on the northwest Brittany coast. Within a short period of about 2 weeks, almost the entire cargo (223,000 tonnes of crude oil from Iran and Arabia) was lost to the sea. Approximately 300 kilometres of different types of shores have more or less been polluted (Grigalunas, 1982). The wreck was no more than 1.5 miles from the shore; therefore, the time of weathering of the oil at the surface of the sea before it went ashore was a few hours to a few days only. Thus, a large quantity of the aromatic fraction was still present in the oil when it touched the coast and aromatic fractions are more toxic to the marine fauna than other fractions. Stranded oil is not readily removed from low-energy sedimentary beaches and drains down into the substratum where low oxygen concentration does not favour bacterial degradation of the oil. Therefore, the oil may retain its toxic properties for some time.

There was no sign of abnormality in the plankton two or three weeks after the spill, although there was a suggestion that the spring plankton outburst was depressed for a period. Although it cannot be doubted that oil pollution kills planktonic organisms, it has not been possible to detect more than very transient effects. Whatever losses incurred are evidently rapidly made good, either by renewed growth or immigration from unaffected areas. However, a few kilometres from the wreck all intertidal species, including resistant species like polychaetes and crabs, perished. It was reported that some 25 million dead large invertebrates drifted on the shore of St. Michel en Greve (Bay de Lannion), together with a huge quantity of dead amphipods. This mortality is likely to be related to the high level of dissolved aromatics. The original communities in some polluted sandy and muddy beaches were replaced by communities comprising a very small number of tolerant species. The general composition of these communities was similar to the opportunistic fauna of a sewerage discharge area and was usually dominated by polychaetes from the families Capitellidae and Cirratulidae. Coincidentally, the recovery patterns of these communities follow more or less in time the ecological succession well-known around a permanent sewage discharge, apparently with the oil (after the highly toxic phase) acting as a form of organic matter input.

The communities of the fine sediments at Morlaix and Lannion were heavily altered by the pollution during the first month following the wreck. The mortality was very severe for the amphipods, the irregular sea urchins and several gastropods. At that time, the impacted communities have not yet recovered their previous richness and diversity on a quantitative basis; however, on a qualitative basis, no species had disappeared completely from the total area polluted by the oil-spill. The impact on exploited species (oysters, kelp, red algae, crustacean and finfish) was varied. Oyster beds are always located in areas well-protected from wave currents and wind action, i.e., in low energy areas. All the oyster beds were heavily contaminated and so were the animals at the sea bottom. However, the oyster is a rather resistant invertebrate and only few animals were killed; most of them continued to grow and remained contaminated until the end of 1978. Decisions were made then to destroy 6,000 tonnes of contaminated oysters and it was only in the early summer of 1979, that oyster beds in the bays of Morlaix and Lannion were used again.

Kelp beds (*Laminaria digitata*) which occurred just below the lowest tide level were not affected by the oil. The reproduction of the kelp in 1978 occurred normally and the density of the young algae in the winter of 1979 showed usual values. The red algae (*Chondrus crispus*) on the other hand, was affected by the pollution and a general decrease of biomass was observed in 1979. Dungeness crab, sea spider and lobster populations showed no evidence of adult mortality in the first week after the wreck. However, chemical analysis showed that accumulation of hydrocarbon occurred in the hepatopancreas rather than in the flesh of these crustaceans.

Fishery statistics did not show significant differences between 1978 and 1979. However, several types of fin disease (including fin erosion and blood irrigation) have been detected in flatfishes since the summer of 1978. By the end of 1978, it was shown that for plaice, the juveniles from the 1977 year class had a slow growth; 3-year old fishes were absent from the coast and no animals from the 1978 year class were caught! In general, the flatfish reproductive physiological processes have been affected by the oil pollution (non-lethal effects) as well as the survival of larvae and juveniles.

Whatever other effects oil pollution may have, the loss of sea birds attracts the greatest public concern. Sea birds are not harmed by the toxicity of the oil, but if the liquid oil contaminates a bird's plumage, its water-repellent properties are lost. As a result, water is able to penetrate the plumage to displace the air trapped between the feathers and the skin. This air layer provides buoyancy and thermal insulation and with its loss, the plumage becomes waterlogged and the birds may sink and drown. The loss of thermal insulation also results in a rapid exhaustion of food resources in an attempt to maintain body temperatures, followed by hypothermia and commonly, death. Birds also attempt to free their plumage of contaminating oil by preening. They end up swallowing quantities of oil which may cause intestinal disorders and renal or liver failure. Known seabird casualties numbered 4,572 [c.f., 30,000 known seabird deaths caused by the grounding of *Exxon Valdez* in March 1989, Alaska (35,000 tonnes of crude oil)].

(c) *Showa Maru*

The grounding of the Japanese supertanker *Showa Maru* in January 1975 in Singapore Straits, (7,700 tonnes) is considered to be the largest oil spill incident in the region. The spill caused extensive defoliation and death of mangroves. Three years later, no sign of regeneration was reported (Soegiarto & Polunin, 1981). Similarly, the spill from *Diego Silang* (6,000 tonnes) caused by collision, in the Malacca Straits in July 1976, resulted in defoliation of mangrove trees mainly due to the smothering of the pneumatophores (Bilal, 1985).

(d) *Exxon Valdez*

The *Exxon Valdez* grounded in Alaska on March 1989 spilling 35,000 tonnes of crude oil into the sea causing some 30,000 seabird deaths. In addition, a thousand or more sea otters (*Enhydra lutris*) were killed; but with their high reproductive rate (populations are capable of growing at 17-20% per annum until they reach a ceiling imposed by their food supply), the Alaskan populations were expected to recover quickly.

2. HEAVY METALS

Metals are natural constituents of seawater and assessing the effect of inputs resulting from human activities is complicated by the very large natural inputs from the erosion of ore-bearing rocks, wind-blown dust, volcanic activity, forest fires and vegetation. The intense sedimentation in estuaries traps a large amount of metals which become adsorbed onto sediment particles and carried to the bottom. Thus, sediments in industrialized estuaries with major ports contain the legacy of a century or more of waste discharges. Metals of biological concern may be divided into three groups:

a. light metals (e.g. sodium, potassium, calcium) are normally transported as mobile cations in aqueous solutions,

b. transitional metals (e.g. iron, copper, cobalt, manganese) are essential in low concentrations but may be toxic in high concentrations,

c. metalloids (e.g. mercury, lead, tin, selenium, arsenic) are generally not required for metabolic activity and are toxic to the cell at quite low concentrations.

Transitional metals and metalloids are collectively known as heavy metals.

Mercury pollution (Minamata disease)

The Japanese people have a special concern for environmental pollution related to mercury compounds since they have had experience with Minamata disease which occurred in both Kumamoto and Niigata prefectures. Minamata disease was caused by the consumption of seafood contaminated with methylmercury compounds discharged from the Chisso Company's Minamata factory. In 1952, the chemical plant started synthesising acetaldehyde from acetylene with inorganic mercury compounds as the catalysts. Very small amounts of methylmercury compounds were synthesised in the process as byproducts and discharged into the Minamata Bay and Shiranui Sea, resulting in mercury contamination of seafood and the development of Minamata disease in the animal and human populations. This illness affected only fishermen and their families and first appeared in 1953, but was not diagnosed as metal poisoning derived from fish and seafood taken from part of Minamata Bay until 1956. In all, 2000 cases were recognized; of these, 43 died during the epidemic and over 700 survivors were left with severe permanent disabilities. Fishing in part of the bay was banned from the start of 1957 and the epidemic halted; but, it was not until 1959 when it was shown that mercury was the toxic element involved and the source was the effluent from the Minamata factory. It proved to be a classical example of methyl mercury poisoning, which is more dangerous to humans than inorganic mercury because it cannot be excreted. It therefore acts as a cumulative poison and since it can cross the barrier from blood vessels in the brain into the nervous tissue, it causes progressive and irreversible brain damage.

Cadmium pollution (itai-itai disease)

Cadmium achieved notoriety in the aftermath of the Minamata disaster when it was suspected of being responsible for an outbreak of itai-itai disease in a Japanese village on the Jintsu river. This painful disease affected the bones and joints (in particular) and resulted in 100 deaths. It was attributed to contamination of rice by cadmium from the effluent from a zinc smelter.

3. HALOGENATED HYDROCARBONS

Hydrocarbons containing fluorine, chlorine, bromine, or iodine (i.e., the halogens) differ from petroleum hydrocarbons because most of them are not readily degraded by chemical oxidation or bacterial action. Like metals, they are permanent additions to the environment but, unlike metals, they are man-made, and do not occur naturally. Low-molecular weight hydrocarbons in the sea are not regarded as a particularly serious threat as they do not appear to accumulate in marine organisms. However, the higher molecular weight hydrocarbons such as pesticides and PCB's (polychlorinated biphenyls) accumulate in animal fat tissues. During the 1960's there were increasing signs that the widespread and intensive use of pesticides, most obviously DDT (dichloro-diphenyl-trichloroethane), was having unforseen and unwelcome consequences for the natural environment. In 1964, fish were found to be dying in an area around the marine outfall of a Danish factory manufacturing the pesticide parathion. Lobsters, *Homarus gammarus*, were affected over a much wider area.

One of the richest agricultural areas in California, specialising in vegetable and salad crops is the Salinas river valley. The Salinas river which drains the valley does not flow in summer as it is blocked by a sand bar at its mouth. During the rainy season, the river breaks through the bar and flows into the Monterey Bay. The bay has a sluggish and irregular circulation and any pollution remains there for some time. In February 1969, the river burst the sand bar and floodwater carrying an enormous amount of silt flowed into the bay. During the previous 10 years, DDT had been used intensively and pesticide residues were carried with the silt-laden floodwater into the bay. As a result, an exceptionally large number of sea birds died in the following months - all had remarkably high liver concentration of DDT residues. Sea lions were also found dead on the beaches.

4. DREDGING SPOIL, INDUSTRIAL SOLID WASTES AND HEAT

Regular dredging is often necessary to keep ports, harbours, rivers and approaches to channels open for shipping. The dredged material called dredging spoil may be used for land reclamation, but is more often dumped at sea. It was reported that more than 91 million tonnes of dredging spoil was dumped at licensed offshore sites in northwest European waters (excluding the Baltic) in 1986; and the United States dumps three times as much (Clark, 1992). Dredging spoil is often anoxic and especially, if it comes from harbours or industrialized estuaries, is contaminated with metals, pesticides and persistent oils. These contaminants are generally not available to organisms as they are adsorbed onto silt particles.

If the dredging spoil remains in piles on the seabed, it generally does not become oxygenated and the contaminants remain biologically unavailable, rendering the dump site harmless. However, if the dredging spoil becomes oxygenated, the metals may be freed from their association with the silt particles and enter the food chains. Some dredgings are regarded as too contaminated as a result of this potential risk to be safely dumped at sea. An example of this type of dredging is that found in the inner harbour of Rotterdam; dredging spoils are no longer dumped in the North Sea, but are deposited on an artificial island instead. This island has a capacity for about 20 years' dredgings, by which time it is hoped that the river Rhine, the source of the most contaminants will be sufficiently cleaned for sea dumping to be resumed.

Although some animals are able to burrow to the surface of the dumped material without much difficulty, the immediate impact of dumping dredging spoil is a smothering of the benthic fauna in the dumping grounds. The results of a study carried out in the fjord at Uddevella on the west coast of Sweden (1971-1972) showed that immediately after the dredging of a new channel, there was a loss of diversity at stations near the site of operations due to a failure of recruitment of several bivalves (owing to increased sediment in the water), but the position was restored a year later. Benthic animals in the area accumulated high concentrations of metals when dredging was in progress, but returned to former levels within 18 months.

Ash is an example of industrial solid wastes. It is emitted from coal-fired power stations and consists of large, fused lumps of clinker and a considerable amount of very fine powder. This fine material is composed mainly of silicon dioxide with oxides of aluminium and iron, and a variety of metals present in trace concentrations. Power stations in Newcastle and Blyth in northeast England dump 600,000 to 700,000 tonnes per year at sea. At the Blyth dumping ground, some species such as the gastropod *Turritella* and the foraminiferan *Astrorhiza*, common at the time when dumping started, are now rare or eliminated.

Cooling water and often other industrial effluents are discharged at a higher temperature than that of the receiving waters and they constitute 'heat' pollution. The greatest amount of heat discharged to the sea is in the form of cooling water from coastal power stations. In the tropics, there is negligible fluctuation in the sea temperature as well as power demand during the year. However, in temperate regions, the demand peaks during winter and so the greatest discharge of cooling water occurs when the sea temperature is low and falling. The Turkey Point power station in Florida discharges cooling water in a situation where quiet, shallow soft-bottom areas are dominated by turtle grass, *Thalassia*. This marine grass forms the basis of a specialised community supporting a characteristic fauna. The temperature of the sea around the discharge is 30-35^{0}C in summer and a further increase of 5^{0}C or more is damaging to *Thalassia*. About 9.3 ha of turtle grass has been destroyed by this outfall and a further 30 ha shows reduced growth.

5. ORGANIC ENRICHMENT FROM HUMAN ACTIVITIES

Effects of organic enrichment from human activities such as domestic sewage or wood pulp effluent on benthos have been well-documented. These effects include an overall decrease in the number of species, an increase in average body size of individuals, and shifts in species dominance and dominant trophic guilds. Recently, with the rapid growth of the aquaculture industry, it has been shown that this seemingly "clean" industry can substantially alter natural communities.

Aquaculture involves farming marine and aquatic organisms at tremendous densities, and is reported to attain levels of productivity that are greater per unit area than the productivity of any other form of animal protein on earth. The accumulation of excess feed and faeces in the vicinity of the culture site often causes substantial physical, chemical and biota changes. Some of the physical and chemical effects of aquaculture include increased organic carbon, nitrogen and phosphorus content, increased rate of sediment oxygen consumption, decreased sediment redox potentials, the generation of hydrogen sulphide and methane. The effects of mariculture on benthic infaunal communities are consistent with the generalised trends described for other sources of organic enrichment (Pearson & Rosenberg, 1978). At the perimeter of the culture site, there is often a zone that is low in species richness with high infaunal density. The species found in this area are usually opportunistic species (most notably members of the *Capitella capitata* species complex).

It is evident that the impacts of marine pollution are numerous and varied. In this paper, it is only possible to highlight some of the more prominent types of marine pollution and their associative impacts through the use of certain case studies. However, it is obvious that benthic communities are easily and readily affected by marine pollution and are thus, good potential biological indicators with which to assess the quality of the marine environment.

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FIELD ASSESSMENT OF HUMAN IMPACTS ON THE MARINE ENVIRONMENT

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INTRODUCTION

Human activities that contribute towards pollution of the marine environment are many and varied. Effective prevention of pollution may be negated by the lack of an integrated coastal management policy where activities under the control of one agency may unintentionally be in conflict with another, and result in overall inefficient management measures.

Field observations are useful at enhancing identification of activities that can contribute to pollution of the marine environment. They also permit quick identification of possible sources and give the observer a better appreciation of the range of activities that can pollute coastal waters.

METHODOLOGY

Participants were sent on a boat ride along the southern coast of the mainland and around the offshore southern islands to record the various activities in these areas. A map was provided indicating locations of the different types of human activities (Fig. 1). Prior to the field evaluation, participants were informed of the national policy on pollution control and management of the different activities by relevant agencies. They were also requested to note similar activities in their countries. Field trips were also organised to one of the sewage treatment works and to the Singapore River and Kallang Basin, to see how pollution of the seas can be reduced and managed.

SOURCES OF IMPACTS

The locations of human activity and possible sources of impacts on the marine environment are indicated by alphabets A to M in Fig. 1.

A. Entire coastline of this stretch has been altered by foreshore reclamation to provide concrete piers for ship repair and maintenance yards and marine-based industries. Reclamation destroyed coastline benthic habitats and increased sedimentation. Chemicals used in these industries may be carelessly disposed of into the sea.

B. This narrow channel is heavily used by boat and ship traffic through and across it. Water is constantly moved by wash of vessels. The channel is also dredged frequently to keep it sufficiently deep for large vessels, thus disrupting soft-bottom benthic habitats, releasing sediment-locked pollutants into the water, and increasing sediment levels.

C. Large oil-fired power generating plants situated on one of these islands to provide electricity for the island group and part of the mainland. Thermal pollution has an impact on benthic communities particularly on species which are not actively mobile. Other islands in this group support oil-refineries and petrochemical industries, some of which are yet to be built. Possible contamination of the marine environment by careless or accidental discharge through human error.

