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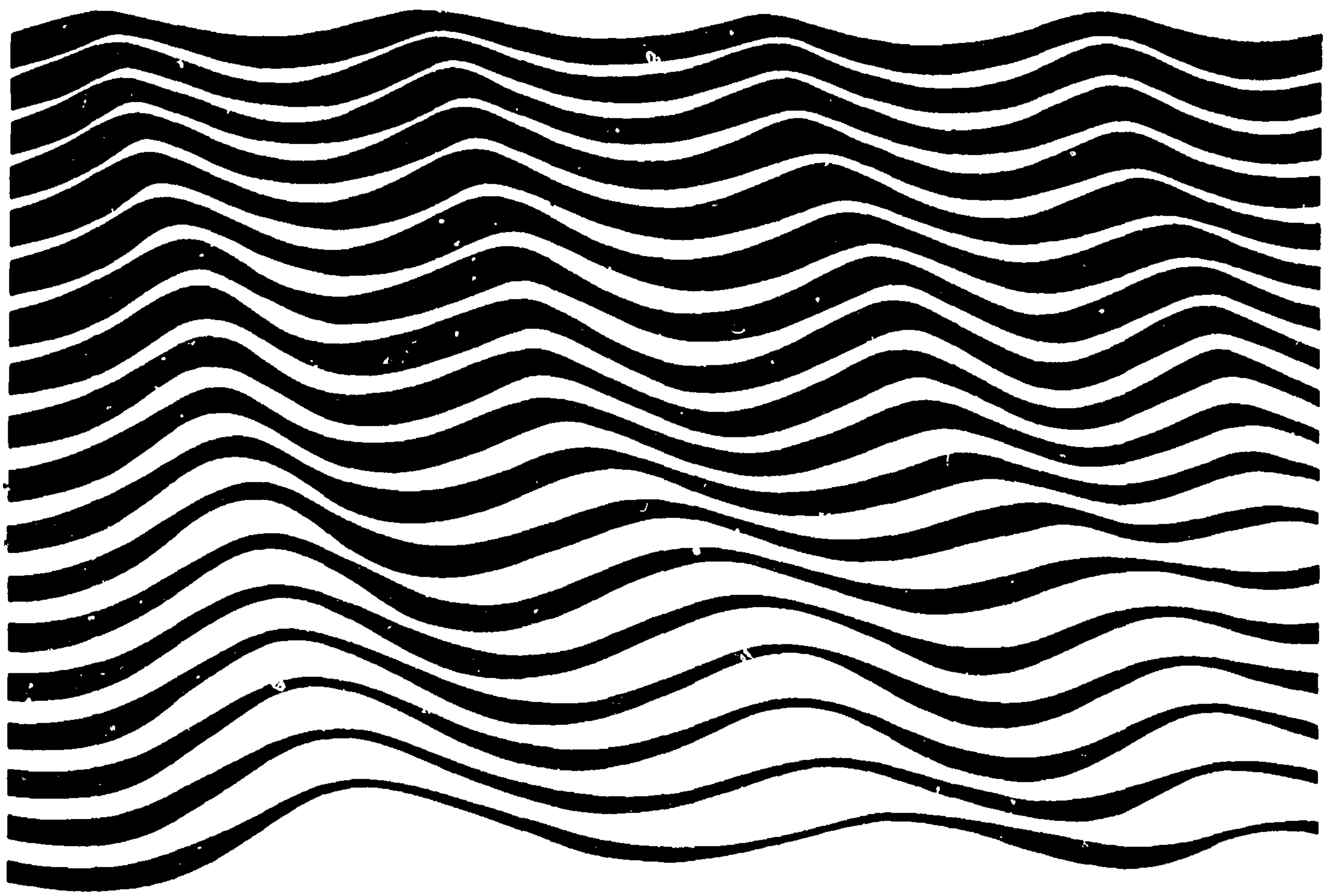
Comparing coral reef survey methods

Report of a regional Unesco/
UNEP Workshop
Phuket Marine Biological Centre
Thailand, 13-17 December 1982



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No.		Year
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18	Coral reef management in Asia and the Pacific: some research and training priorities Report of a Unesco workshop held in Manila, Philippines 21-22 May 1981 English only	1982
19	Mareas rojas en el Plancton del Pacífico Oriental Informe del Segundo Taller del Programa de Plancton del Pacífico Oriental, Instituto del Mar, Callao, Perú 19-20 de noviembre de 1981 Spanish only	1982
20	Quantitative analysis and simulation of Mediterranean coastal ecosystems: The Gulf of Naples, a case study Report of a workshop on ecosystem modelling Ischia, Naples, Italy, 28 March to 10 April 1981 Organized by the United Nations, Educational, Scientific and Cultural Organization (Unesco) and the Stazione Zoologica, Naples English only	• 1983
21	Comparing coral reef survey methods A regional Unesco/UNEP workshop, Phuket Marine Biological Centre, Thailand, December 1982 English only	1983

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PREFACE

Unesco Reports in Marine Science are designed to serve specific programme needs and to report on developments in projects conducted by the Unesco Division of Marine Sciences, including those involving collaboration between the Division and the Intergovernmental Oceanographic Commission, particularly in the field of training, education, and mutual assistance in the marine sciences.