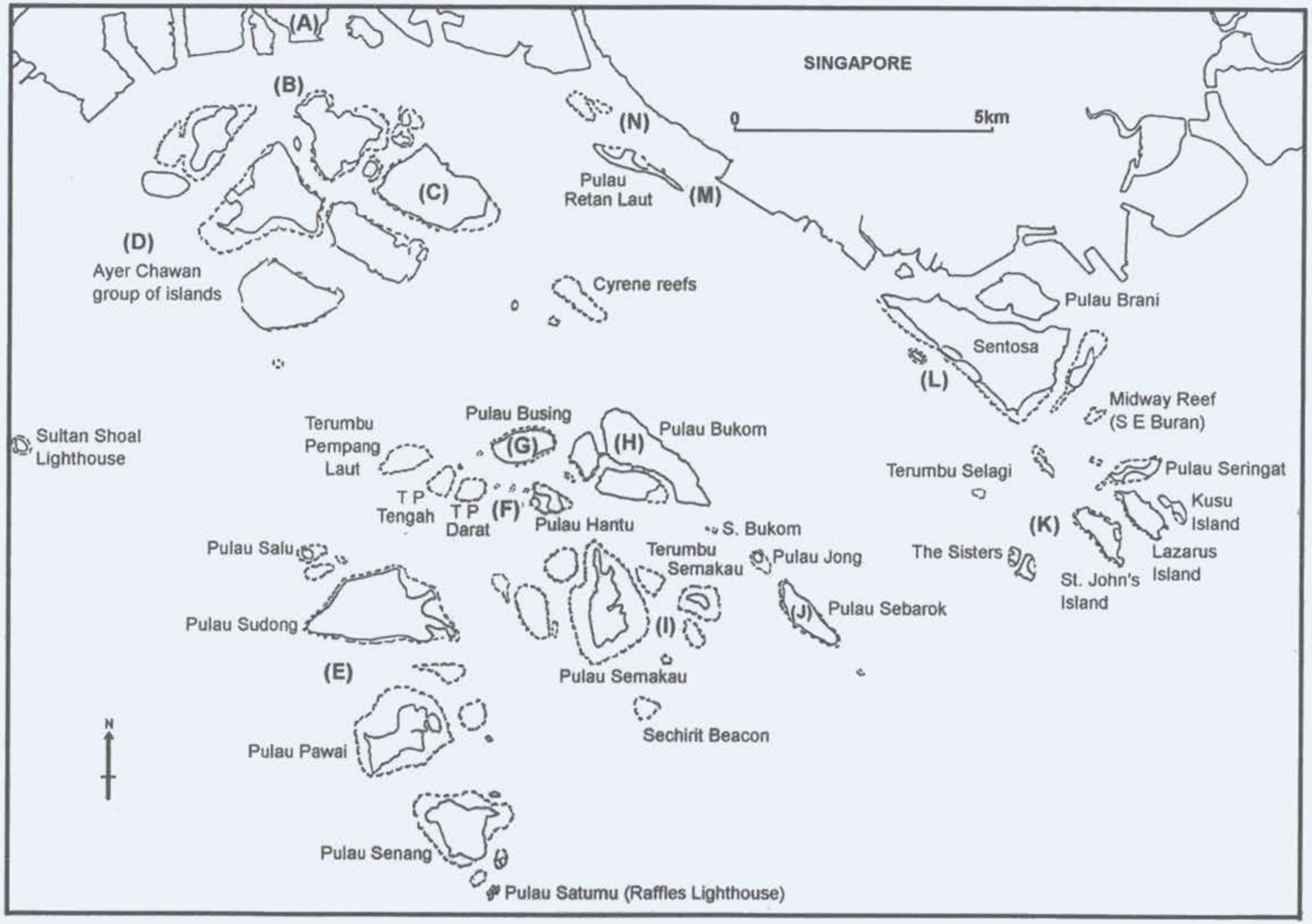

Figure 1. Map of southern coast of Singapore and offshore southern islands indicating locations of activities and possible impacts to the marine environment (see text for explanation).

D. Entire island complex including Pulau Ayer Chawan, will be merged through land reclamation to form one large land mass. Filling of channels will destroy benthic habitats and alter current regime and tidal patterns in the area. Sedimentation expected to increase further.

E. This group of islands (Pulau Salu, P. Sudong, P. Pawai and P. Senang) is restricted for military use. Live-firing exercises are conducted here and the public is prohibited from entering the area. Prohibition of public access helps to some extent in conserving marine resources, but erosion from shelled target areas and direct firing of rounds into the sea causes trauma in marine organisms and increased sedimentation.

F. The island of Pulau Hantu and its western patch reefs are used for recreation. Past reclamation has affected some benthic habitats through burial and sedimentation.

G. Crude storage facility built on this man-made island (Pulau Busing) which was enlarged through land reclamation. Risk of contamination through accidental discharge.

H. Oil refinery built on these islands (Pulau Bukom) which have been linked and expanded through land reclamation. Risk of contamination through accidental discharge.

I. Area (eastern side of Pulau Semakau to Pulau Sakeng) has been used for the dumping of dredged spoils which has destroyed benthic habitats there and in the surrounding areas. It is to be bunded for use as an offshore solid waste dump and strong control measures are being taken to prevent destruction of the surrounding areas.

J. Oil-slop treatment facility on Pulau Sebarok. Tankers are required to discharge sludge at this treatment facility. Possible contamination through accidental discharge.

K. This island complex (including St. John's, Lazarus and Kusu) is soon to be developed for residential, recreational and research uses. It will require land reclamation to establish links between some of them and to alter coastline shape of others. Sewage has to be treated and released into the sea. Possible elevation of nutrient content and sediment levels.

L. The entire southern coastline of Sentosa Island has a man-made beach and is developed for recreation. Facilities include resort hotels and swimming lagoons. Original soft-bottom habitats and communities destroyed. Some parts of semi-enclosed swimming lagoons trap sediment.

M. Entire coastline from southern tip across to the west built with concrete piers, wharves and other port facilities for cargo handling and storing. Original benthic habitats destroyed. Natural land-sea interaction and dynamics completely changed.

N. Major land reclamation being undertaken for expansion of port facilities. Further destruction of soft-bottom habitats and increased sedimentation. Current regimes altered.

There are numerous activities within this limited spatial area which also serves as the world's busiest harbour. The various activities are regulated by different agencies. Impacts are apparent from the dredging of navigational channels and dumping of dredged spoils further offshore. These, together with widespread reclamation, have raised the sediment load and reduced water visibility to an average of 2m compared to 10m before the mid 1960s when such activities were minimal. In addition, there is always the potential of oil spills and chemical discharge from accidental collision of vessels or human error within land-based industries.

CONTROL MEASURES

The management of oil pollution of the seas comes under the jurisdiction of the Port of Singapore Authority. Surveillance and heavy penalties have almost eliminated the incidence of illegal discharge or dumping of oil or sludge. Fast response action plans have been drawn up to deal with accidental spills. The Ministry of the Environment manages land-based sources of pollution and controls their contamination of the marine environment. Factories are not permitted to discharge wastes into the sea. They have to treat wastes on site before discharging them into the sewer system where they undergo further treatment. Unannounced checks are made to ensure that factories and industries comply with this regulation. All sewage is treated at secondary level before being discharged into the sea. Sewage outfall in some cases is extended 1.5km from the coastline. Coastal water quality is monitored regularly to ensure that it remains within acceptable levels.

Participants were taken on a tour of the Seletar Sewage Treatment Works which is based on the conventional activated sludge process using mechanical surface aerators. The effluent produced meets the Royal Commission Standards of 20ppm for Biochemical Oxygen Demand and 30ppm for suspended solids and is discharged into the sea to ensure that it does not contaminate drain or stormwater.

The 10-year cleaning programme of the Singapore River and the Kallang Basin took national priority to restore these systems to an unpolluted condition and with water of a quality that could be used for aquatic recreation. Participants were briefed on the effort, taken to a high building for an aerial view of these rivers and brought to the rivers for a closer view of water quality and their sand banks. Flotsam and jetsam were prevented from being washed to the sea by booms stretched across the rivers, and manually removed periodically.

SOFT-BOTTOM BENTHIC COMMUNITIES: STRUCTURE, FUNCTION AND ECOLOGICAL IMPORTANCE

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INTRODUCTION

The concepts discussed below are drawn from general review papers, particularly those of Alongi (1989a,b; 1990) and Thrush (1991), as well as the author's own experience. Where particular facts or figures are cited, the appropriate citations indicate their sources. Attention will be focused on nearshore soft bottom habitats typical for the Southeast Asian region. Because of the nature of work that has been done and published, the material in this lecture will be confined to considerations of the invertebrate fauna, with some treatment of the microalgal and bacterial components. Discussions of fisheries in the tropics may be found in numerous references.

GENERAL CONSIDERATIONS

Nearly 40% of the total open ocean area and 30% of the total area of the continental shelves of the world are located in the tropics (Alongi, 1990). Examples of typical littoral habitats with soft bottoms are:

sandy beaches (quartz, carbonate, or mixed)
mud and sand flats
sea grass beds
salt marshes
mangroves
coral reefs (particular zones).

The gradual accumulation of work done in the tropics has pointed to the following characteristics:

1. Variations in faunal densities and species richness are widest in the tropics probably due to the great variety of habitats and environmental conditions found here.

2. Determinants of spatial and temporal patterns are:

   a. primary production in the water column - since this is an important source of food supply to the benthos, it helps determine their abundance and distribution,

   b. sediment characteristics - the type and coarseness of the sediment govern delivery of food and oxygen to interstitial organisms,

   c. associated physical-chemical conditions - these include parameters such as organic matter, salinity, temperature, pH and redox potential,

   d. biological factors - these include competition and predation.

In the tropics, control, in particular, is exerted by monsoonal rains, temperature (which is generally high), salinity (which is usually high, but also variable), carbonate sedimentation and compaction, dissolved oxygen (which is low and variable), dissolved nutrients, sedimentation (usually from rivers; this leads to smothering), and anoxia (due to stratification of the water column).

STRUCTURE

The distribution and abundance of soft bottom organisms reflect the temporal and spatial mosaics of the major regulatory factors enumerated above. They are also influenced by:

1. life history factors - these cover considerations of the different life stages that species may undergo, including phases that are spent in either the pelagial (water column) or the benthos, as well as life spans,

2. motility - the movement or dispersal of organisms will obviously result in particular spatial patterns,

3. feeding modes - soft bottom organisms may be classified as filter-feeders, deposit feeders, or active predators.

Zonation in the soft bottom benthos is most obvious in sandy beaches. This is caused by variations in exposure and beach slope. Various authors (cited in Alongi, 1990) have come up with a classification scheme generally conforming to the following:

"Supralittoral"	- dominated by amphipods, isopods, crabs,
"Midlittoral"	- dominated by spionid polychaetes,
"Infralittoral"	- dominated by echinoderms, gastropods, bivalves.

Diversity of soft bottom organisms is found not to be necessarily greater in the tropics as compared to higher latitudes (Alongi, 1990). Diversity is significantly influenced by salinity, sediment type, and organic matter in the sediment.

Sediment organisms could be conveniently classified and described according to a broad size spectrum. This is roughly composed of the following:

MACROFAUNA:	retained on a 0.5mm mesh,
MEIOFAUNA:	retained on a 0.1mm mesh and measuring less than 0.5mm in total length,
MICROFAUNA:	measuring less than 0.1mm in total length
MICROPHYTES:	microscopic plants,
BACTERIA:	measuring in the order of microns.

Dominant taxa among the macrofauna are usually the Polychaeta, Crustacea, Gastropoda, and Bivalvia. The meiofauna are commonly dominated by members of the phylum Nematoda.

The density of soft bottom organisms is generally lower in the tropics due to the operation of relatively stressful environmental factors. These include low planktonic production, a moderate to high degree of climatic disturbance, as well as other factors enumerated above. In his review, Alongi (1990) presents the following ranges for densities. For macrofauna, the range is 0 - 40,000m^{-2}, although in one study, up to 1.5Mm^{-2} were registered. This was for a beach littered with kelp debris. Meiofaunal densities were found to range between 0 - 20,000/10cm^{-2}. Densities are lower in mangroves, with values less than 500/10cm^{-2}.

The biomass per area of macrofauna in the sediment is higher than that of meiofauna. Ranges of values have been found to be as follows (Alongi, 1990): for macrofauna, 0.2 - 70.9$gWWm^{-2}$ (mean = 14.5), and for meiofauna, 1.0 - 26.9$gWWm^{-2}$ (mean = 9).

The soft-bottom benthos probably do not experience the kind of distinct seasonality characteristic of higher latitudes. Temporal patterns depend greatly on distance from the equator. These patterns are due to effects of physical-chemical cues on spawning and the composition of feeding types (due to temporal variation in food supply).

In the wet tropics, mortality or migration of organisms is brought about by effects of the monsoon, which is accompanied by lowered salinities and increased sediment erosion. In the dry tropics, variations in population densities occur in response to changes primarily in temperature and salinity. Other events that bring about changes in species patterns over time are the El Nino Southern Oscillation (ENSO), and localized upwelling.

FUNCTION

Considerations of function here will focus on processes at the ecosystem level. However, even ecosystem function is determined by events at lower levels of organization. In a sense, processes such as energy production and consumption are eventually explained by metabolism at the level of the individual organism.

A. Physiological and behavioral responses to stress

The most important factors that cause changes in physiology and behaviour are temperature and salinity. Adaptations of organisms to these factors are manifested in horizontal and vertical migration, aestivation, hibernation and habitat modification (e.g, ventilation of tubes, burrows).

The effect of temperature on metabolism is to increase oxygen uptake up to a particular threshold (depending on the species concerned). Likewise, growth is temperature dependent. In general, the tropics are characterised by higher growth rates.

In terms of reproduction, most tropical species are considered to be either discontinuous breeders, or to breed at low rates throughout the year with peaks occurring at particular times of the year. Reproductive patterns are cued by temperature, salinity, lunar rhythms, and availability of food.

B. Primary production

Many unvegetated habitats in the tropics have relatively low rates of net primary production or are heterotrophic (P/R < 1) (Alongi, 1990). There is also an absence of seasonality. Microalgae have been found to have a productivity of 0 - 2762mgC$m^{-2}d^{-1}$ (although most values generally fall below 1gCm^{-2}d-1) (Alongi, 1990). This is within the lower end of the range measured in temperate habitats.

Chlorophyll *a*, which is a measure of biomass, ranges between 0.1 - 6.2µgg^{-1}DW (with values generally less than 5µgg^{-1}DW) (Alongi, 1990). No significant correlation has been established between standing stock and productivity.

The productivity of bacteria for surface mangrove sediments is 0.05 - 1.1gC$m^{-2}d^{-1}$(Alongi, 1989b). For coral reef sands, it is 0.02 - 0.37gC$m^{-2}d^{-1}$. Various tools to measure the metabolism of marine micro-heterotrophs include the use of radiolabels to estimate cell production (DNA synthesis), protein and RNA synthesis, and anaerobic mineralisation processes (sulphate reduction, methanogenesis, nitrate reduction). Fluxes in oxygen or carbon dioxide are evaluated to quantify respiration.

C. Secondary production

The term "secondary production" refers to the production of biomass by organisms higher up the food chain, i.e., which are ultimately dependent on primary producers for organic matter production. These organisms are considered to be "heterotrophic". The simplest forms of heterotrophic organisms (after the heterotrophic bacteria) are the protozoans and fungi. There exist, however, a paucity of information on these groups, and of methods to estimate their production.

The most knowledge is available for the macrofauna. Their production/biomass (P/B) ratios have been observed to increase towards warmer latitudes. This trend could be explained by characteristics of the macrofauna which include greater mobility, faster growth, higher mortality, and shorter life spans. P/B ratios range between 0.3 -54.1 (Alongi, 1990). Biomass production, on the other hand, has a range of 0.04 - 1812.5kcalm^{-2} (Alongi, 1990).

Macrofaunal respiration lies between 43 - 1200mgCm^{-2}d^{-1} (Alongi 1990). These values are within the upper end of the range for temperate habitats. Macrofaunal respiration is therefore moderate to high, and outpaces net primary production in many localities. It is highest in coral reefs or coastal lagoons where detrital debris frequently accumulates.

D. Energy flow

The flow of energy in tropical soft bottom ecosystems could be explained by a common paradigm that holds true also for temperate systems. Major pathways are:

DETRITUS → BACTERIA and FUNGI → MIXED DETRITAL CONSUMERS (OMNIVORES and HERBIVORES) → LOWER CARNIVORES → HIGHER CARNIVORES with myriad juxtaposed pathways and feedback loops (esp. among DETRITUS → DOM → MICROBES pathways)

A significant degree of benthic-pelagic coupling takes place because of the relatively close dependence of the benthos on food supply from the overlying water column. This coupling, however, decreases from shallow coastal and shelf regions to the deep sea.