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SUMMARY

A workshop organised by Unesco, UNEP, and the Phuket Marine Biological Centre was held at the Phuket Marine Biological Laboratory, Thailand, in order to compare coral reef survey methods commonly used in South East Asia and the Pacific region. The overall aim of the workshop was to provide the contributing experts with an opportunity to examine the strengths and weaknesses of methods currently used, with the intent of eventually developing standard procedures for use in various preliminary surveys. To this end, participants defined the goals that should be achieved by preliminary surveys and subsequently field tested the kinds of information generated by a variety of methods. Comparisons were drawn between the results obtained by field tests of these methods on reefs at Phi Phi Island, southeast of Phuket in the Andaman Sea.

The workshop recognised the need to limit the trade in corals and coral reef fish that is conducted by trans-shipping illegally harvested material through secondary countries. In addition, the workshop recommended the formation of an organisational device that would permit work at an international level on coral reef problems. Researchers were also encouraged to use one other method (such as the point-quarter method) as a backup to present practices. An adequate data base may then be created for future decision-making on the need for standard techniques concerning initial reef surveys.

ABSTRACT

Nine papers dealing with aspects of coral reef survey methods generally used in South East Asia, the Pacific, and elsewhere were prepared for the Unesco/UNEP Workshop on Coral Reef Survey Management and Assessment Methods in Asia and the Pacific (Phuket, Thailand, 13-17 December, 1982).

Included in this report are those papers, an introductory overview, and comparative results, obtained by experienced researchers from field work undertaken during the workshop on reefs at Ko Phi Phi Don, a small island to the southeast of Phuket in the Andaman Sea. In addition, an outline of survey goals and conclusions regarding the general applicability of methods to differing objectives are presented. Formal recommendations concerning limitation on trade in corals, future harmonisation of general survey methods and formation of an organisational structure to facilitate international work on coral reef problems are also developed.

NOTES

The workshop was organised on a cooperative basis by the Unesco Regional Office for Science and Technology for South East Asia, the Phuket Marine Biological Centre of Thailand and the UNEP Project on the Study of Coral Resources and Effects of Pollutants and Other Destructive Factors on Coral Communities and Related Fisheries in the East Asian Seas Region. The latter project is coordinated by the Natural Resources Management Centre of the Philippines.

The authors and participants are responsible for the choice and presentation of the facts contained in this book and for the opinions expressed therein, which are not necessarily those of Unesco or the United Nations Environment Programme and do not commit the organisations in any way.

The designation employed and the presentation of material throughout the publication do not imply the expression of any opinion whatsoever on the part of Unesco or the United Nations Environment Programme concerning the legal status of any country, territory, city, or area of its authorities, or concerning the delimination of its frontiers or boundaries.

TABLE OF CONTENTS

1. INTRODUCTION

The Unesco/UNEP Workshop on Coral Reef Survey Management and Assessment Methods was held from 13-17 December 1982, in the Conference Room of the Pearl Hotel in Phuket and on Phi Phi Island, Thailand. It was attended by participants from Guam, Thailand, the Philippines, Indonesia, Singapore and Malaysia, and by representatives from UNEP and Unesco. The full list of participants is given in Annex I to this report. Dr. Hansa Chansang of the Phuket Marine Biological Centre acted as the local organiser. In all, eleven participants and seventeen observers attended.

The Deputy Director-General of Fisheries of Thailand, Mr. Vanich Vareekul, welcomed the participants on behalf of the host country. The text of his welcoming address is given in Annex II. Dr. J.R.E. Harger, Unesco representative, outlined Unesco's Major Interregional Project on Research and Training leading to the Integrated Management of Coastal Systems (COMAR). Under COMAR, various activities in the field of coral reef research and management have been and are being undertaken, including the present workshop. He also gave an overview of Unesco activities planned for the near future under the same project (Annex I). Dr. D. Elder, UNEP representative, described the UNEP Regional Seas Programme. He stressed the importance of the present meeting as the first concrete activity of this regional seas programme in the field of coral reef research and management (Annex I).

The meeting adopted a rotating chairmanship, and Mr. R. Aertgeerts was elected rapporteur.

The workshop was divided into two sections:

(1) Review and theoretical analysis of commonly used techniques (2 days);

(2) Field Trial and comparison of methodologies (3 days).

The first section reviewed methods of coral reef assessment as presented in papers solicited for the purpose of dealing with survey programmes known to participants. As part of the review, participants examined the major elements of survey techniques that could be employed to gather essential information regarding the distribution and structure of coral reefs in areas where resources might be in short supply. An agreed-upon basis for descriptive terminology was developed, together with an outline of the goals that should be addressed by a coral reef survey.

A short review of the UNEP East Asian Seas Action Plan concerning coral reefs was presented to participants by Dr. E.

Gomez and Dr. D. Elder.

The second section of the workshop involved field assessment of major survey techniques presented in workshop section 1. The field programme provided an opportunity for participants to gain experience in the application of methods regularly used by one another and to develop the basis for consistent reporting.

As the result of a last-minute withdrawal of a participant from Australia, no paper was available to deal with manta board surveys at the time of the conference. A paper dealing with a rope tow survey conducted in the Persian Gulf was, therefore, substituted.

This Report was prepared by the Unesco Regional Office for Science and Technology for South East Asia, Jalan M.H. Thamrin 14, Jakarta, Indonesia.

2. CORAL REEF NUTRITION OVERVIEW

2.1 SOURCES AND DESTINATIONS OF NUTRIENTS IN CORAL REEF ECOSYSTEMS

by

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INTRODUCTION

It has long been recognised that coral reefs are among the most productive and diverse communities in the world (Marsh, 1976; Lewis, 1977). Yet the oceanographic regions in which coral reefs flourish are often very oligotrophic, i.e. contain few nutrients (Sargent and Austine, 1949; Odum and Odum, 1955; Kohn and Helfrich, 1957; Stoddart, 1969).

ZOOPLANKTON AS A NUTRIENT SOURCE

Although many fishes, corals, and other invertebrates feed on zooplankton, studies with zooplankton nets determined that the density of drift zooplankton in the waters surrounding coral reefs was too low to support the metabolism of the animals that feed on zooplankton (Odum and Odum, 1955; Johannes, Coles and Kuenzel, 1970). However, observations during night dives and of stomach contents of corals (Porter, 1974) indicated that there were other groups of zooplankton coming from undiscovered sources. Since we traditionally sampled zooplankton by towing nets, we naturally assumed that coral reef communities receive their nutrients from plankton drifting from the ocean across the reef. Our methods created our assumptions. But in 1977, Alldredge and King (Great Barrier Reef) and Porter, Porter and Batac-Catalan (Philippines) set out demersal plankton traps and found a major source of zooplankton that left the reef substratum at night and returned before dawn. In 1979, Hamner and Carleton reported swarms of copepods which stayed too close to the substratum or to topographic features of the reef to be collected by net; yet did not move into the substratum where they could be collected. These newly discovered swarms of copepods (*Acartia*, *Oithona*, *Centropages*) were regularly found in densities of 500,000 to 1,500,000 per m^3. They, therefore, formed the greatest concentration of potential food on the coral reef for those animals that fed on zooplankton. They would not have been discovered by standardised methods. Instead of zooplankton drifting in from the open sea, most of the zooplankton which the other reef animals fed upon were resident zooplankton. Much of the coral reef system is self-contained and the nutrient materials are recycled.

The recycling of nutrients also takes place at the physiological level by the exchange of nutrient materials between symbionts within an organism (Lewis, 1973; Muscatine, 1973; Muscatine and Porter, 1977; Pomeroy *et al.*, 1974; Taylor, 1973a, b).

NUTRIENT RECYCLING

Among the most self-contained of reef systems are the enclosed lagoons of the Tuamotus. For example, Takapoto is a raised atoll with an enclosed lagoon that is approximately 16 km long, 4.5 km wide and average 23 m deep. This approximately 1.6 x 10^9 m^3 of water is connected to the sea by a couple of hoas that one can easily wade across. The surrounding ocean is oligotrophic with very low nutrients (0.36 μ at gl^{-1} NO_3-N; 0.26 μ at gl^{-1} PO_4-P) and chlorophyll *a* (0.14 μgl^{-1}) contents (Sournia and Ricard, 1976). The waters within the enclosed lagoon have even lower nutrients (o.22 μ at gl^{-1} NO_3-N; 0.12 μ at gl^{-1} PO_4-P) but much higher chlorophyll *a* (0.46 μgl^{-1}) contents (Sournia and Ricard, 1976). Yet the main industry of Takapoto involves the production of pearls by filter-feeding bivalves (Pollack, 1978, 1979). Tons of bivalves (*Pinctada*, *Arca*, *Tridacna*) live in the lagoon (Richard *et al.*, 1979) despite the fact that the water is very sparse in nutrients. It may be that the enclosed lagoonal system is so self-contained that the nutrients are rapidly recycled and contained in the biomass of the bivalves and fishes. Like the tropical rain forests, coral reef ecosystems may be able to withstand pruning and recycling, but not harvesting and exporting. Most of the nutrients are recycled and not imported. The removal of living materials from a coral reef community on a large scale might cause depletion at a rate at which the system would be unable to replenish and maintain itself. At Takapoto, the oysters are harvested but only the pearls are exported; the meat is eventually recycled into the lagoon. If we scrape a temperate shoreline of barnacles, we would expect the barnacles to return in a year or so since barnacles feed on imported suspended material. If we dredge or dynamite a reef, we might expect recovery to take a very long time. Since the nutrients have been lost, a substantial amount of time may be required for the necessary processes to build up another stockpile.

NUTRIENTS AND ACANTHASTER OUTBREAKS

The sudden input of nutrients into coral reef systems can have substantial effects on species' interactions in the coral reef community. High islands have greater potential for nutrient runoff than do low sandy atolls. Lagoonal areas of high islands have more suspension-feeding sponges than the seaward reefs of high islands or the lagoons or seaward reefs of atolls. Highsmith (1980) found that corals had significantly greater infection of burrowing bivalves (suspension-feeders) in areas of higher primary productivity. *Sargassum* is almost entirely restricted to high islands and almost never found on atolls (Tsuda, 1976). *Enteromorpha* bloom only around areas of nutrient input from groundwater seepage. (FitzGerald, 1978).

Perhaps the most spectacular effects of terrestrial nutrient runoff are the outbreaks of *Acanthaster planci* which devastate coral communities (Birkeland, 1982). Lucas (1982) has shown by laboratory experiments that the larvae of *Acanthaster planci* cannot live on densities of phytoplankton normally found in waters around coral reefs. They can only survive on concentrations of phytoplankton found in phytoplankton blooms. Phytoplankton blooms occur in certain areas on Guam at the beginning of the rainy season (Marsh, 1977), at the time of Acanthaster planci spawning. It is in these areas that outbreaks of Acanthaster planci originate. Since terrestrial runoff occurs around high islands but not around low sandy atolls, we would expect outbreaks of Acanthaster planci to occur around high islands and not around atolls if nutrients from terrestrial runoff were the cause of the outbreaks. We find this to be the case if we examine the data in the compilation of survey results by Marsh and Tsuda (1973). Nineteen out of 21 outbreaks occurred around high islands when 23 high islands and 22 atolls were surveyed (χ^2=21.5***).