E. Ecological importance

The ecological importance of soft bottom communities is still poorly appreciated. Their obvious importance relates to their ecological roles which include reworking of the sediment, and the recycling of carbon and nutrients. The latter is brought about mainly through the detrital feeding activities of many benthic organisms.

The fisheries potential of marine environments is directly related to the soft bottom benthos. Fisheries are linked to benthic organisms via energy transfer within the food chains. Predation by demersal fishes and crustaceans on the sediment organisms has been found to be more intense in the tropics than in higher latitudes. Finally, soft bottom areas serve as nursery grounds for numerous commercially viable species.

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BIOINDICATORS: SPECIES AND COMMUNITIES

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GENERAL CONSIDERATIONS

Responses to pollution by soft bottom communities have been established with reasonable certainty. Altogether, the onset of pollution appears to lead to the occurrence of dominance by small, opportunistic species, the lowering of species diversity, and the decline of population densities. Hence, responses are nearly always negative (Young & Young, 1982).

"Indicator species" are species whose responses to environmental changes can be used and interpreted as a measure of those changes (Parker, 1991). In order to achieve this, it is important to know their life histories, natural population fluctuations, and ecology.

POLYCHAETES AS BIOINDICATORS

Experience in soft bottom ecology has revealed polychaetes, members of the phylum Annelida, to be useful as bioindicators. In numerous studies, polychaetes have served both as ecotoxicological test organisms and as pollution indicators (Pocklington & Wells, 1992).

A. Polychaetes as ecotoxicological test organisms

As ecotoxicological test organisms, polychaetes are used in bioassays and in monitoring. One particular use of polychaetes in bioassays is to test sediment toxicity. The advantages of polychaetes are: they are abundant, easy to sample, easy to transport, soft-bodied, possess a wide size range, have a life cycle that is neither too long nor too short, are easy to maintain in laboratory cultures, and yield estimates of physiological responses that are similar to those of other organisms.

Effects of possible environmental problems are monitored in terms of reproduction, growth, and mortality. Widely used families for the purpose are the Nereidae and the Dorvilleidae. Polychaetes are used to monitor effects of pollution, particularly as manifested in bioaccumulation or biomagnification. Common pollutants of concern are the PCB's and metal organic complexes. Polychaetes are examined for body burdens of particular chemical residues.

The advantages of polychaetes for this purpose are:

1. the organisms accumulate harmful materials within their tissues in proportion to the concentrations of these substances in the environment,

2. genera used have species which are cosmopolitan, ecologically significant, and easily collected,

3. some species have patterns of organ- or tissue-specific bioconcentration.

B. Polychaetes as pollution indicators

As indicators of pollution, polychaetes are of use both at the species level, and at the population and community levels. At the species level, polychaetes are recommended because they are usually the dominant soft-bottom fauna. A useful indicator, therefore, is the PRESENCE or ABSENCE of particular species. Families which contain commonly used indicator species are the Capitellidae (e.g. *Capitella capitata*) and the Spionidae (e.g. *Paraprionospio*).

Polychaetes are also useful pollution indicators at the population and community levels, again because they are usually the most abundant fauna. In many instances, they also account for the most number of species in the sediment. Furthermore, polychaetes are extremely responsive to environmental changes. Indices used to detect responses to environmental forces at the population or community levels are changes in diversity, abundance, biomass, dominance and numerical distribution (e.g. departures from log-normal distribution).

Advantages of polychaetes for the purpose are: they are in direct contact with sediments or the water column; abundant and readily available; easy to sample; found to occupy different trophic levels; in possession of various habits (e.g. sedentary, mobile, tube-building); and having different feeding modes (e.g. deposit-feeding, filter-feeding, predatory). On the other hand, the limitations with the use of polychaetes as pollution indicators pertain to the paucity of taxonomic, biological and ecological information on them as a group.

One species commonly used as a bioindicator is *Capitella capitata.* One important reason for this is its cosmopolitan distribution. It is scarce or absent where the macrobenthos is diverse. This is probably due to competition and/or predation (Sanders *et al.*, 1972; Young & Young, 1982). The densities of *C. capitata* have been observed to increase with organic enrichment. This could be attributed to the burrowing and deposit-feeding habit of the species. When its numbers increase, it appears to exclude other species.

PROBLEMS WITH INDICATOR SPECIES

Recent research has brought to light problems with indicator species which have arisen from difficulties with taxonomy (Parker, 1991). Examples are *Polydora ligni* (polychaete), *Capitella capitata* (polychaete), and *Mytilus edulis* (mollusc). Obviously, questionable taxonomy would undermine their utility as indicators, particularly if conclusions drawn from observations of their responses to a perturbation in one locality would be presumed to hold for the "same" species in different localities. The species given as examples here have actually been found to be species complexes.

CASE STUDY FOR SCOTLAND AND SWEDEN

An illustrative case study, though drawn from a temperate example, is that of Pearson & Rosenberg (1976). Two fjords in Scotland and Sweden were compared in terms of responses to organic pollution. The fjords were originally subject to low organic inputs. Presumably because of this, the macrobenthos exhibited a high degree of specialisation and sorting of potential food.

High organic loading resulted from the operation of cellulose industries in the immediate vicinity of both fjords. Specialist species were observed to be reduced after a period of time, and were replaced by smaller species which were relatively static in space. Hence, there was less reworking of the sediment. This led to decreased oxygenation of the deeper sediment layers, as well as to an increased rate of accumulation of unused organic matter. The sediment eventually underwent defaunation. The authors note that, in this case, it was important to study ecological SUCCESSION. No species should be studied in isolation. Diversity indices also proved to be useful.

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ECONOMIC IMPORTANCE OF SOFT-BOTTOM BENTHIC COMMUNITIES

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INTRODUCTION

Soft-bottom benthic communities perform significant roles in maintaining the functional integrity of their habitats, and at the same time support other life in the marine environment through trophic interconnections. Compared to other marine habitats, soft-bottom habitats are the least understood and appreciated as they are not readily or easily seen. Mud and sand seabeds do not appear to have the same kind of luxuriant life seen in other habitats such as coral reefs. This, however, is not indicative of low species diversity or abundance. Contributing to high species diversity are the many smaller epibenthic forms which spend their lives buried or burrowing through the soft bottom.

These habitats continue to receive impacts from the variety of human activities and are seldom considered for management. Their importance and contribution to the marine environment must be recognised as they perform significant roles (Table 3). Many species are economically exploited for food, traditional medicine and other commercial applications, but the habitats from which they are fished and the levels at which they are harvested are seldom linked to coastal management measures.

TABLE 3 Benefits of soft-bottom benthic habitats and communities of the East Asian Seas.

FOOD	MEDICINE	INDUSTRY	SCIENCE	ECOLOGY
seaweeds	seaweeds	animal feed	genetic bank	biodiversity
peanut worms	sponges	food additives (fish, oyster sauce)	biotechnology	nutrient cycling, source, sink
polychaetes	polychaetes	ornaments (shells, urchins)	connections with other marine systems	bioturbation
shrimps/prawns	shrimps (chitin/chitosan)	pearls		environmental condition indicator
crabs	mudlobsters	limestone (dead shells)		interaction with adjacent habitats
horseshoe crabs	horseshoe crabs	aquaculture (e.g. cockles)		nursery
bivalves	gastropods			food source
gastropods	sea cucumbers			supports fisheries
sea urchins				
sea cucumbers				
demersal fishes				

BIODIVERSITY

More than 450 families of soft-bottom benthic fauna have been recorded from across the ASEAN (Association of Southeast Asian Nations) region through the ASEAN-Australia Living Coastal Resources Project between 1986 and 1994. Dominant were the arthropods and annelids. Benthic communities adjacent to coral reefs exhibited the richest familial diversity as well as the highest number of families exclusive to it. A benthic community in the Philippines affected by a brine outfall showed the least familial diversity amongst all sites across the region. The data suggest that there are differences between soft-bottom communities in association with different ecosystem types and that there is some influence between soft-bottom habitats and associated ecosystems. Of the 52 families that were common to all benthic habitats associated with different ecosystems, 32 were annelids, 11 molluscs and the rest arthropods (chiefly crustaceans).

ECONOMIC BENEFITS

Benthic living resources have numerous economic and commercial applications throughout the region (Table 4). Species harvested for direct use as food include shrimps, crabs, bivalves, gastropods, sea cucumbers, sea urchins, sipunculids (peanut worms), annelids, demersal fishes, seaweed and horseshoe crabs. The multi-million dollar cockle industry in West Malaysia is dependent on mudflats prevalent along the west coast. In parts of Indonesia such as Bali, annelids locally referred to as "nyale" worms seasonally discharge reproductive segments laden with eggs which float to the surface. These are collected for human consumption. Sea cucumbers are harvested for food while sea urchins are collected for their eggs.

In addition, benthic habitats serve as nursery grounds and also a rich source of food that supports the higher trophic levels. They contribute effectively to fishery productivity in the surrounding waters. The rich supply of nutrients from deep seas which can be brought up to the surface only through upwelling contribute to increased productivity of the upper water column. This is evident from the higher fish catch from upwelling areas. Many benthic species are exploited for use in various industries, such as pearl growing, animal feed, food additives and marine ornaments. Shells of dead bivalves and gastropods, abundant in mud bottoms are collected to produce limestone. Attention is now given to the use of high-grade chitin from shrimps of soft-bottom benthic habitats for the manufacture of contact lenses.

Many species from these habitats have been and are still used in traditional medicine. The body fluid of some species of sea cucumbers (e.g. *Phyllophorus* spp) is believed to have medicinal values. In Malaysia, specimens are collected and the body fluid extracted through a small slit made in the body after which, the sea cucumber is returned to the habitat. The fluid is left standing until clear before being decanted, bottled and sold as "air gamat". This folk medicine is said to cure a wide range of ailments including asthma, sinus problems, and healing of both, external and internal wounds. The potency of the fluid apparently increases with age. Occasionally, the sea cucumber itself is used, where it is dried and turned into powdered form for use with food or drink. The former approach however makes better management sense. In southern Thailand, the chitinous shell of the mudlobster, *Thalassina*, is dried, baked, turned into a powder and used as a traditional cure for asthma. The use of benthic species in traditional medicine would be an interesting area for scientific research into bioactive compounds.

Being sensitive to changes in the environment, soft-bottom communities can be used as biological indicators of such impacts. Pronounced changes in community structure or population abundances of some species can serve as reliable indications of change. Some echinoderms are extremely sensitive to environmental change. Polychaetes such as *Capitella capitata* survive well in low oxygen conditions and a sudden increase in their numbers indicates an impact which may not have been obvious.

MANAGEMENT

Human activity has resulted in the introduction of many substances into the marine environment and is the main cause of marine pollution. Soil is eroded through deforestation, agriculture and poor land management. Toxic substances and excessive nutrients from untreated industrial waste and sewage contaminate marine sediments. Shellfish beds have been known to be affected such that the fishery can no longer remain commercially viable. The contamination of bivalves by human pathogens has created health risks. In uncontaminated habitats, overfishing of benthic resources has led to their depletion and the lack of management encourages the irrecoverable removal of breeding populations.

TABLE 4 Commercially valuable species from soft-bottom benthic habitats in the East Asian Seas region.

Seaweeds
- *Caulerpa*
- *Enteromorpha*
- *Gracilaria spinosa*
- *Kappaphycus*
- *Polycarvernosa cylindrica*
- *Sargassum*

Sponges
- *Petrosia*

Sipunculids
- *Sipunculus sipunculus*

Polychaetes
- *Eunice*
- *Nereis*
- *Perinereis*

Gastropods
- *Babylonia canaliculata*
- *Cerithidea quadrata*
- *Chicoreus ramosus*
- *Conus*
- *Cypraea*
- *Melo (Cymbium) melo*
- *Natica tigerina*
- *Nerita*
- *Strombus canarium*
- *Trochus*
- *Turbo*

Cockles
- *Anadara granosa*
- *A. ferruginea*
- *A. indica*
- *A. nodifera*
- *A. pilula*
- *Arca rufescens*

Clams
- *Amussium pleuronectes*
- *Atrina*
- *Donax*
- *Glauconome*
- *Meretrix meretrix*
- *Paphia undulata*
- *Pecten*
- *Pinctada*
- *Pinna*
- *Placuna placenta*
- *P. placuna*
- *Solen grandis*
- *S. strictus*
- *Teredo*

Mussels
- *Modiolus sanhausii*
- *Perna viridis*

Oysters
- *Crassostrea belcherei*
- *C. iredalei*
- *Saccostrea iredale*

Shrimps
- *Metapenaeus affinis*
- *M. barbata*
- *M. brevicornis*
- *M. elegans*
- *M. ensis*
- *M. lysianassa*
- *M. tenuipses*
- *Parapeneopsis hardwickii*
- *P. hungerfordi*
- *P. maxillipedo*
- *P. sculptilis*
- *P. uncta*
- *Penaeus caniculatus*
- *P. indicus*
- *P. japonicus*
- *P. latisulcatus*
- *P. merguiensis*
- *P. monodon*
- *P. penicillatus*
- *P. semisulcatus*
- *Trachypenaeus granulosus*
- *T. longipes*
- *T. malayanus*
- *T. pecadorensis*
- *Thennus orientalis*
- *Squilla* (stomatopod)

Crabs
- *Charybdis cruciata*
- *Emerita*
- *Hippa*
- *Portunus pelagicus*
- *Scylla serrata*

Horseshoe crabs
- *Carcinoscopius*
- *Tachypleus*

Sea urchins
- *Diadema setosum*
- *Echinothrix diadema*
- *Tripneustes gratilla*

Sea cucumbers
- *Bohadschia marmorata*
- *Holothuria atra*
- *H. scabra*
- *Phyllophorus*
- *Spinifera ocellata*
- *Stichopus variegatus*

Sea squirts

Fish
- *Periophthalmus*

Development has also caused massive alteration of the physical environment and coastal engineering has smothered or destroyed many soft-bottom benthic habitats, or altered current regimes which in turn changes environmental conditions of the habitats. Constant dredging of shipping lanes causes these habitats to be completely disrupted as well as release pollutants which have settled in the sediment. Marine dumping of dredged sediments buries and kills benthic communities and increases sedimentation of large areas of the surrounding seafloor.

The ecological value and economic importance of benthic communities are seldom realised. This is attributed to the fact that benthic habitats remain submerged and insufficiently seen to be appreciated. In the terrestrial environment, impacts are readily seen and usually dramatic enough to attract attention. Activities which have an impact on benthic habitats need to be examined and appropriate management action taken to prevent further unnecessary abuse of the system. With proper management, soft-bottom benthic resources can continue to perform their significant functions and remain beneficial to humans.

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SURVEYING SOFT-BOTTOM BENTHIC COMMUNITIES: DESIGNING A SAMPLING AND MONITORING PROGRAMME

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THE NATURE OF STRESS IN THE MARINE ENVIRONMENT

In considerations of monitoring the marine environment for the detection and characterisation of possible problems, it is useful to clarify, first of all, the definitions of relevant terms. Some useful definitions are as follows (GESAMP, in press):

STRESS - A chemical or physical process that leads to a response in a biological system, within an organism, or at the level of whole organisms or assemblages.

DISTURBANCE - A chemical or physical process *caused by humans* that may or may not lead to a response in a biological system, within an organism, or at the level of whole organisms or assemblages. Disturbances include stresses.

MONITORING - The observation of a variable over space and/or time in order to determine the condition or state of the ecosystem.

Furthermore, disturbance may be categorised as follows (Underwood, 1989):

"PULSE" - intermittent, temporary, acute.

"PRESS" - long-term, chronic.

POPULATION RESPONSES TO STRESS

The next logical point of consideration would be the response of populations in the marine environment to stress. Underwood (1989) defines the following types of response:

1. Inertia - lack of response to perturbation.

2. Resilience - determined by magnitude of stresses from which a population can recover.

3. Stability - determined by rate of recovery following stress.

Factors affecting response to stress are the following:

1. Timing, magnitude, order of stresses.
   Synergisms between simultaneous or successive stresses.

2. Stage in life history of the organisms concerned.
   Position in the food web.
   Density dependence or independence.

   Thus, in order to be able to interpret patterns of response of soft bottom communities to a perturbation, knowledge of life histories and interactions among organisms is indispensible. Interactions include competition and predation.

3. Non-linearity of responses.

4. Variability - this is a key component to consider. Large *temporal* fluctuations in abundances of organisms occur naturally. The detection of a particular stress is possible only if it causes a response much greater than the response to background stresses (note that in the context of experimental design, such detection is achieved with a predetermined level of statistical probability.)