While terrestrial runoff has a substantial effect on coral reef ecosystems around high islands, it cannot be significantly influential around atolls which, above the waterline, consist only of sand bars. At Takapoto, it seemed to be the recycling of nutrients in the contained water mass that appeared to maintain the large standing crop of the system. This residence time of water may also explain some other anomalies in the tropical marine systems. An upwelling of nutrients occurs off southeast Taiwan in the Kuroshio current; yet the fisheries are rich off Okinawa to the north. This may be because the water mass remains fairly cohesive as the Kuroshio current flows north despite the fact that the productivity of phytoplankton is still too low to support fisheries. By the time the water mass reaches Okinawa, the phytoplankton cells have divided enough times to build up a standing crop large enough to support fisheries.

This same process may explain why Acanthaster planci outbreaks have been a chronic problem on Ponape but have apparently not occurred on Kosrae. While Kosrae and Ponape are both high islands that have the greatest potential for phytoplankton blooms of all the Carolines (Cowan and Clayshulte, 1980), the waters around Ponape are contained in a lagoon surrounded by a barrier reef, while the waters around Kosrae, which is surrounded by fringing reef, are carried away and dispersed by longshore currents. At Ponape, the lagoon may act as an incubator with the water having a long enough residence time to allow phytoplankton to build up a standing crop large enough to support larvae Acanthaster planci. Although the waters off Kosrae contain enough nutrients to allow phytoplankton blooms, the waters move away from the island before the phytoplankton have undergone enough cell divisions to build up a standing crop sufficient to support larvae of Acanthaster planci. The dispersion of water could also thin out the concentration of Acanthaster planci larvae as well as their food supply. Studies of fish larvae indicate that the upwelling of nutrient-rich water leads to phytoplankton blooms, but the movement of the upwelling waters disperses food organisms. The food particles are too low in concentration to support larval anchovy growth (Smith and Lasker, 1978).

The *Acanthaster* outbreaks on Guam originated at the northern ends of both Tumon and Agana in both 1968 and 1979, but not at other bays. While the water has a relatively long residence time at the northern ends of these two bays (cf. Marsh, 1977, for Tumon Bay), the sediment plume is apparently carried directly out of the other bays and dispersed into the open sea.

To test "productivity", or rates of biomass accumulation, at these various sites, fouling panels were set out in groups of four in the open and in groups of four in fish-exclusion cages at each of the sites. Four sites were in slow-current areas and four were in closely-matched, fast-current areas. In all cases, inside and outside cages, slow-current areas showed greater rates of biomass accumulation than did fast-current areas. Furthermore, the two areas in which outbreaks of *Acanthaster planci* originated in the past showed double the rate of benthic biomass accumulation of any of the other areas. This again indicates that the *Acanthaster planci* may have survived better in such areas of higher productivity, perhaps because of terrestrial nutrient runoff and the relatively long residence time of water.

EFFECTS OF CURRENT SPEED

Demersal plankton traps caught greater numbers in slow-current areas than in closely-matched, fast-current areas. This indicates that resident plankton are more productive in slow-current areas. Much of the drift plankton are meroplankton or reproductive items such as eggs and larvae, indicating that fish and invertebrates may spawn in fast-current areas for dispersal rather than concentrating in areas of high productivity.

Fouling panels of the same size were set out at the same depths and for the same durations of time on offshore islands, as well as on the continental coast of the Caribbean (Birkeland, 1977). They were also placed on the side of an island with upwelling in the eastern tropical Pacific coast of Panama and on the opposite side of that island (Birkeland, 1977). The same procedure was followed in fast-current areas and closely-paired, slow-current areas around Guam. Rates of biomass accumulation on these panels and the nature of the biota at the site (e.g. whether sponges, planktivorous fishes or herbivorous fishes are prevalent) are more clearly predictable by the nature of the surrounding land masses and the local residence time of the water than by differences between oceans.

CONCLUSION

I believe that a knowledge of the effects of land masses of various forms, terrestrial runoff of nutrients into nearshore waters, and residence time of water on the productivity of marine communities and on the reproductive patterns of the populations is essential if we expect to obtain a workable understanding of the fisheries potential and dynamics of the tropical marine communities.

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POINTS RAISED DURING PRESENTATION

During the discussion of Dr. Birkeland's address, it was felt that one of the reasons why coral reefs did not readily recover from dynamiting was that the nutrients which had been accumulated in the system were dispersed to the open sea. The absence of Acanthaster outbreaks on coral atolls of the Pacific might be attributed to the absence of emergent land mass; on the other hand, the problem of Acanthaster infestation on the South China Sea coast of peninsular Malaysia may be attributed to nutrient runoff from nearby land areas. Acanthaster outbreaks were postulated to be due to the development of phytoplankton blooms resulting from nutrient runoff from the high islands during heavy rain.