UTILITY OF MONITORING

Monitoring will enable the measurement of natural rates of change of populations (variability). It is insufficient for PREDICTION of the potential impact of most stresses.

DESIGNING A SAMPLING AND MONITORING PROGRAMME

A. General considerations

The intended means of analysing the data should be considered in the design of the monitoring programme. This will determine the kinds and amounts of data to be collected. The type of analysis will, in turn, be guided by the specific information or answers that are sought for by means of the monitoring exercise. Data analysis and interpretation falls under two general categories:

UNIVARIATE PROCEDURES - for estimates of spatial and temporal variability;

MULTIVARIATE PROCEDURES

- for complex sets of variables and co-variables
  e.g., choosing a single or a few species from a diverse assemblage as indicators,

- for correlations between data on organisms and on physical-chemical variables.

B. Variables in monitoring

In the selection of variables for monitoring, the following characteristics of an "ideal" parameter could serve as a guide: it should be sensitive to the anticipated stress. It should be characterised by low variability. It should be temporally coherent (Kratz *et al.*, 1994).

Enumerations of data are usually of two kinds: qualitative and semiquantitative. Examples of qualitative data are observations simply of the "presence" or "absence" of particular taxonomic groupings. Semiquantitative (ordinal) data are usually classified into categories of "absent, rare, common, and abundant." Obviously, the latter types of data allow for more rigorous analyses and for more confident conclusions to be drawn.

In terms of monitoring parameters, a range representing hierarchies or "tiers" of indicators is available, from the cellular, organismal, population, up to the community level. For large-scale monitoring of soft-bottom habitats, the abundance of organisms is usually the primary variable of interest in monitoring stress (Underwood, 1989). Whatever the choice of monitoring variable, it is strongly admonished to "get away from preoccupation with averages," as only an analysis of the *variability* will allow a true understanding of processes the community under investigation is undergoing.

Experience in soft-bottom work has shown that the finest levels of taxonomic resolution may not be necessary to detect patterns. For the purpose, the family level may be adequate (Lenat & Barbour, 1994).

C. Considerations of design

A review and critical evaluation of progress made in the formulation of experimental designs for monitoring programmes are provided in Underwood (1989, 1991, 1992). Some salient concepts are summarised below:

1. "Before-after" design
This is the simplest and probably the earliest design employed for detecting and characterising the effects of an impact in the environment. As the term implies, it requires replication in time *before* and *after* an impact. An improvement on this design has been the recommendation to sample at *random* time intervals. This design is considered to be seriously flawed unless it incorporates adequate spatial replication.

2. "Control-impact" design
This design calls for the sampling of only 2 sites, the impacted site (where a perturbation is known to occur), and a "control" which should be sufficiently removed as to be known *not* to be affected by the presumed impact. Despite intensive spatial and temporal sampling within each site, this still constitutes PSEUDOREPLICATION. Hence, there is clearly a need for independent replication in both TIME and SPACE.

3. "Beyond-BACI" design (A.J. Underwood)
This involves an asymmetric design incorporating several (randomly selected) control sites and 1 perturbed site. It allows the detection of impacts that affect spatial differences, temporal variances, or their *interactions.*

4. Correlation analysis
This type of approach results in an analytical exercise whereby the degree of association between response indicators and indicators of environmental stress or exposure is examined. For example, a population variable such as density could be related to an apparent gradient of perturbation. The design becomes problematic if other confounding variables exist, although statistical tests such as the Analysis of Covariance should be able to assist in interpretation of the data.

Notes (from GESAMP, in press):
The design should incorporate sufficient POWER to detect a pre-determined level of stress (couched as a hypothesis). A statistician can help determine intensity of sampling needed to achieve adequate power against the alternative hypothesis, given prior knowledge or "gut feel" about the dynamics of a putative disturbance within a given site, and the ecological responses of the biota concerned, including the degree of natural variability.

In statistical analysis, two types of error are encountered:

TYPE I ERROR - the probability of detecting an apparent change when none has occurred. This is usually the basis for planning environmental surveys (as shown by the nearly ubiquitous use of $P = 0.05$);

TYPE II ERROR - the probability of failing to detect change when it has occurred; in environmental protection efforts, this is the *more serious* error to commit ("precautionary principle").

Thus, increasing power of a sampling programme will involve:

Increasing probability of Type I error = 1- probability of Type II error

D. Spatial considerations

In the selection of locations for a monitoring programme, the main consideration, obviously, is that a representative picture be obtained for the impacted area, and how this compares to a control (or several control) sites. Implicitly, a desirable characteristic would be one that imparts the ability to extrapolate to a larger scale.

One relevant criterion in this regard is "temporal coherence" (Kratz *et al.*, 1994), meaning that the responses of the benthic communities selected for sampling are consistent over time and space. This would allow results to be generalised over larger spatial and temporal scales than the actual monitoring programme would have covered. To accomplish this, a mechanistic understanding of important controlling factors on the communities concerned is required.

In order to capture with reasonable accuracy the complexities of spatial pattern which occur in the soft sediment benthos from extremely small (e.g. on the order of centimeters) to very large (e.g. on the order of several kilometers) scales, spatial hierarchies of sampling are recommended. This would involve the use of nested sampling designs.

E. Temporal considerations

Frequency of sampling should be determined by knowledge of the time scale of stresses, and the rates of recovery by benthic populations from these stresses. Fine points to consider would be rates of change of species, longevity, recruitment dynamics, timing of stress relative to the life cycle, and other population attributes that affect stability and resilience. It is to be noted that time lags exist with respect to the detection of stress. Specifically, predictions of abundance based on physiological measures are not likely to be accurate.

F. Independence of sampling

It is crucial that samples collected are accurate, unbiased, and representative. A particular problem arises with fixed areas of sampling. In such cases, a bias is retained throughout the duration of monitoring, and is ultimately incorporated in the statistical analysis. For example, a stress is revealed by the interaction "treatment x time"; repeated measures tend to overestimate the significance of this interaction.

G. Constraints

The ultimate limiting factors in any monitoring programme are the logistics and costs involved. A.J. Underwood (pers. comm.) recommends more investment in PILOT sampling programmes to structure the "routine" monitoring programmes better. To be taken into consideration, among others, are scale, variances, and replicates required.

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SAMPLING SOFT-BOTTOM BENTHIC COMMUNITIES: METHODOLOGY AND EQUIPMENT

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(Adapted from English *et al*, 1994)

INTRODUCTION

Soft-bottom benthic communities play an important role as support systems in many coastal resources and are extensively found in the tropical regions. Those near the coast are subject to increasing effects of domestic and industrial pollution, and since many of the species are sessile, they provide useful indications of habitat quality.

Specific sampling programmes are needed to monitor disturbances, such as pollution and these should involve appropriate sampling design which takes into consideration the objectives of the study. All such studies require a knowledge of the natural spatial and temporal variability of benthos. However, there is a lack of such information for tropical soft-bottom benthos. Therefore, the initial sampling programme should establish the broader scale variability of benthos and describe any shallow to deep gradients in community structure. This is most effectively done using samplers such as dredges and sledges which collect over a wide area. More intensive sampling may then be done with quantitative samplers such as grabs.

The proper use of sampling equipment is important for any sampling programme so that manpower efficiency and sampling time is maximised. There are two categories of sampling equipment; electrical (battery operated) and mechanical.

AMBIENT ENVIRONMENTAL PARAMETERS

Environmental (physical and chemical) parameter measurements are important as they characterise the conditions at the sampling site during time of sampling. The types of physical-chemical parameters are numerous, and those chosen for measurement may vary from site to site, depending on local conditions, objectives and needs. There are many different types of commercial equipment available in the market for the measurement of the various parameters and the choice of equipment used will depend on the needs and budget of the users.

The parameters discussed here are considered important to the 'health' of aquatic systems (Table 5). Not all are required for any one sampling and the choice rests on the discretion of the experimenter. There are no set rules on how many readings be taken for each parameter at any one sampling station. Again, the sampling designs depend on the researchers. The protocols for the use of the various equipment will not be discussed as they depend entirely on the type of equipment used. The instruction manuals provided with each equipment should suffice for the purpose.

Table 5 List of physical-chemical parameters, units of measure and examples of equipment that can be used

Parameters	Units of measure	Equipment
Physical parameters:		
Vertical depth	meters (m)	Depth sounder or weighted shot line
Vertical light penetration	centimetres (cm)	Secchi disc
Irradiance (light intensity)	$\mu mol/m^2/s^2$ or $\mu E/m^2/s^2$	Light meter e.g. LICOR light meter
Sediment grain size	micrometer (μm) or millimetre (mm)	Brass sieves of various mesh size
Temperature	degree Celsius (^0C)	Temperature meter or mercury thermometer with accuracy of $\pm$ 0.5^{0}C
Cloud cover	octa	No equipment, visual observation
Chemical parameters:		
Dissolved oxygen	parts per million (ppm)	Oxygen meter or handheld digital millivoltmeter with an oxygen electrode
Salinity	parts per thousand (‰)	Salinity meter or refractometer
pH	-	pH meter

Logistics

Other equipment

A water sampler, such as a Nansen bottle or a Niskin bottle, to collect water samples from the desired depths to measure parameters like dissolved oxygen, conductivity and pH (if equipment for *in situ* sampling not available). Plastic bags or jars for sediment samples.

Maintenance

Rinse all equipment with freshwater after use. Equipment with electronic components should be cleaned with a wet/damp cloth. Habitual cleaning of equipment after every sampling trip is important as it prolongs the life of the equipment, especially electronic ones. All electronic equipment should be stored in a clean, dry and dust-free place.

Data recording

Record physical-chemical parameters for each sample into field notebooks or data sheets and sample labels. An example of a physical-chemical parameter datasheet is given in Fig. 2.

Data management

Transfer the physical-chemical parameter data into a database. An example of data structure is described in the data management section. Data must always be checked and verified after entry. Data must always be backed-up regularly.

SOFT-BOTTOM FAUNA SAMPLING METHODOLOGY

The sampling equipment described here are the sledge, grab, dredge and trawl. They are all ideal for small boat operation. Sampling programmes which include the **sledge** and **grab** are considered to be the minimum requirement for characterising nearshore habitats. The dredge can be used as an alternative sampler to the sledge in areas which have very soft substratum. If sledge sampling indicates the presence of seagrass beds, beam trawling should be carried out to sample the more mobile associated species.

Logistics

Equipment

a. Sledge, grab, dredge and trawl.
b. Boat (motorised or otherwise).
c. Motorised winch and davit (optional).
d. Seawater pump (optional).
e. Rope (12 mm diameter) or cable (the warp) to tow or lift the equipment.
f. Sorting box (Fig. 3).
g. Wire-mesh sieves (5mm, 3mm, 2mm, 1mm and 0.5mm). Sieves should be made of stainless steel or bronze gauze (Fig. 4).
h. Compass or GPS.
i. Plastic specimen jars or vials.
j. Waterproof labels and pencils. Preprinted labels ensure that all relevant information is recorded.
k. Forceps.
l. Dissecting (stereo) and compound microscope. A camera lucida and/or camera attachment is useful.
m. Use standard identification sheets to document specimens collected.

Maintenance

Wash field equipment with freshwater after each trip.

Site selection

The length of the transects, total number of transects, number of sampling stations and intensity of sampling will depend greatly on the width of the continental shelf, the primary objective of the study and the facilities available. Transects should be perpendicular to the coast to maximise the gradient and should be replicated (at least 2). A series of sampling stations should be established along the transects. It is advisable to have a greater number of sampling stations close to the coast where zonation patterns show the greatest gradient.

AMBIENT PARAMETERS DATA SHEET

LOCATION :

STATION :

DATE : TIME :

GPS :

HABITAT :

WEATHER : Sunny / Cloudy / Overcast / Rain / Drizzle CLOUDCOVER : oktas

MAX DEPTH : ft m

SECCHI DEPTH : cm

PHYSICAL PARAMETERS	DEPTH (m)								
	Air	Surface							
Temperature (°C)									
Salinity (‰)									
Conductivity (µS)									
Dissolved oxygen (ppm)									
pH									
Light intensity (µmol/m²/sec)									

REMARKS:

Figure 2. An example of a physical-chemical parameter datasheet.

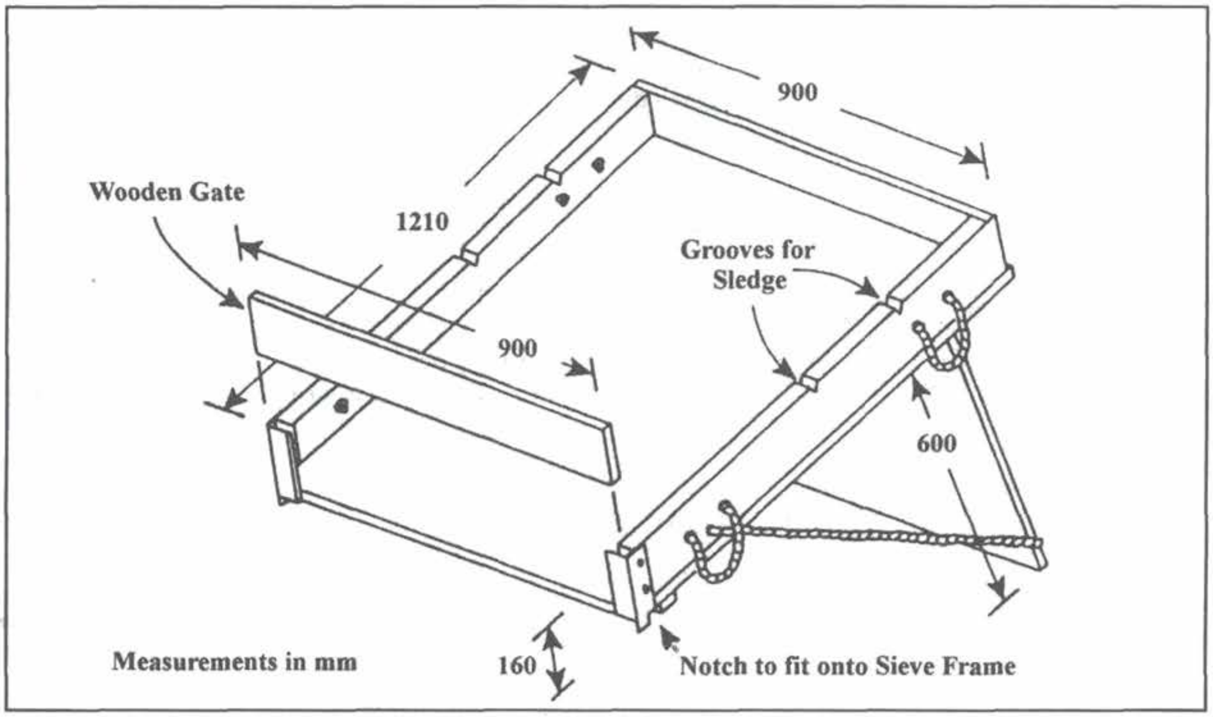

Figure 3. Sorting box.

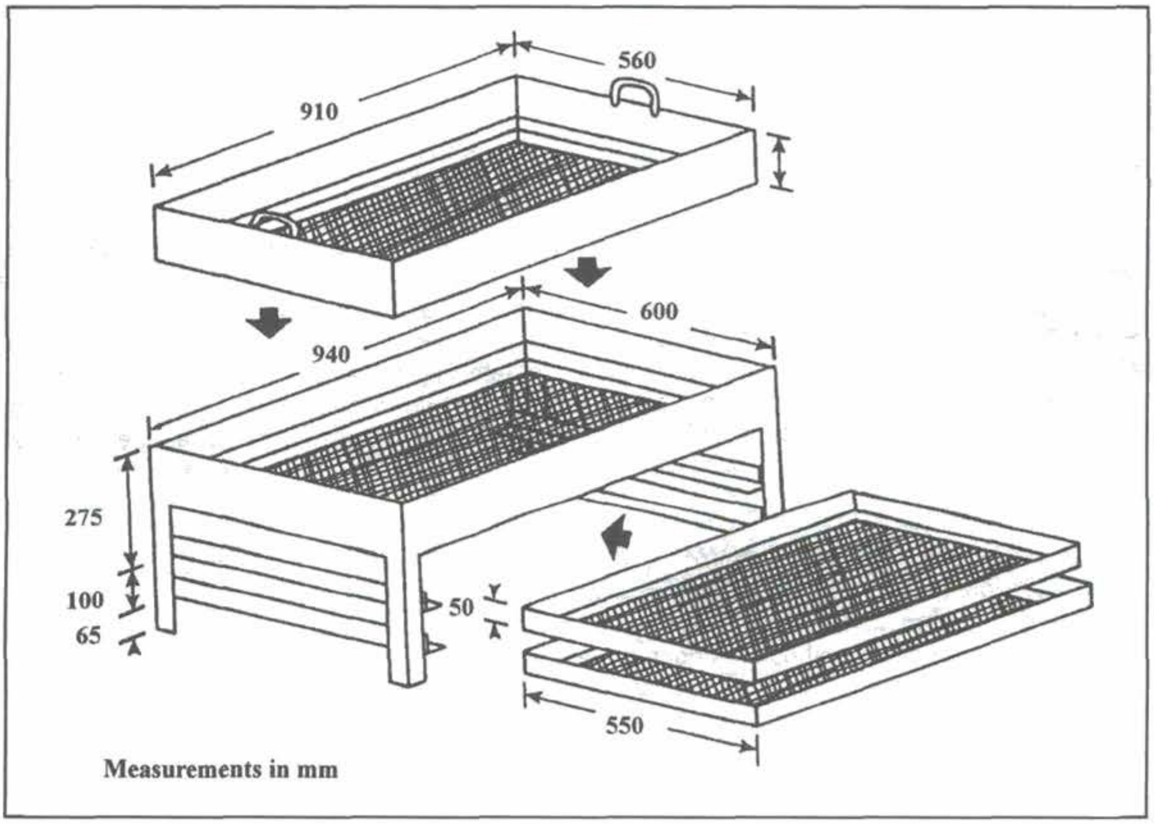

Figure 4. Wire mesh sieves.

General procedures

A preliminary survey, using the sledge and grab, should be done first to characterise the area selected for sampling. Samples may be taken at regular intervals along the transect (e.g. 2-4 nautical miles). Attention should be given to changes in depth and sediment type so that future sampling can be refined to reflect zonation patterns.

The Ockelmann sledge (0.65 metre gape) and the Smith-McIntyre grab (0.05 x 0.05 metres) are recommended. The minimum mesh sizes for sieving samples are 1mm and 0.5mm respectively.

All sampling runs of the sledge, trawl or dredge should be perpendicular to the transect (i.e. parallel to the shore) at each station. This minimises changes in depth during the sample run, i.e. keeps the sample at the same depth gradient. The grab samples should be obtained from the stations along the transect. **At least three replicate samples of each type of sampling gear should be taken at each station.**

If sledge sampling indicates the presence of seagrass beds, beam trawling should be carried out to obtain the more vagile species, such as juvenile shrimps and fishes that constitute an important part of such ecosystems.

The position of each station established on the transect should be recorded at the beginning of sampling that station. A GPS (Global Positioning System) can be very useful. Otherwise, a handheld compass can be used to determine the bearings with reference to at least 2 permanent landmarks established as reference points. Mark the station position with a radar reflector buoy, or if this is not available, a buoy.

If specific sampling sites do not use transects, the principles must remain the same. Hence, for any site there should be a number of stations with replicate sledge and grab samples.

SAMPLING EQUIPMENT

SLEDGE

The sledge is designed to collect fauna resting on the seabed, i.e. epifauna. However, it provides only semi-quantitative sampling. The sledge is good for initial characterisation of an area because epifaunal organisms are often highly persistent through time. Sledges have been deployed to collect demersal plankton (Myers, 1942), newly settled benthic organisms (Ockelmann, 1964), deep sampling (Hessler & Saunders, 1967) and shallow intertidal zone sampling (Coleman & Seagrove, 1955). The recommended sledge is a 0.65 metre gape Ockelmann sledge (Fig. 5) with the net having a stretched mesh size of 1 centimetre. The sledge must be easily handled by a minimum of manpower operating from a small boat. If the boat available is too small to operate the recommended sledge, a 0.5 metre gape sledge should be used.

The position of the station should be determined using a GPS or compass. The ambient parameters, location, date, time, type of gear, replicate number and other data should be recorded on a data sheet or field notebook. All sledge tows must be done perpendicular to the transect (i.e. parallel to the shore). At least 3 replicates should be done at each station. Lower the sledge on the towing wire or rope (the warp). The length of the warp should be at least 6 times the depth of the water at the sampling station. In very shallow water, the warp should be up to 15 times the depth of the water.

Set up a series of sieves of 5mm, 3mm, 2mm and 1mm mesh size. After a 10 minute tow, haul the sledge back to the boat and empty the sample into the sorting box. Lift the wooden sorting box and place it onto the series of sieves. Leave the wooden gate in place and gently hose down with seawater, picking out the larger animals. If there is excess water, be prepared to lift the gate slightly, releasing the water onto the sieves. The remaining tailings are then washed through a series of sieves and the smaller organisms remaining on the sieves are removed.

Preserve echinoderms, soft corals and sponges in alcohol while all other specimens are to be preserved first in 10% buffered formalin. Slit the body wall of large specimens or inject them with preservatives. Store specimens in 70% alcohol. Label samples with the site, station number, position, depth, type of gear, replicate number, time and date. Further information such as tidal or weather conditions should be noted. The waterproof label should be placed inside the container and distinguishing details can be marked on the exterior for quick identification. Take samples back to the laboratory for identification using taxonomic keys (Arnold & Birtles, 1989).

Advantages

Collects a broad cross-section of benthic organisms, including larger (long-lived) but scattered organisms, which may show more stable long-term patterns.

Disadvantages

Provides only semi-quantitative sampling.

DREDGE

The dredge is an invaluable tool in exploratory surveys for examination of the nature of the upper layer substratum and its fauna. Dredges have a heavy metal frame designed for variable penetration into the sediment and they can be used on a variety of sediment types. However, the dredge does not give quantitative samples. Despite this, the dredge gives a good overview of the community and is a reliable sampling device.

Dredges have the longest history of use of any benthic sampler. Their design is determined by the purpose for which they are being used. This can vary between breaking off pieces of rock to limited penetration for collection in muddy sediments. For example, Nalwalk *et al* (1962) used sturdy rock dredges for geological sampling, and Clarke (1972) used a heavy dredge for sampling mixed boulder and mud substrate.

The Naturalists' or Rectangular dredge samples a shallow layer of substratum or can be used in very soft substratum. The heavier framed Charcot dredge and anchor dredges penetrate more deeply (Eleftheriou & Holme, 1984). A standard 60 centimetre Charcot dredge is recommended (Fig. 6) with a stretched mesh size of 2 centimetres. The mesh of the cod-end should be 60 ply. In areas where the substratum is very soft, use the lighter Naturalists' Rectangular dredge with a net of stretched mesh size 2 centimetres.

If the recommended dredges are not available, substitute with any standard dredge which can be handled with a minimum of manpower and operated from small boats. A weak link should be employed to minimise the loss of gear due to snagging. A swivel should be inserted between the towing rope and the dredge. The deployment of the dredge and the sorting *in situ* are similar to that for the sledge.

Advantages

Useful in broad area surveys and inventories.
Samples deeper into the substratum.
Simple design.

Disadvantages

Provides, at best, semi-quantitative data.
Opening can get clogged in certain substrata.
Potential for uneven sampling of epifauna and infauna due to 'skipping' during the tow, especially if the warp is too short.
Relatively small area/volume sampled. High-power requirements in soft substrata.

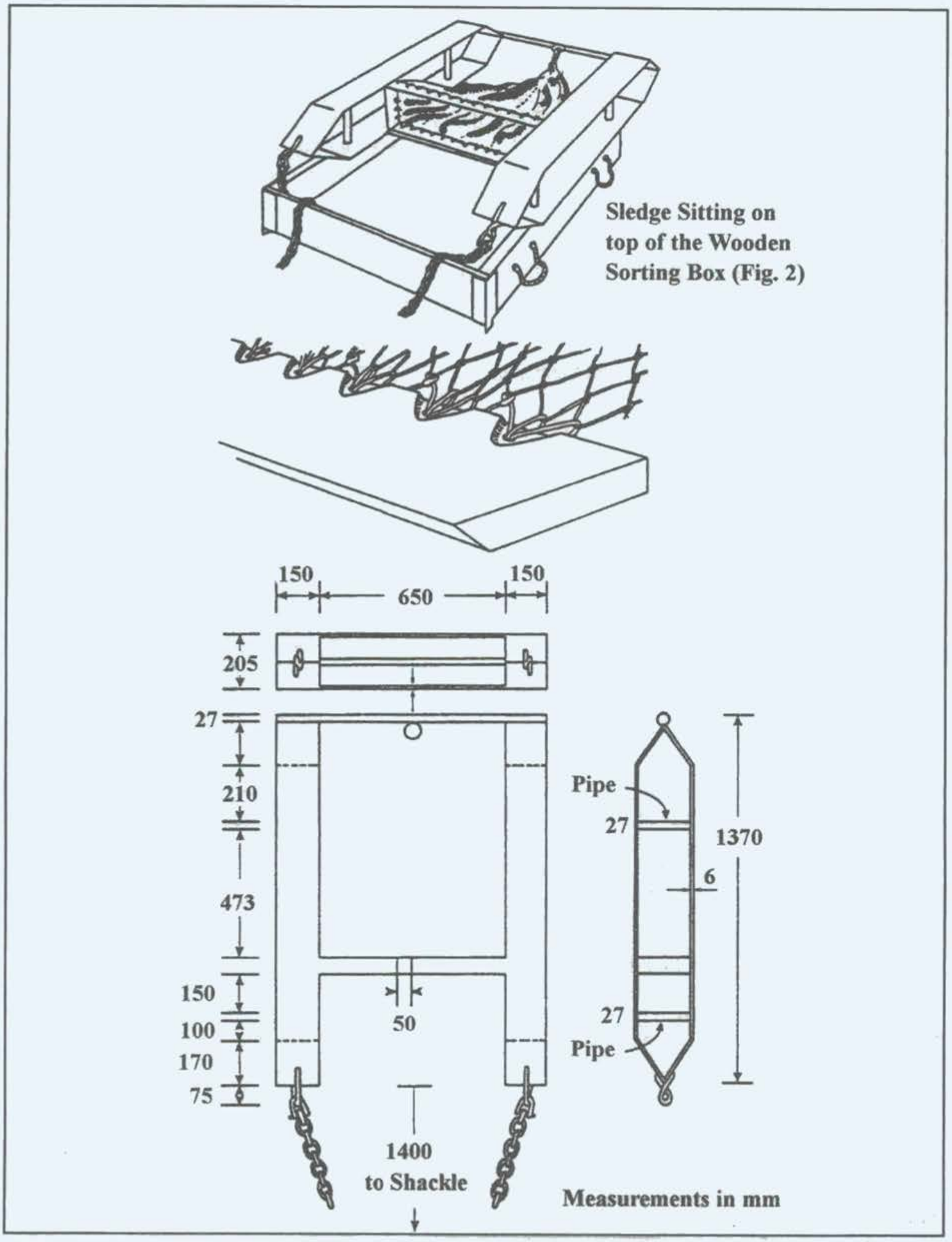

Figure 5. Ockelmann sledge.

Figure 6. Charcot dredge.

Standardisation for sledge and dredge sampling

Use the recommended equipment.
Tow the sledge or dredge for the same length of time on all tows (10 minutes is recommended).
The final (smallest) sieve mesh size should be 1mm for the sledge and 2mm for the dredge.
Record the type of sledge or dredge used with particular reference to the dimensions and the mesh size.

Laboratory sorting for sledge and dredge sampling

Samples that have been collected and kept in formalin should be rinsed with water to facilitate sorting. Pour the formalin through a sieve to prevent possible loss of specimens, then rinse the sample with freshwater before pouring out into large sorting trays (preferably white). *Sorting of samples fixed in formalin should be carried out where there is good circulation of fresh air (ideally sorting is done in a fume hood).* Process the samples preserved in alcohol in the same manner. If possible, preservative solutions should be recycled.

Sort specimens into their respective groups and place larger species (e.g. macroalgae, sponges, and corals) in separate trays. Care should be exercised in sorting and picking small specimens (e.g. annelids and shrimps). The use of soft touch forceps to pick up specimens will help avoid crushing them.

Identification should be carried to at least the family level, and to species level if possible. Absolute counts should be done, except for colonial or uncountable groups like corals, sponges, bryozoans, algae, for which wet weight will give some quantification. If wet weights are not measured then presence/absence data must be recorded.

Data recording and processing for sledge and dredge sampling

Record the ambient parameters, location and description of the site. Describe the equipment being used for collecting the samples, including dimensions and mesh size. Identify species to at least the family level and use standard identification sheets to document the species collected.

Enter the data into the database using the data structure described in the database management section. Always check and verify data after entry. Always backup data regularly.

GRAB

Grabs have been used as sampling devices since early this century. It is an effective device for collecting quantitative samples of organisms which inhabit the sediment, in particular the slow-moving and sedentary members of the epifauna and infauna. The grab is lowered vertically from a stationary boat to take a sample of sediment of a given surface area.

In a discussion of macrofauna sampling techniques, Eleftheriou & Holme (1994) found only 3 types of grabs which collected a quantitative sample and were reasonably light: the van Veen grab (van Veen, 1933), the Smith-McIntyre grab (Smith & McIntyre, 1954) and the Day grab.

Of these, the Smith-McIntyre grab which was designed for working from a small boat in the open sea, was considered the best choice for more open sea conditions. Lighter grabs have more limited penetration into firm sediments, therefore, it is unlikely that deeper burrowers will be sampled. It is therefore advisable to use dredge samples to supplement information obtained by the grab.

A 0.05 square metre Smith-McIntyre grab (Fig. 7) is recommended since it can be easily handled with a minimum of manpower from a small craft. Samples are put into the hopper resting on a base which directs the washed sample into the sieves (Fig. 8). A series of wire mesh sieves for grab samples should include 5mm 2mm, 1mm and 0.5mm mesh sizes. If the Smith-McIntyre grab is not available, use a van Veen grab (Fig. 9). Take at least 5 replicate samples at each station.

Determine the position of the station with a GPS or compass. Record the ambient parameters, location, date, time, depth, gear, replicate number and other data on a data sheet or field notebook.

Lower the grab vertically, at a slow and steady speed, to the seafloor from a stationary boat. Additional weights may be added to the grab when water currents are strong and when penetration of the sediment is difficult. Contact with the seabed triggers the buckets to close. After the grab is triggered, pull it up slowly onto the deck of the boat. Once on deck, place the sample on the hopper and hose down gently with running seawater. The run-off or tailings are directed through the series of sieves.

Large organisms can be removed during the washing process and placed directly in properly labelled wide-mouthed preservation containers (preferably plastic). Preserve echinoderms, soft corals and sponges in 70% alcohol while all other specimens in 10% buffered formalin. *With large samples, care should be taken to ensure that there is sufficient preservative and that it is adequately mixed through the sample.* Rose Bengal vital stain is recommended for staining the organisms in the samples.

Label samples according to the station, position, grab number, time and date. Further information such as tidal and weather conditions should be noted. The waterproof label should be placed inside the container and distinguishing details can be marked on the exterior of the container for quick identification. All sieved material can be kept in this condition until sorted out in the laboratory where specimens can be identified using taxonomic keys.