3. REVIEW OF SOME CORAL REEF ASSESSMENT METHODS COMMONLY USED IN SOUTH EAST ASIA, THE PACIFIC AND ELSEWHERE

3.1 A CONTRAST IN METHODOLOGIES BETWEEN SURVEYING AND TESTING

by

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INTRODUCTION

Before beginning a survey, it is important to address objectives precisely with operational definitions. Basic procedures that are quite productive for one purpose can be counterproductive for another. For example, to monitor environmental quality according to standards set by law, to do comparative regional surveys or studies of temporal variations of subjects such as larval fishes, or to test hypotheses concerning questions such as causes of environmental degradation, standardised sampling programmes must be designed to insure the consistency of data acquisition within the studies. An overly standardised approach can be detrimental to exploratory surveys for assessment of latent resources or in searching for unknown causes of sporadic phenomena.

In this working paper, I will first present potential causes of concern regarding overstandardisation in exploratory surveys. I will then provide an example of the need for closely-placed controls in field experiments that test hypotheses. Finally, I will outline some considerations for the number of replicates required in a sampling or experimental programme. The methods for sampling coral reef organisms that have been most useful to the University of Guam Marine Laboratory personnel during the past ten years are described in the section on replicates. Although the examples given in this paper to illustrate problems with various designs of exploratory surveys or field experiments are from my own experience with zooplankton or sessile benthos, the problems are general and apply to fisheries and other subjects.

RISKS OF STANDARDISATION IN EXPLORATORY SURVEYS

To illustrate the risks of overstandardisation, let us review the sampling methods for zooplankton. In conducting a study of zooplankton in areas with different current patterns, we did replicate samples both by pushing pairs of nets in front of our boat and, alternately, before and after, towing the same sized nets through the same site behind our boats. We found that a different picture of zooplankton community structure would be obtained from the same place and time depending upon whether the net was pushed at the front of the boat or towed behind. Motile organisms such as crustraceans or larval fishes were more predominant in push-net samples and fish and invertebrate eggs of all kinds were more numerous in pull-net samples (Table 1). Both push-net and pull-net samples showed consistent characteristics. Although the techniques are reliable enough to be useful in comparative studies and in testing hypotheses, any particular sampling method gives a biased picture of reality. Looking for latent resources or working towards a more complete picture of the real world, field observation must be used in conjunction with a variety of sampling techniques.

Due to standardisation in sampling plankton with nets, it was generally assumed that coral reef animals which fed on zooplankton were supplied their resource by water currents bringing zooplankton across the reef from the open sea. Quantitative studies with drift nets indicated that the drift zooplankton in waters surrounding coral reefs were not abundant enough to meet the metabolic requirements of the animals feeding on them (Johannes *et al.*, 1970). Alldredge and King (1977) and Porter *et al.* (1977) invented a new sampling device to trap demersal plankton residing on a reef. They found that this was a major source of nutrients for coral reef animals which had not been recognised previously.

TABLE 1

A comparison of results from 16 replicate pairs of samples from the same make of zooplankton net, pushed and pulled.

Taxa	Push $\bar{Y} \pm s_{\bar{Y}}$	Pull $\bar{Y} \pm s_{\bar{Y}}$
Acartia sp.	387 ± 98	184 ± 55
decapod zoeae	79 ± 29	25 ± 11
fish larvae	3.6 ± 0.74	1.3 ± 0.30
fish eggs	253 ± 61	378 ± 81
invertebrate eggs	168 ± 43	202 ± 49

The greatest concentration of zooplankton biomass near coral reefs, the copepod swarms (Hamner and Carleton, 1979), would not have been discovered by net or trap. The copepod swarms stay too close to reef structures to be accessible to plankton nets pushed or towed by boat. The copepod species that swarm do not enter the substratum and large concentrations of the species are unlikely to be caught in a demersal plankton trap. Although these swarms are the greatest single concentration of coral reef zooplankton, they would have been missed by standard sampling techniques. Copepod swarms were discovered by divers' observations. They can be collected by direct pursuit with a plankton net pushed by a diver (Emery, 1968), with a suction device (Emery, 1968), or by engulfing the water mass with a large plastic bag (Hamner and Carleton, 1979).

These examples demonstrate that any particular sampling programme or technique will only show a limited portion of the picture. Any combination of techniques may provide a biased and incomplete picture. While the example cited involved zooplankton, the principle applies to other subjects as well. The search for latent resources or the quest for knowledge of the mechanisms involved in the functioning of the coral reef ecosystem should not be restricted by a rigid standardisation of techniques. We should use a variety of sampling techniques, including exploratory observations and interviews with indigenous experienced fishermen (Johannes, 1981).

Conclusions are robust if they stand the test of a variety of techniques or approaches. If they are based on one test, the conclusions may be an artifact of the method itself. When a series of different experiments require different statistical tests, but are basically testing the same scientific hypothesis, the probabilities from independent tests of significance can be combined. The different tests can include those performed by others and those recorded in the literature. R.A. Fisher (1954) found that $-2 \ln p$ is distributed as $\chi^2\{2\}$. Therefore, to combine probabilities from independent tests of significance, you sum the natural logarithms of the probabilities, multiply the sum by -2, then look up the significance of the combined probabilities in a chi-square table with the degrees of freedom being two times the number of tests. As Hamner and Carleton (1979) said, "The use of imprecise but distinctive sampling techniques provides greater credence in the final conclusion than would the use of a single technique, no matter how precise the replicates.".

NECESSITY OF CLOSELY-PAIRED CONTROLS IN FIELD STUDIES

Once latent resources are found or hypotheses involving causal mechanisms have been generated, it is necessary to standardise the sampling technique within each test so that the data are acquired in a consistent manner. This permits statistical analysis. For all experimental or comparative studies, I believe the necessity of controls must be emphasised because the factors influencing any community, population, or individual in nature are practically infinite. Because of this, it is difficult to demonstrate the influence of one factor without always pairing individuals under the influence of a particular factor in an area with controls which are in that same area. The controls are influenced by all of the same factors except for the particular factor under study.