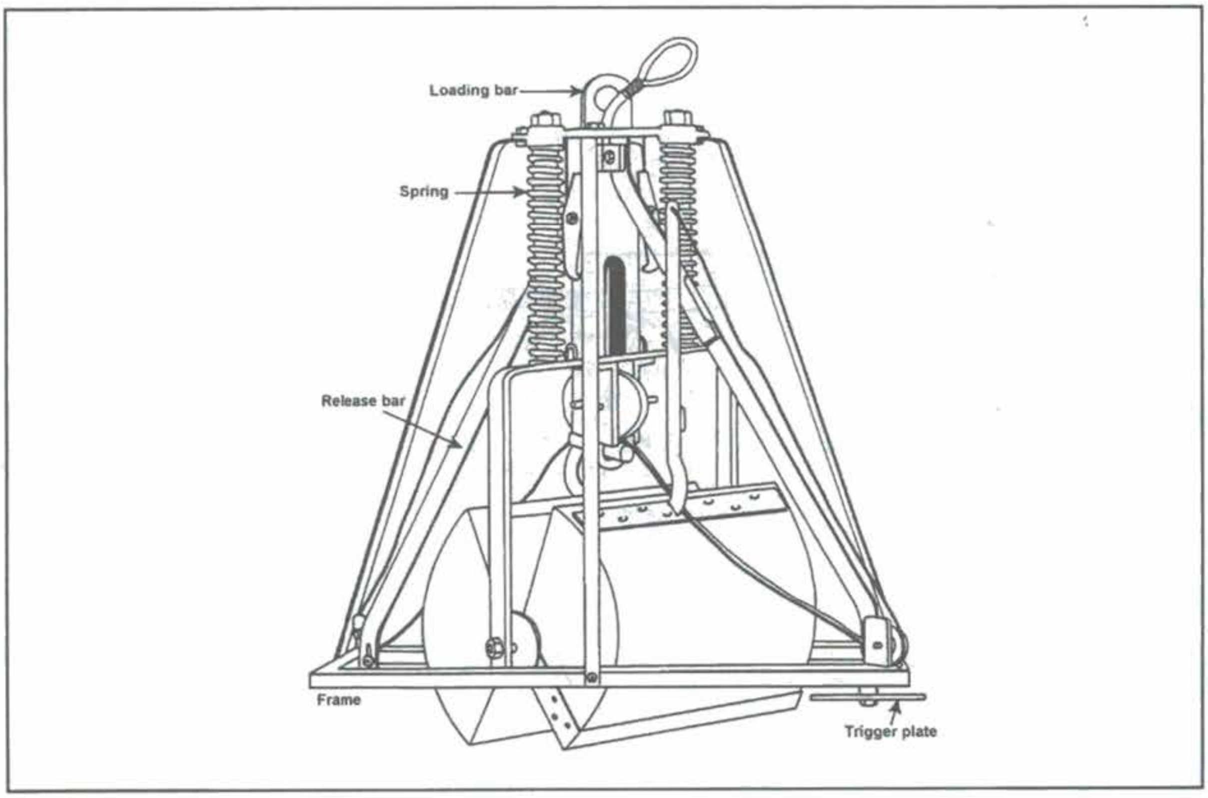

Figure 7. Smith McIntyre grab.

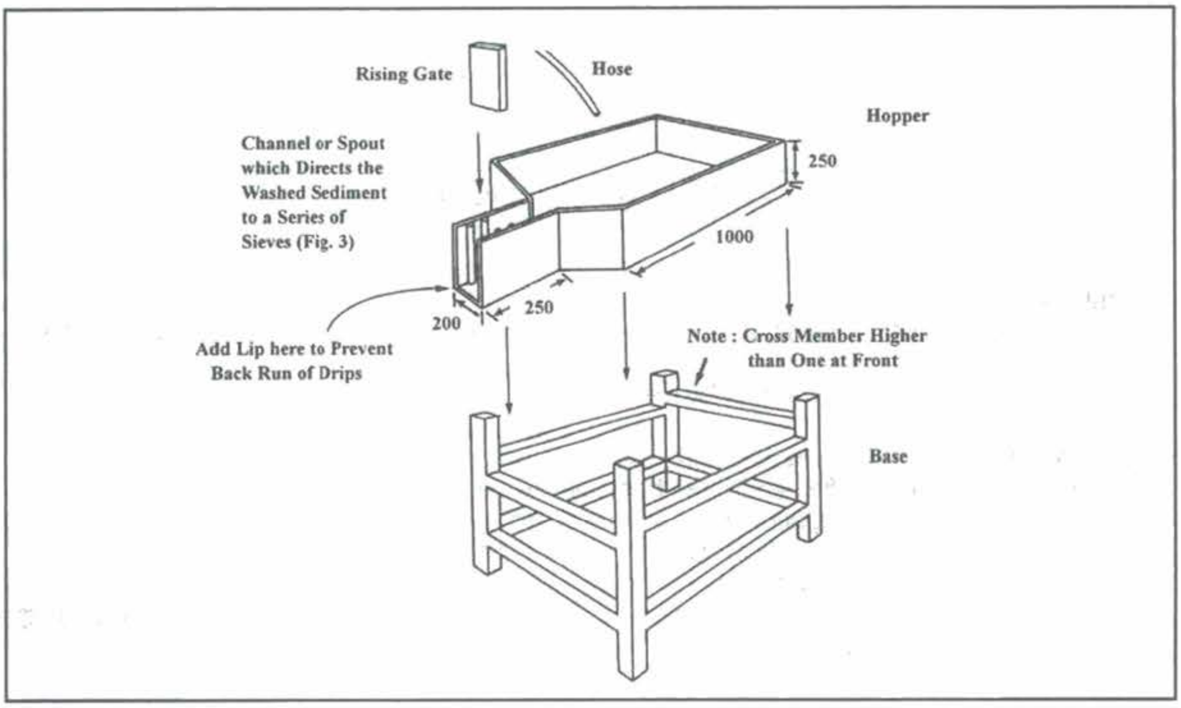

Figure 8. Hopper.

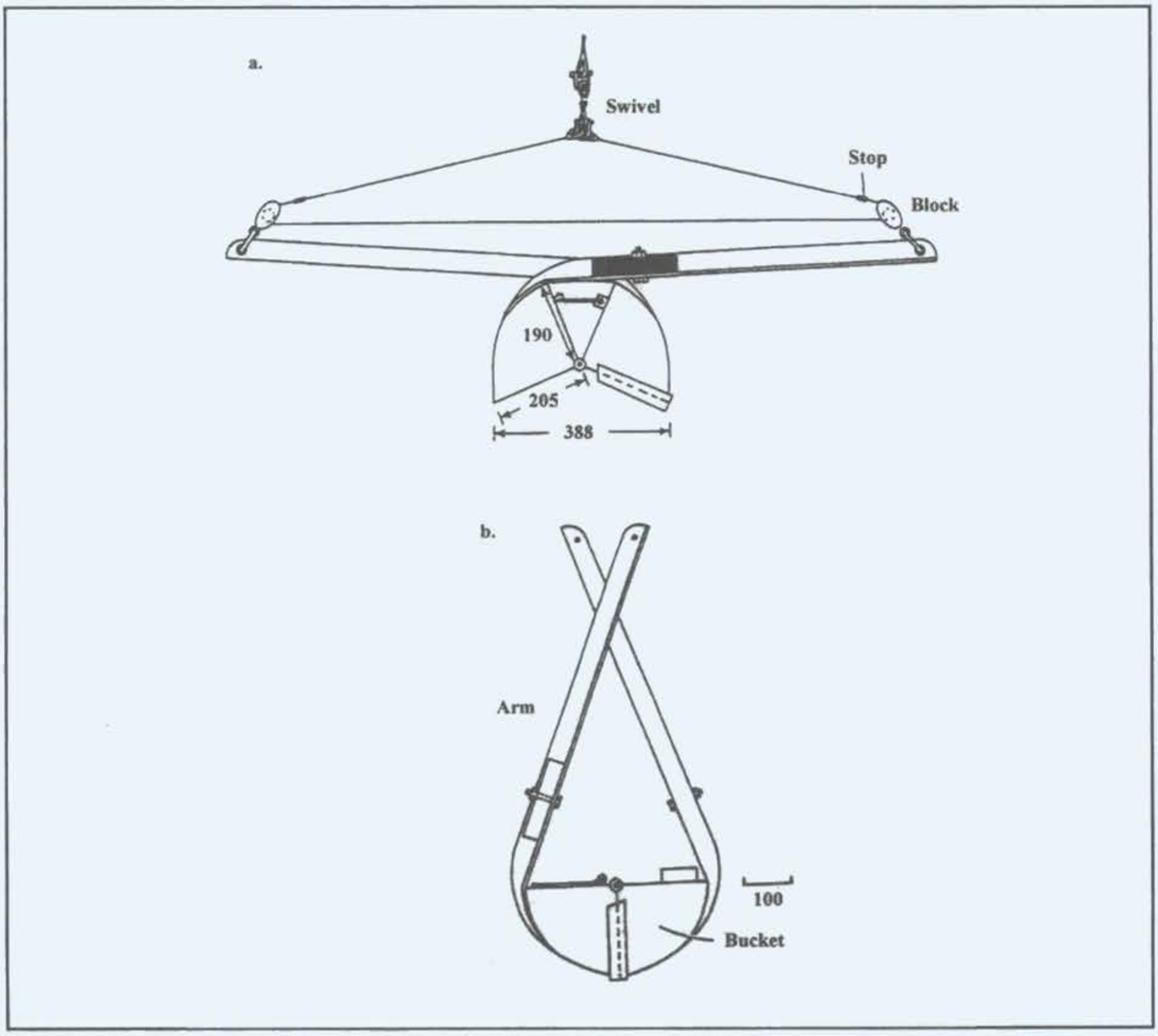

Figure 9. van Veen grab (a: before triggering, b: after triggering).

Advantages

Collects quantitative samples of slow-moving and sedentary members of the epifauna and infauna.

Ease of handling and operation from a small boat.

Disadvantages

Infauna collection is affected by depth and profile excavated by grab.

Penetration depth is dependent on the type of substrata.

Does not adequately sample scarce or fast-moving animals.

Premature triggering of grab may occur.

Jaws may not close completely, causing loss of samples. Profile of the bite gives unequal samples of different depths through the sediment.

Standardisation for grab sampling

Use recommended equipment. The final (smallest) sieve mesh size should be 0.5 millimetres. Record the type of grab used, with particular reference to the size of the grab and its depth penetration.

Laboratory sorting for grab sampling

The samples that have been collected and kept in formalin should be rinsed with water to facilitate sorting. Pour the formalin through a sieve (0.5mm) to prevent possible loss of specimens, then rinse the sample with freshwater before pouring out into large sorting trays (preferably white). *Sorting of samples fixed in formalin should be carried out where there is good circulation of fresh air (ideally sorting is done in a fume hood).* Process the samples preserved in alcohol in the same manner. If possible, preservative solutions should be recycled.Put subsample from the tray into a petri dish for examination under a low-powered dissecting microscope. Pick out all the specimens in the sample, separating into major classes first.

Care should be exercised in sorting and picking small specimens (e.g. annelids). The use of soft touch forceps to pick up specimens will help avoid crushing them. Put specimens into small labelled vials and add preservative (remembering to insert a waterproof label). Keep for sorting into family, genus and species (if possible). Continue this process until the whole sample (in the tray) has been sorted. Identify the specimens from each sample to at least family level using taxonomic keys. If necessary send unknown species to experts for identification.

Data recording and processing for grab sampling

Record the ambient parameters, location and description of the site. The equipment being used for collecting the samples must be described, including dimensions. Standard identification sheets should be used to document the species collected. Taxonomy of fauna collected should be carried to at least the family level, and to species level, if possible. Enter the information into the database using the data structure described in the database management section. Always check and verify data after entry and always backup data regularly.

TRAWL

In order to get overall information about the soft-bottom community, the upper part of the community which includes the epifauna and that portion of the nekton which lives just above the bottom should be sampled. This includes fast-moving animals such as fish and squid, which are too mobile for the other sampling gears, but can be collected using a trawl net.

Trawls such as the Beam, Agassiz and the Otter have been used for qualitative sampling of the epifauna. Otter trawls have also been effective for commercial fishing. Trawl sampling can effectively supplement information obtained by grab and sledge in benthic surveys.

A 10 metre Otter trawl with 3 cm mesh is recommended (see Fig. 10 for commercial Otter trawl). Determine the position of the station using a GPS or compass. Record the ambient parameters, location, date, time, depth, gear type, replicate number and other data on a data sheet or field notebook. Take at least 3 replicate samples at each station.

Check that the cod-end of the net is tied up, as this can be easily forgotten. Lower the trawl with wire towing line (warp). The length of the warp on the trawl should be approximately 6 times the depth of the water at the station. Careful observation should be made when paying out the trawl.

For example:

The otter boards should be set in order to widen the net.
The float or the headline should not be entangled with the bottom line.
The cod-end of the net should be spread out regularly.

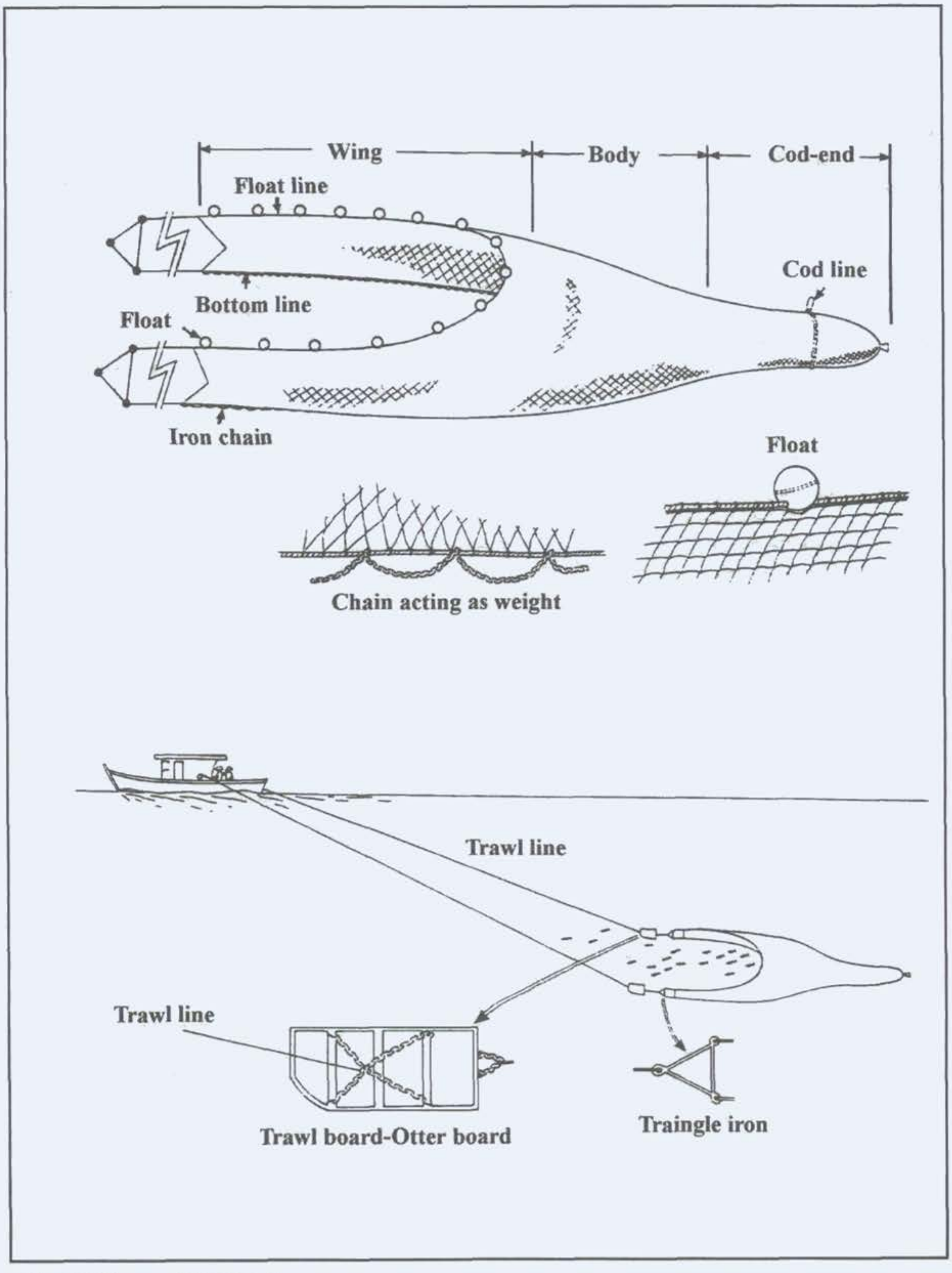

Figure 10. Otter trawl.

After the desired length of wire has been paid out, the time of trawling starts. Tow the trawl for 20 to 30 minutes at 2 knots (or the equivalent of a slow walk) boat speed, parallel to the shore. Carefully monitor the direction of the tow. After the net is retrieved, the contents of the cod-end should be washed onto a large sorting tray.

Preserve echinoderms, soft corals and sponges in 70% alcohol. Other specimens are to be preserved in 10% buffered formalin. Take the preserved samples back to the laboratory for identification using taxonomic keys.

Advantages:

The trawl can collect larger epifauna and demersal nekton to complement that collected by other gear.
Collects fast moving animals.
Useful for collecting the more scarce members of the epifauna.

Disadvantages

Cannot collect quantitative data.
The gear is large and requires heavy equipment (e.g. winches and booms) for operation.
Requires a relatively large boat to operate.
Collects relatively few animals in relation to the area swept by the net.

Standardisation for trawl sampling

Use the recommended equipment.
Tow the trawl for the same length of time on all tows.
Record the type of trawl used, with particular reference to its dimensions and mesh size.

Data recording and processing for trawl sampling

The ambient parameters, location and description of the site must be recorded. The equipment being used for collecting the samples must be described. Taxonomy of fauna collected should be carried to at least the family level. Standard identification sheets should be used to document the species collected. Always check and verify data after entry. Always backup data regularly.

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DATABASE MANAGEMENT

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WHAT IS "DATA"?

Data are factual information (as measurements or statistics), not belief or opinion. Data are used as a basis for reasoning, discussion or calculation.

WHAT IS A DATABASE?

A database is a collection of information that has been organised or arranged in a logical and consistent manner. In general, database refers to a computerised system in which the information is organised into a series of records. Each of the series has a strictly defined structure.

WHAT IS A DATABASE SYSTEM?

A database system comprises the data and all of the associated programmes and procedures for adding, deleting and extracting the information. It includes all of the requisite components including:

- hardware
- operating and application systems software
- data and data dictionary
- user interfaces (developed under the application software) and
- standards and procedures used to manage the operation and further development of the system.

This will ensure that the components are compatible with one another and clearly specified so as to enable effective interfacing to other systems. Compatibility ensures that the efficient operation of the system can be maintained without the need to duplicate or re-write utilities and/or applications every time a new component is added to the system. Clearly defined specifications will facilitate enhancement and development of the system and allow third parties to develop interfaces which extend its utility (e.g. through the development of Geographical Management Information Systems and Decision Support Systems).

WHY THE NEED FOR DATABASE MANAGEMENT SYSTEMS?

In the monitoring of complex ecosystems, such as soft-bottom benthic communities, coral reefs or mangroves, large amounts of data must be collected over long time periods. A database management system allows this quantity of data to be effectively organised and stored. When data are stored in an accurate and reliable way, every new information adds to the previous data in a consistent way. This accumulation of data becomes a tool that managers and scientists can use in understanding complex ecosystems.

WHY USE A DATABASE?

There are many reasons why a database should be an integral part of any monitoring programme. The process of designing the database and defining the data within the database produces a set structure to which the data must conform. As a result, there is data consistency. Databases with the same structure can be easily joined, thereby allowing data collected at differing times or locations to be merged into one large dataset.

Databases are very good at dealing with large amounts of data. By reducing duplication of data, relational database systems are very efficient in the way they store data. This is the most economical approach (in terms of the use of disk space) and is also the easiest structure to edit and update.

Data quality is ensured by databases having data input screens that help inexperienced users, checking programmes that locate errors in the data, and the underlying structure of the database that promotes data consistency. Most data packages such as statistics or presentation packages, can use the data either directly from the database or from data files extracted from the database. This allows users to access a wide range of statistical and presentation routines. The structure of the database allows for data integration, that is, enabling different datasets to be joined. Therefore individual datasets can be integrated with regional or international databases.

WHY NOT USE A SPREADSHEET?

Most people use a spreadsheet rather than a true database for storing data because of the flexibility and ease of use of the former. As there is no need to define tables, structures etc., a spreadsheet is initially quicker. However it is inappropriate and limited for large datasets and can lead to major problems in data consistency and integration.

It is difficult to maintain and enforce data consistency in spreadsheets because of its flexibility and ease of use. As an example, a spreadsheet will allow any mix of values within each column; numbers mixed with dates and character values. A database, by enforcing a set structure, will not allow this, as there is greater protection against invalid values and automatic checking of data input.

Databases encourage set structures, which act as the foundation for integrating different datasets into regional or international datasets. The data inconsistency that may occur in a spreadsheet makes it difficult to integrate datasets that are stored in spreadsheets.

Databases are very good at handling large amounts of data; being able to quickly find and display data. A spreadsheet has no such capability, making it cumbersome and slow for large amounts of data. Most modern databases will hold as much data as there is disk space while most spreadsheets have set limits on the amount of information they can hold.

Databases have the ability to retrieve data based on often complex queries, with its in-built query languages and support structures, such as that of a Relational Database. Databases allow complex queries to be performed. This gives maximum access to the data. A spreadsheet has little to no querying ability.

Databases have powerful in-built programming languages that include complex querying languages. They also include routines for generating input screens and reports and often contain powerful in-built statistical routines. The macro capabilities of spreadsheets are less powerful and are designed for a range of tasks, the least of which is in manipulating data.

Example structure of a linear dataset:

SAMPLE	FIELD_CODE	ABUNDANCE
1	A	23
1	B	34
1	C	14
2	B	15
2	C	16
2	D	68
2	E	45
3	A	21
3	C	17
3	D	17
3	E	42

Example structure of a two-dimensional dataset (data as above):

SAMPLE_NO	FIELD_CODE				
	A	B	C	D	E
1	23	34	14	0	0
2	0	15	16	68	45
3	21	0	17	17	42

WHAT TYPE OF DATABASE TO USE?

The ASEAN-Australia Living Coastal Resources Project database is relational in nature. The basic design of this relational database consists of three type of tables; Sample File, Data Files and Taxonomy (Reference) Files. The Sample File defines the how, when and where data were collected. The Taxonomy File defines species for which there are data. The Data Files contain the actual observations upon which most analyses would be based. The additional file type referred to as an Ambient File (giving information on field conditions at the sample site) is effectively an extension of the sample file.

From the point of view of management, this database design has many benefits. It compacts the amount of data and allows dissemination of different classes of information to different users without extensive manipulation of raw data files.

For each sample or observation that is taken, one record is entered into the Sample File. The sample is given a unique code, called the SAMPLE_ID, which identifies that sample in the Data Files. The Sample File therefore holds the information that describes the sample: what type of sample it was, the location, the date, the data collector, etc.

The Data File has entries for every observation or reading, that is, it contains the actual data collected. Every entry in the Data File is identified by the SAMPLE_ID, this field is the joining field between the Sample and Data Files (thus Relational Database). The relationship between the records in the Sample File and Data File can be one-to-one respectively, or one-to-many respectively, but not many-to-many.

For any code used in the Data File (e.g. species), a full description is given in the Taxonomy File. The fieldcode used in the Data File will be the link between the Data and Taxonomy File. This allows codes to be used in data collection and entry while retaining access to the full description.

Example of a Sample File:

SAMPLE_ID	LOCATION	SITE	TRANSECT	STATION	DATE	DATA_TYPE	DEPTH
SGBEB0001	P. Semakau	North	A	1	250395	D	6
SGBEB0002	S. Buloh	West	C	1	130195	G	8
SGBEB0003	Cyrene	South	C	2	220295	D	7

Example of a Data File:

SAMPLE_ID	REPLICATE	PHYLANAME	FIELDCODE	ABUNDANCE
SGBEB0002	1	Annelida	Minuspio	1
SGBEB0002	1	Annelida	Cheilonereis	10
SGBEB0002	2	Mollusca	Species ABC	2
SGBEB0002	3	Mollusca	Solen brevis	4

Example of a Taxonomy File:

FIELDCODE	SPECNAME	GENUS	FAMILY	ORDER	CLASS	PHYLA
Solen brevis	Solen brevis	Solen	Solenidae	Solenoidea	Bivalvia	Mollusca
Species ABC			Mytilidae	Mytiloida	Bivalvia	Mollusca

The Sample File and the Data File are linked by the SAMPLE_ID field; the Data File and the Taxonomy File are linked by the FIELDCODE field.

Looking at the Data File above with a SAMPLE_ID of "SGBEB0002"

a. The details of how, what or where this observation was from can be obtained from the Sample File. The record in the Sample File with the SAMPLE_ID of "SGBEB0002" shows that this observation was collected at transect C, site West of S. Buloh on 13 January 1995 with the use of a grab from a depth of 8 metres.

b. The details of the FIELDCODE used in the Data File can be found by linking to the Taxonomy File. The last record in the Data File has a FIELDCODE of "Solen brevis". From the Taxonomy File, the full details of this specimen is given.

HOW TO MANAGE A DATABASE?

Simply inputting data into a database system is not going to be useful. The data must be managed. There must be procedures for ensuring that the data are entered correctly, that the database is described and that the data is backed-up. It is important to define responsibility for the various components of Data Management. By allocating responsibility for the various stages of data handling, it is possible to enforce standards of data quality. The person who collected the data may be made responsible for data entry and checking, while backing-up of data and storing data may be the responsibility of someone working in a computer centre.

Data collection is the most important part of any environmental monitoring programme. Once the data are recorded on a data sheet, it becomes the fact of the measured variable at a particular time. After this is the transcribing, manipulating and analysing of this fact.

To ensure that the data from the field data sheet is transferred accurately to the database, a set of procedures should be set up for data handling. This would include procedures for allocation of SAMPLE_ID codes, data entry, data checking and validation. In addition, there should also be procedures for adding variables and tables, backup and archiving of data and storage of the field data sheets and collected specimens.

Data handling procedures alone do not necessarily include data quality. There is the need to know how accurate and precise the data collected are, and also if the field measurements can be repeated. To help ensure data quality, it is important to understand the data and the experimental design. Other ways of ensuring data quality include the use of field data sheets which help to ensure that all the data are collected and that it is collected and recorded in a uniform manner. It also makes reference to raw data at a later date more convenient. Data should be entered into the database as soon as possible after collection. This is to enable ambiguities to be sorted out while collectors can still remember the survey and also allow missing data to be re-collected or sites to be re-surveyed if necessary..

Having data entry programmes within the database also help ensure data quality. Checks can be built into a programme which could include range checks (limit values to fall within a reasonable range), thus making sure data are valid. The main task in ensuring data quality is data checking. This step cannot be over-emphasised. Besides manually checking entered data, it is possible to run data checking programmes to pick up logic errors, missing values and out-of-range values. Other important parts of data management are data backup and archiving. Data must be regularly backed up and stored in a secure place away from the original data source. Original field data sheets and specimens should also be stored securely. In order for data quality procedures to be carried out, the responsibility coupled with authority, must be given directly to a single person.

The data dictionary is part of database management as it gives a full description of the database allowing other users to understand the structure of the database; the experimental design, and the relationships between datasets. It would include a description of the project (background, aims), the sampling methods used, the sampling design (definition of a sample and a replicate), each file and how it is related to other files, each field in each file with definitions and any software used or programme listing.

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DATA ANALYSIS OF BENTHIC COMMUNITIES

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There are numerous techniques used to analyze data from environmental studies to assess the change in community structure. These can be grouped broadly into three categories:

1. Univariate analyses

The means of diversity indices and indicator species abundance ± their confidence intervals are often used to represent the communities. Analysis of variance (ANOVA) can then be used to discriminate between sites. By comparing these parameters with historical data, inference as to whether the communities are stressed can be made. If the diversity indices decreased in magnitude or there is an increase in the numbers of indicator species (opportunistic species), then the communities are stressed. Regression techniques can be used to link these parameters with environmental variables.

2. Distributional techniques

This class of techniques can be thought of as intermediate between univariate and multivariate analyses. These include rarefaction curves, ranked species abundance (dominance) curves, k-dominance curves, ABC plots, etc.

3. Multivariate analyses

This involves data matrix in the form of a *p* (species) by *n* (samples) array of scores (counts or biomass). The *n* samples might consist of a number of replicates (possibly only one) at each of a number of sites or times. Examples of multivariate analyses are hierarchical classification (CLUSTER), multidimensional scaling (MDS) and principal component analysis (PCA).

UNIVARIATE ANALYSIS OF DATA

Diversity indices and species abundance models

There are many different indices on diversity. Each of these indices seeks to characterise the diversity of a sample or community by a single number. It is often very confusing as an index may be known by more than one name and written in a variety of notations using a range of log bases.

Diversity appears to be a very simple and straight-forward concept; then why are there so many competing indices? Answer: diversity measures take into account two factors!

a. **species richness** (i.e., number of species),

b. **evenness/equatability** (i.e., how equally abundant the species are).

High evenness, which occurs when species are equal or virtually equal in abundance, is conventionally equated with high diversity. Many of the differences between indices are associated with the relative weighting that they give to evenness and species richness.

There are three main categories of species diversity measures:

i. **species richness indices** (these indices are essentially a measure of the number of species in a defined sampling unit; e.g. Margalef and Menhinick indices),

ii. **species abundance models** (describes the distribution of species abundances in a community by referring to the model which provides the closest fit to the observed pattern of species abundances; e.g. log normal, geometric distribution),

iii. **indices based on the proportional abundance of species** (e.g., Shannon and Simpson indices, which reduces richness and evenness to a single figure).

Indices based on the proportional abundance of species

Species abundance models involve some fairly tedious model fitting and often require the use of a computer, although they provide the fullest description of diversity data. Indices based on the proportional abundances of species provide an alternative approach to the measurement of diversity. These are often called **heterogeneity indices** because they take into account both evenness and species richness. Southwood (1978) referred to them as non-parametric indices because no assumptions are made about the shape of the underlying species abundance distribution.

<u>(a) Information theory indices</u>

e.g. Shannon index of diversity

Shannon and Weaver independently derived the function which has become known as the Shannon index of diversity. It assumes that individuals are randomly sampled from an "indefinitely large" population and that all species are represented in the sample.

$$H' = -\sum p_i \ln p_i$$

Log to the base 2 is often used in calculating the Shannon diversity index but any log base can be used. The choice of the log base must be consistent, however, if diversity is to be compared between samples. The value of Shannon diversity index usually falls between 1.5 and 3.5 and rarely exceeds 4.5. The variance of H' can be calculated and used to test for significant differences between samples using 't'.

Analysis of variance (ANOVA) provides a test of the null hypothesis, H_0: No difference between the sites.

Multiple comparison tests can be used to follow up if the F-test is significant so as to compare all pairs of sites.

<u>(b) Dominance measures</u>

e.g. Simpson's index

Simpson's index is heavily weighted towards the most abundant species in the sample while being less sensitive to species richness. The equation used to calculate Simpson's index is:

$$D = \sum \frac{[n_i(n_i - 1)]}{[N(N-1)]}$$

As D increases, diversity increases and Simpson's index is therefore usually expressed as 1 - D or 1/D.

Value of diversity measures

There are two main areas in which diversity measures can be applied. The first is in conservation, and the second is in environmental monitoring. In the former, the principle is based on the fact that species-rich communities are better than species-poor ones. In environmental monitoring, adverse effects of pollution will be reflected in a reduction in diversity or by a change in the shape of the species abundance distribution. In both cases, diversity is used as an index of ecosystem well-being. However, environmental monitoring makes extensive use of diversity indices and species abundance distributions while conservation management concentrates on measures of species richness.

Environmental assessment

The use of diversity measures as environmental indicators was based largely on the assumption that **diversity will decrease with pollution or enrichment** (e.g. Rosenberg, 1976; Wu, 1982). Nearly every index and model has been tried at one time or another and opinions differ widely as to which is the best. Some ecologists prefer to examine the full shape of the species abundance distribution while others prefer simple richness or dominance measures.

May (1981) noted that stable, equilibrium communities often follow a log normal pattern of species abundance. When a mature community becomes polluted, its species abundance distribution shifts backwards through succession to take the shape of the less equitable log or geometric series. Refer to classic data on effect of organic pollution on the diversity of a diatom community by Patrick (1973). Gray & Mirza (1979) and Ugland & Gray (1982) also proposed that pollution-induced disturbance can be monitored by a departure from a log normal distribution to one where there is increased dominance. However, it has been disputed that not all equilibrium communities are characterized by log-normal distributions and stressed ones are not.

Others (e.g. Shaw *et al.*, 1983) opted for a Berger-Parker style dominance index and showed that it can register the effect of organic effluent on the diversity of macrobenthos.

A whole range of measures has been used in environmental assessment. Given the popularity of the Shannon index, it is not surprising that it is widely used in pollution monitoring. Egloff & Brakel (1973) used the Shannon index to monitor change in the diversity of benthic macroinvertebrates along a stream in Ohio, U.S.A.. Diversity dropped dramatically below a sewage outfall. This occurred irrespective of whether diversity was calculated at the level of genus, order or class. Other water-quality parameters, e.g. BOD (biological oxygen demand) and faecal coliform counts, paralleled the change in diversity. Wu (1982) also used the Shannon index to assess the response of epibenthic communities in Tolo Harbour and Channel in Hong Kong. This is a subtropical environment subjected to a gradient of organic pollution and Wu found a clear increase in diversity with increasing distance from the pollution source.

The Shannon index was used to measure the impact of dredging on the marine benthos of a large tropical sublittoral sandbank off Queensland, Australia (Poiner & Kennedy, 1984). They recorded a significant decrease in diversity in the dredged areas. The surrounding non-dredged areas showed an increase in species richness, but not in diversity as measured by the Shannon index.

Interpretation of results

Green (1979) suggested that diversity measures are an inappropriate way of measuring the effects of pollution. This conclusion is partly based on the observation that a number of studies have shown that diversity can be dependent on factors other than pollution. It is important to distinguish causation and correlation. The observation that diversity increases as pollution decreases does not automatically prove that one is a direct response to the other. Therefore, care must be taken when interpreting the results of studies of this nature.