The necessity of this can be seen by taking a closer look in Table 2 at the data summarised in Table 1. Although the means and standard errors of the means indicate that motile animals are found in greater numbers in pull-net samples, the differences between push-net and pull-net samples are not found to be significant for any taxon when tested with a 1-way anova or t-test. The reason for this becomes apparent when we examine the original data (Table 2). The push-net and pull-net samples in each row were taken in the same place and within ten minutes of each other. The data in different rows were from different places and times. The variance resulting from factors relating to differences in place and time was so great that no significant differences could be demonstrated by comparisons between the 16 data in the push-net column and the 16 data in the pull-net columns for *Acartia sp.* ($t_{s\{30\}}$=1.23ns, $F_{s\{1,30\}}$=1.513 ns).

When an examination is made of the direction of differences between numbers of specified organisms taken in paired push-net, pull-net tows, it is clear that something must be wrong with the preceding analysis. From simple binomial considerations, the likelihood of either all push-net or all pull-net samples containing the larger collection of *Acartia* is very low {$p= (\frac{1}{2})^{16}=1.5\times10^{-5}$}, and for fish eggs {$p= 16(\frac{1}{2})^{16}=2.4\times10^{-4}$}.

Accordingly, if we factor out the differences between rows and compare only the differences between columns with a 2-way anova or by subtracting one column from the other and testing whether the mean difference is equal to zero with a paired-comparisons t-test, then we find the push-net and pull-net collections show very significant differences for both *Acartia sp.* ($t_{s_d}\{15\}$=3.11**; $F_{s\{1,15\}}$=9.66**) and for fish eggs ($t_{s_d}\{15\}$ = 3.27**; $F_{s\{1,15\}}$ =10.72**). Of course, t-test and 1-way anovas referred to earlier were improper since the samples being compared were not independent.

These data and calculations have been presented to provide an example of the variance in natural systems. This requires that controls be included in field studies, allowing the individual influenced by the factor under study to be closely paired with another control individual, influenced by all sources of variance but the one under study.

TABLE 2

Counts of *Acartia sp.* and fish eggs in 16 collections made by pushing zooplankton nets at the bow of a boat and in another 16 collections made by pulling the same sized zooplankton nets at the same depths but about 10 m behind the boat. The *Acartia sp.* and fish eggs in each row are from the same collection and the push-net collections were taken in alternation, just before or just after the pull-net collections in the same area. The "+" or "-" sign is a mark for quick reference as to whether the push-net collection contained more or less *Acartia sp.* or fish eggs than the pull-net collection at a particular time and place.

	Acartia sp.		fish eggs	
	push	pull	push	pull
	+ 77	44	- 30	63
	+ 119	20	+ 59	47
	+ 372	233	-182	379
	+ 330	65	-249	466
	+ 83	7	-800	827
	+ 260	125	-350	879
	+ 859	250	-153	171
	+1440	420	-110	199
	+ 58	33	- 50	72
	+ 70	7	- 63	70
	+ 350	106	-188	281
	+ 262	125	-276	668
	+ 75	13	-780	970
	+ 235	150	-525	671
	+ 750	730	-103	130
	+ 850	610	-135	156
$\bar{Y} \pm S_{\bar{Y}}$	387 ± 98	184 ± 55	253 ± 61	378 ± 81

An example of the importance of closely-paired controls can be found in studies of the effects of exposure to oil spills on the health of corals. A number of studies have been cited in the literature in which both field and laboratory studies have been made on the effects of oil on hermatypic corals (Johannes, 1975). Very few of these indicated signs of damage and almost none showed definite evidence (Grant, 1970; Rutzler and Sterrer, 1970; Johannes, Maragos, and Coles, 1972; Shinn, 1972). Shinn (1972) stated that "it would seem safe to conclude then that crude oil spills do not pose a significant threat to Atlantic reef corals". Hermatypic corals are very important in the ecology of reef communities, providing habitat, as well as significantly entering into community metabolism. Therefore, it was important to assess as thoroughly as possible the effects of oil spills on the health of corals. Since mortality did not occur, rate of growth was taken as the best quantitative, objective measure that integrated a variety of physiological effects. Further, much of a coral's success in a community, i.e. its strength in competition with other species for space or its ability to tolerate grazing and predation, depends upon its rate of growth.

In a study in Panama for the U.S. Environmental Protection Agency, the reef-building coral Porites furcata was collected and stained to mark the size at the initiation of the experiment. It was then experimentally subjected to Bunker C oil or placed in pure seawater as a control and replaced in the Porites bed where originally collected (Birkeland et al., 1976). After 61 days, the amount of growth added since the staining process was compared between the controls and those treated with oil.

The experiment was repeated over two 61-day intervals. Heads of Porites furcata, all about the same size (about 10 or 12 branches), were each collected from a depth of 4.6 m (15 ft) near the laboratory. They were placed in plastic bags with Alizarin red S bone stain, sealed closed, and left for 6 hours (11:00 to 17:00) in shallow water (0.3 m or 1 ft in depth). After 6 hours of staining, they were placed overnight in an outside fiberglass tank with running seawater.