It is also important to note that an increase in species diversity might not necessarily indicate that the environmental quality is better. For example, enrichment may initially cause an increase in diversity but this can be at the cost of a shift in the composition of the community. An oligotrophic lake experiencing moderate inputs of nitrates and phosphates may acquire more species - is this a sign of a better system? Therefore, those involved in environmental assessment must be clear about what they mean by environmental quality.

The strongest argument against the use of diversity indices as derived criterion or predictor variables in environmental studies is that other statistical methods retain more information in the biological data while reducing them to a more useful and ecologically meaningful form. A multivariate statistical approach is often more appropriate. Example: refer to benthic faunal patterns in the Winnipeg River related to pulp mill effluent. Using diversity indices, it can be seen that there is some depression of diversity values immediately below the effluent discharge, but the downstream values are about the same as the unpolluted upstream values. However, if cluster analysis is used to analyse the same data, patterns relating to degree of impact are evident: the upstream stations form a distinct cluster. The cluster analysis of course retains information about which taxa characterise each of the stations whereas diversity indices do not.

DISTRIBUTIONAL TECHNIQUES

Graphical or distributional representations extract information on patterns of relative abundances without reducing the information to a single summary statistic (e.g. diversity index). The distribution of species abundances among individuals and the distribution of species biomasses among individuals can be compared on the same terms by using distribution plots.

The Abundance-Biomass Comparison (ABC) method of determining the levels of disturbance (may be pollution induced or otherwise) on benthic macrofaunal communities is one such example. It is logical from theoretical and empirical evidence to visualize that the *k*-dominance curve for biomass will lie above that of the abundance curve in undisturbed or unpolluted communities. In disturbed communities, the reverse situation occurs. Warwick (1987) reported compliance to these predictions in few sets of data. Using a data set from the subtidal Java macrofauna in Mlonggo Bay, he demonstrated that ABC curves at the three shallower stations show a close coincidence and crossing of the curves indicating that they are maintained at an intermediate successional stage. The 30 m station, however, represents the mature condition.

Warwick (1987) concluded that the ABC method is robust and sensitive to various kinds of disturbance, which could be natural and/or pollution-induced. In addition, it was stated that the method is conservative in that no cases have been found where unpolluted or mature condition has been indicated in situations of known pollution or other disturbance. However, there have been occasions where undisturbed sites were categorised as moderately polluted. He attributed this to sampling error or to some undetected disturbance. Lim & Gratto (1992) found that several obviously organically enriched sites at salmon farms in the Bay of Fundy (Canada) were erroneously categorised as undisturbed/unpolluted. Furthermore, a number of the 'control' sites were classified as being affected by some form of disturbance. Many other workers (e.g. Beukema, 1988; Ibanez & Dauvin, 1988; Weston, 1990) also found that the method incorrectly characterised the disturbance status at some of their "control" sites. Lim & Gratto (1992) concluded that the reliability and use of this technique in identifying areas disturbed by organic enrichment have yet to be established.

MULTIVARIATE ANALYSES

Multivariate procedures consider each species to be a variable and the presence/absence or abundance of each species to be an attribute of a site or time. Therefore, subtle changes in the species composition across sites or in the abundance of particular species across sites are not masked by the need to summarise the combined characteristics of the site as a single value.

Cluster analysis

The main aim of cluster analysis is to find 'natural groups' of samples such that samples within a group are more similar than samples in different groups. The cluster technique has been used to partition sites or times into groups, distinguish between replicates within sites/times (i.e. whether replicates within sites/times fall into same cluster) and to define species assemblages. An essential step in cluster analysis is to obtain a measure of either the similarity (proximity) or difference (distance) between each pair of sites/times.

Multidimensional scaling (MDS)

Multidimensional scaling endeavours to find, using an iterative process, the best fit between input dissimilarities and distance between samples in the resultant ordinated space. This technique is often chosen over Principal Components Analysis (PCA) by many ecologists as PCA assumes a linear response in abundance of species along environmental gradients and is thus considered to be a poor reflection of reality.

Ordination

The main objective of ordination is to reduce the dimensionality of a complex multivariate set of data with a minimum loss of information. The distance between two samples plotted in space corresponds in some way to the value of the distance measure used to represent their dissimilarity. New axes (called factors), are denoted as linear combinations of the measurement variables and these new axes are ordered so that the first factor accounts for most of the variation among samples and the last factor explains the least.

It is not possible in this paper to list all the advantages and disadvantages of these analyses with examples for illustration. I have included a recommended reading list for information on these statistical analyses and in particular, I would like to draw attention to the excellent review, critique and summary of the use of multivariate analyses for various benthic macroinvertebrate surveys by Norris & Georges (1993).

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APPLICATION OF RESULTS IN MANAGEMENT DECISIONS

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REASONS FOR MONITORING

At the present time, the institution of monitoring programmes is becoming more widespread simply in order to cope with changes to the natural environment that societal development brings about. Policy makers are beginning to realise the importance of understanding the natural dynamics of the marine environment and its resources in order to deal with the inevitable effects of human impact. The ultimate objective is to preserve those aspects of the natural environment that are most useful to human society. With respect to the sea, these include the production of goods (food, industrial products, ornaments), protection of the shoreline against physical destruction by ocean waves and currents (as in the case of coral reefs), and aesthetic and recreational benefits.

Thus, the first objective of a monitoring programme in the context of management is simply to characterise important habitats and resources in order to understand their dynamics particularly in the event of human-induced change. Another purpose of monitoring is introduced when an environmental problem (or problems) is suspected. Monitoring would help establish the spatial scale and patterns of an impact as well as its temporal variability.

USES OF MONITORING

In an instance when an environmental disturbance does exist, monitoring is aimed at detecting the *signal* (the stress response) to this disturbance above the *noise* generated by other sources of variability. Because of limitations inherent in data collection and interpretation, the detection of effects of an impact will always be based on some probability level. The information obtained can be used to GENERATE A HYPOTHESIS about the presumed disturbance. This will be the basis of managerial action to be planned (see below).

As mentioned above, monitoring will be needed to further characterise a problem in terms of its spatial extent (magnitude, scale), distribution and temporal variation (frequency, duration). When coupled with specific tests, observations or experiments, results of monitoring could also help shed light on probable causes of a problem. In addition, some insights could be obtained as to possible effects on the biota and on the physical-chemical environment.

MANAGERIAL ACTION

Interpretation of data obtained from monitoring could help guide subsequent managerial action to address an environmental problem. The most straightforward approach would be to direct the action at the cause of a problem. An example would be to shut down or relocate a polluting industry.

Where the above course of action is not feasible, management action may be directed at the symptoms or the effects of the disturbance. An example is mitigation of pollution or remediation. Efforts at habitat restoration may also be considered under this approach.

It is recommended that management decisions also incorporate the continuation of the monitoring effort over the long term. The purpose would be to verify if a problem has been solved or abated, in cases where direct management intervention has been instituted. If it has not, monitoring would detect if the problem is worsening or not.

SCIENTIFIC EVALUATION OF ENVIRONMENTAL DECISION-MAKING

This is a crucial element in the management process. Correct scientific evaluation would indicate, for example, if correct hypotheses or models were used to underlie the management action. Scientific methods also ensure that data are interpreted properly.

The implementation of mandatory environmental impact assessment (EIA) studies before development or disturbance of any site in many countries is one way to ensure that correct scientific evaluation is linked to the managerial process. According to Green (1979), a good impact study is one in which impact effects are judged against previously collected baseline data. Such an optimally designed impact study is best used when the results provide the basis for subsequent monitoring to detect future impacts of the same type.

The terms used to describe the three types of applied environmental studies, namely, baseline, monitoring and impact studies have often been used rather loosely. Some clarification to the definition of these terms is necessary before the discussion of an optimal impact design leading to correct managerial decisions could be made. A baseline study is one in which the data are collected and analysed for the purpose of defining the present state of the environment, the biological community, or both. The present state would usually contain some pattern of spatial or temporal variation. A monitoring study has the purpose of detecting a change from the present state. If the data are used to detect change in the biological community (as in the case of our theme for this workshop), it is known as a biological monitoring study. The objective of an impact study, on the other hand, is to determine whether a specified impact causes change in the environment or the biological community and, if it does, to describe the nature of that change. One may be able to obtain both pre-impact and post-impact data (in an ideal optimal case and design) or only post-impact data. The assessment of the impact of oil spills provide examples of cases whereby there are usually only post-impact data available.

There are basically four prerequisites for an **optimal** impact design. First of all, it is important that the impact has not occurred yet, so that pre-impact baseline data provide a temporal control to which the post-impact data can be compared. This is whole *raison d'etre* behind the implementation of mandatory EIA studies. Secondly, the types of impact, time and place of occurrence must be known in order to formulate a sampling design appropriate to hypotheses testing. Otherwise, one could be conducting a monitoring study to detect impact, rather than an impact study to test against the null hypothesis of no change due to impact! It must also be possible to obtain accurate measurements on all relevant environmental and biological variables in association with the individual samples. Last but not least, there must be an area that will not receive the impact to serve as a control.

The first and last of these criteria imply that controls in both time and space are necessary. This is to ensure that evidence for impact effects on the biological community is based on changes in the impact area that did not occur in the control area. If the spatial control is missing, and only pre-impact and post-impact samples from an impacted area are available, one runs the risk that a significant change may be unrelated to the impact. The change observed could have occurred independently from the impact anyway. If the temporal control is missing, it might not be possible to detect a difference between an area subjected to the impact and an area not subjected to it, existed before the impact occurred. For example, if a firm accused of mercury pollution rebutted with a comment: "It might have been like that before we started operation", and there is no temporal control to substantiate the case, then mercury pollution cannot be conclusively related to the specific industrial source.

Given that the four prerequisites for optimal impact study design are met, the choice of a particular sampling design and statistical methodology should be based on the following criteria. One must be able to test the null hypothesis that any change in the biological community of the impact area, over a period of time which includes the impact, does not differ from the control area. It must also be possible to separate effects caused by natural environmental variation unrelated to the impact and also possible to relate to the impact, any demonstrated change unique to the area of impact.

The analysis method used must be able to efficiently and effectively display both change due to impact in relation to other sources of variation and the relationship between impact-related change in the environmental variables as well as impact related change in the biological variables. The results should also be applicable for subsequent biological monitoring to detect future impacts. Last but not least, the test of the null hypothesis that no change due to impact must be as conservative, powerful and robust as possible. If it is conservative, it will have a low probability α of making the Type I error, that is, concluding that there were biological effects of the impact when in fact there were none. If it were powerful, it will have low probability β of making the Type II error, that is, concluding there were no biological effects when in fact, there were. If it were robust, the stipulated error levels will not be seriously affected by the kinds of data commonly encountered in environmental studies.

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RECOMMENDATIONS

AREAS FOR FURTHER TRAINING

Participants identified the following five priority areas as useful to the further development of marine pollution monitoring and management programmes in their countries:

a) benthic community analysis
b) statistical data analysis
c) bioindicators
d) management applications
e) nutrient impacts on the environment.

It was agreed that future activities should focus on these 5 areas to assist member countries reach the level of expertise required for implementation of effective programmes. It was acknowledged that there is varying capability within member countries and that some will require assistance in the form of funding and expertise for their national training and capacity-building programmes.

FOCUS OF NEXT WORKSHOP

Participants requested that the next workshop to be held in Australia focus on nutrient Impacts, eutrophication and red tides. This may include sessions on :

* key field/laboratory techniques
* measurement of phytoplankton blooms
* taxonomy of toxic phytoplankton species
* algal-coral interactions
* water chemistry
* monitoring techniques
* sediment studies.

These should be linked to management applications. Participants felt that there was no need for real examples (e.g., field visits to sites affected by eutrophication). Instead, emphasis should be more on techniques. There should be reduced emphasis on taxonomy, so as to minimise overlap with the ASEAN-Canada project, but a greater emphasis on data analysis for the various techniques to be discussed. Based on this feedback, Dr. Trevor Ward proposed that the next workshop to be held in Australia be entitled "**Eutrophication Processes and Pollution Management**".

NETWORKING

As highlighted in the recommendations of the Phuket workshop, the need for a formal interactive network is essential for member countries if the goal of developing integrated multidisciplinary approaches to problems on a regional and sub-regional scale is to be realised. Such a network will provide the necessary infrastructure to initiate regional cooperation.

The proposed network can establish mechanisms for:

a) informal exchange of information/data between member countries
b) sharing of expertise between member countries
c) developing standardised methodologies to facilitate regional analysis of data
d) maintaining a central database.

The following network structure was proposed (based on the model developed in the ASEAN-Australia Living Coastal Resources Project) :

- each country will be represented by a national coordinating agency (NCA) which is technically involved in marine pollution monitoring and management (it was suggested that the agencies represented at this workshop be identified as NCAs subject to the approval of country focal points)

- each NCA will coordinate national activities with other interested national institutions

- two NCAs within the regional network should be nominated as main coordinators

- main coordinators will serve a 2-year term after which the appointments are rotated among other NCAs, also for 2-year durations.

it was agreed that this recommendation be brought up for consideration at the next COBSEA meeting so that the structure can be institutionalised and supported with funds for network coordination activities. The two NCAs identified in the recommendations of the Phuket Workshop as coordinators should be appointed as the first network coordinators when the proposal receives endorsement from COBSEA. They are:

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APPENDIX 1

PROGRAMME FOR UNEP WORKSHOP ON SOFT-BOTTOM BENTHIC COMMUNITIES AS INDICATORS OF POLLUTANT-INDUCED CHANGES IN THE MARINE ENVIRONMENT

Singapore, March 20-29, 1995

Monday 20 March

0900	Registration	
1000	Welcome Address	
1030	Reception	
1100	Introduction to workshop content and arrangements	
1230	Lunch Break	
1400	Session 1	Properties of the Marine Environment (Chou) Impacts on the Marine Environment (Chou/Lim)
1530	Break	
1600	Session 2	Impacts on the Marine Environment : Examples (Lim)
1700	End of Day 1 Activities	

Tuesday 21 March

0900-1700	Field trip (by boat) to the Southern Islands of Singapore to assess impacts on the marine environment

Wednesday 22 March

0900	Field Trip to Seletar Sewerage Treatment Works	
1230	Lunch Break	
1400	Session 3	Soft-Bottom Benthic Communities: Structure, Function and Ecological Importance (Yap)
1530	Break	
1600	Session 4	Bioindicators: Species and Communities (Yap)
1700	End of Day 3 Activities	
1830	Workshop Dinner	

Thursday 23 March

0900	Session 5	Soft-Bottom Benthic Communities: Economic Importance (Chou)
1030	Break	
1100	Session 6	The ASEAN-Australia Programme on Benthic Communities (Chou)
1230	Lunch Break	
1400	Field trip to Ministry of the Environment, Singapore River and Kallang Basin	
1700	End of Day 4 Activities	

Friday 24 March

0900	Session 7	Surveying Soft-Bottom Benthic Communities: Designing a Sampling and Monitoring Programme (Yap)
1030	Break	
1100	Session 8	Surveying Soft-Bottom Benthic Communities: Designing a Sampling and Monitoring Programme (contd.) (Yap)
1230	Lunch Break	
1400	Session 9	Surveying Soft-Bottom Benthic Communities: Equipment and Methodology (Loo)
1530	Break	
1600	Session 10	Surveying Soft-Bottom Benthic Communities: Equipment and Methodology (contd.) (Loo)
1700	End of Day 5 Activities	

Saturday 25 March

0900-1700 Field trip (by boat) to Pulau Semakau for hands-on experience with sampling gears

Monday 27 March

0900	Session 11	Data Management (Loo)
1030	Break	
1100	Session 12	Data Management (contd.) (Loo)
1230	Lunch Break	
1400	Session 13	Data Management (contd.) (Loo)
1530	Break	
1600	Session 14	Data Management (contd.) (Loo)
1700	End of Day 8 Activities	

Tuesday 28 March

0900	Session 15	Data Analysis (Lim)
1030	Break	
1100	Session 16	Data Analysis (contd.) (Lim)
1230	Lunch Break	
1400	Session 17	Data Analysis (contd.) (Lim)
1530	Break	
1600	Session 18	Data Analysis (contd.) (Lim)
1700	End of Day 9 Activities	

Wednesday 29 March

0900	Session 19	Application of Results in Management Decisions (Yap and Lim)
1030	Break	
1100	Session 20	Application of Results in Management Decisions (cont.) (Yap and Lim)
1230	Lunch Break	
1400	Session 21	Networking and Group Recommendations (Chou)
1500	Visit to Zoological Reference Collection	
1600	End of Workshop	

APPENDIX 2

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APPENDIX 3

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