The next morning, two coral heads were placed in each of six buckets with just enough seawater to cover them. One hundred millilitres of Bunker C oil was poured into each of four buckets. The other two buckets held the controls. When poured, the oil reached the bottom of the buckets, but immediately floated to the surface through the branches of the corals. The water surface was 23 cm in diameter so the film was 2.4 mm thick. In the first experiment, four corals in two buckets were left with Bunker C oil for 2.5 hours as controls. Since no significant difference was found between the growth of corals exposed for 1 hour and 2.5 hours, all corals were exposed for 2.5 hours during the second experiment.

When removed from the buckets, the corals were replaced in the Porites bed near the laboratory at a depth of 4.6 m. In order to distinguish between the experimentals and the controls, wire bag fasteners were twisted around the base of each coral head, 1 on each of those from 1 hour in oil, 2 on each from 2.5 hours in oil, and 3 on each of the controls. Except for the last step in the entire process, the corals were transferred between containers within water, never breaking the surface. In the last step, however, the oil was poured off and the corals, coated with a film of oil, were placed in buckets of seawater by being lifted through air. The controls were also transferred through air.

Twenty-four hours later, the corals were observed in their field location. All corals appeared quite healthy, including those treated with Bunker C. All polyps were expanded to the same degree as those of the surrounding natural population. Effects of oil treatment were not apparent upon casual observation.

After 61 days in the field, both controls and experimentally treated Porites were collected and sprayed with water to remove the living tissue. The tips of the branches were filed down by hand to the centre so that a flat, longitudinal section was provided for growth measurement. The measurement was made with vernier calipers to the nearest 0.1 mm of the distance between the apex of the pink-stained portion and the tip of the branch.

Before designing the experiment to test the effects of Bunker C oil on Porites furcata, we had already anticipated that growth increments of coral would vary greatly from location to location and from month to month. This variability could not be separated from the differences due to the effects of oil if all the data from controls were lumped together and compared with the data from all corals treated with Bunker C oil. Therefore, the statistical design of the growth experiment was a simple randomised block design and the data were analysed by a paired difference test. A comparison of growth increments between corals used as control and corals treated with Bunker C oil was made for each location and time period to eliminate the effects due to variations of time and location. This also yielded more accurate information on the mean difference in growth due to stress from treatment with Bunker C oil. Three difference measurements were utilised to test the null hypothesis that the average difference is equal to zero. This is equivalent to saying that the mean growth increments are the same.

TABLE 3

The effect of exposure to Bunker C oil on the growth rate of *Porites furcata* The growth took place during 61 days following exposure to Bunker C. Each *Porites* head had ten to twenty branches.

Category	Treatment	Experimental Area[a]	No. *Porites* Heads	Total number branch tips that grew	Mean and standard error of the growth increment (mm/61 days)
	(25 Jan 73 to 27 Mar 73)				
A	Control	1	5	60	4.97 ± 0.03
B	Exposed to Bunker C	1	10	118	4.25 ± 0.02
	(4 Apr 73 to 5 Jun 73)				
C	Control	1	4	74	7.5 ± 0.3
D	Exposed to Bunker C	1	5	76	6.6 ± 0.4
E	Control	2	3	31	5.5 ± 0.3
F	Exposed to Bunker C	2	3	37	4.7 ± 0.3

[a]Area 2 was located 3 m away from Area 1 at the same depth.

The effects of Bunker C oil on the hermatypic coral Porites furcata were especially interesting in view of the lack of apparent damage noted by casual observation. In brief, the Porites subjected to Bunker C appeared quite healthy during the next 61 days, but the difference in growth increments between corals subjected to Bunker C and controls was significant (Table 3). Thus, although exposure to Bunker C oil was not fatal to the Porites, it had some negative effects on its physiology which were reflected in its growth. As was previously mentioned, much of a sessile organism's success in a community, i.e. its strength in competition with other sessile species or its ability to tolerate grazing or predation, depends upon its rate of growth.

Although no difference in growth increments was found between the branches of controls growing in the same areas during the same periods, the growth rates of corals varied both in space (a distance of 3 m at the same depth) and time (two different 61-day periods). The effects of location (3 metre distance at same depth) and time of year (about two months apart) were each greater than the effect of 2.5 hours of exposure to Bunker C oil (Table 3). Therefore, it was very important that the effects of oil were tested alongside closely-situated controls.

Connell (1974) clearly pointed out a basic difference in the design of laboratory and field experiments. In the laboratory, all factors are controlled except for the factor under study, which is manipulated in order to observe the reaction of the subject. Obviously, we cannot control all factors in field studies. In field studies, therefore, we manipulate one factor and allow all other factors to vary naturally. The controls in field studies are individuals for which the factor was manipulated. Thus, controls are not affected by the manipulated factor, but are affected as nearly equally as possible by all the other naturally varying factors.

REPLICATES OVER DETAIL

Considerable spatial and temporal variability exists in natural reef systems. Because of this, estimates of parameters should be obtained from many samples. A regrettable proportion of the papers on coral reef communities provide detailed descriptions of the coral communities in a few square metre quadrats or along a few transects across zones. These detailed descriptions provide estimates of very little reliability of communities of surrounding unsampled areas. I believe that if a trade-off has to be made between the amount of detail in measurements and the number of replicates taken, a more accurate estimate of parameters of the system would be obtained by taking more replicate samples, if necessary at the sacrifice of precision or detail of measurements (Kinzie and Snider, 1978).

To obtain a maximum number of replicates over a maximum area in surveys of sessile benthic communities, the UOG Marine Lab personnel have been using plotless sampling techniques for over a decade. To measure the corals in a 1 m^2 quadrat takes at least an hour in a coral community of intermediate coral density (Colgan, 1981), while an entire 100 m transect of 10 positions (sets of four quarters),with point-quarter plotless method, can be completed in the same area in about the same amount of time (Colgan, 1981). Despite sacrificing detail or precision at each position, taking more samples across a greater area provides a more accurate overall assessment of the system per unit time.

For sessile benthic organisms that are found as discreet colonies or individuals, the point-quarter technique has been found to be the most efficient. This method was presented by Cottam et al. (1953), and Cox (1972) and its use in coral reef research has been reviewed by Loya (1978). The line transect method of Loya (1972) does not provide density values or direct measurements of coral sizes without supplementary measurements which require additional time. Instructions for use of the point-quarter method are given in section 5 of this report.

Less discreet patches of surface occupied by algal turf, crustose coralline algae, filmy encrusting sponges, etc., are difficult to measure by dimensions. We have found that surveying these subjects by the point-quadrat method is more appropriate. This method consists of tallying organisms under the points of intersection of strings tied across 1/16-m^2 quadrats. Four strings tied from both sides of the quadrat give 16 intersecting points for each quadrat. Point intersection data from along a line transect are often used to assess horizontal surface coverage (Loya, 1972, 1978). I suspect that, within a zone, data from random tosses of a point-quadrat would estimate the variance in two dimensions better than would point intersections along a line transect.

Macroinvertebrates, such as urchins, holothurians, and large gastropods, are discreet units that are spread out over such large areas that they should be counted in replicated large quadrats of at least 10 m^2 each. Quadrats of 10 m^2 each are unwieldy. It is difficult to keep track of how much area has been covered within each quadrat when making a search. For both of these reasons, we have found it more practical to lay out a transect line, then swim along one side of it with a metre-stick, counting the macroinvertebrates that pass under the metre-stick in 10 m intervals. We can return along the other side of the transect line, taking counts in replicate 10 m^2 quadrats.

DIRECTION OF TRANSECTS

Transect lines are laid out in one of two rather opposite manners: across zones or within zones. Transect lines running across zones are an attractive method which perhaps provides more clearcut information for descriptive purposes. The resulting data, however, are difficult to analyse statistically. If one intends to make quantitative statements about the results of a survey across zones of a coral reef system, it would be best to take replicate transects and replicate counts within transects as stratified random samples within zones or depth contours. This allows discreet estimates of variance between zones with comparable replicate transects of equal length.

PILOT STUDIES FOR EFFICIENT PROGRAMME DESIGN

In almost all cases, a sampling programme involves comparisons between treatments, sites, times, zones, etc., with replicate subsamples within these categories. The efficiency of an experiment or a sampling programme can usually be improved by cost-benefit analysis. The relative cost of portions of a sampling programme can be evaluated in terms of both time and money by assigning a dollar value to the time and estimating the cost of supplies for each portion. Although it is almost never done, undertaking pilot studies to obtain estimations of the relative magnitudes of variation at different levels of sampling is particularly helpful in designing more economical and more accurate sampling programmes for the particular subject. The reliability of statistics in estimating parameters can often be improved at the same time as the total cost of the project is reduced by carefully assigning the relative number of replicates at different levels of the sampling programme. The most efficient number of replicates at the lowest level of subgroups (n) is:

$$n = \sqrt{\frac{(S^2 \text{ at lowest level}) \times (\text{Cost of next higher level b})}{(S^2 \text{ at next higher level b}) \times (\text{Cost at lowest level})}}$$

To calculate the number of replicates at the next higher level (n_b), we take

$$n_b = \sqrt{\frac{(S^2 \text{ at level b}) \times (\text{Cost of still higher level a})}{(S^2 \text{ at still higher level a}) \times (\text{Cost of level b})}}.$$

We could continue this process through as many levels as necessary, but, of course, it quickly becomes impractical to add additional levels in an experimental or sampling programme. This is because the total number of lower level replicates increases multiplicatively as you add more levels of replication.

The deciding factors for the total number of replicates at the upper level in a programme are controlled by the total resources available in time and money and the final degree to which you need to partition and reduce your variance between treatments in order to decide the question at hand to your satisfaction. The procedures for simultaneously reducing the cost of the project and the error and subsample variance are thoroughly presented in Snedecor and Cochran (1967) and in Sokal and Rohlf (1981). Considering the economic advantages and increased accuracy of results, it is strongly urged that small pilot studies be undertaken in advance of the main programme, whenever possible.

RULES-OF-THUMB ON NUMBER OF DATA

In making decisions about whether to accept or reject null hypotheses and to determine the degree of confidence we have in our statistics as estimates of the population parameters, we consult statistical tables as the objective judge. It would be ideal to have an infinite sample size, the bottom line in the tables, but we cannot. However, in parametric statistics such as the t-test, the probability distribution of statistics with 30 degress of freedom approaches a normal distribution (with infinite degress of freedom). If less than 20 data are obtained, the tests gain power rapidly with additional data. But if over 30 data have been obtained, it takes increasingly great additional amounts of data to make a worthwhile increase in power of the test. Therefore, when data are appropriate for parametric statistics, such as length or weight measurements to characterise the size distributions of cohorts or populations, a rule-of-thumb is to take at least 31 measurements. It is always preferable to take as many data as possible, but if time is limited, try for at least 31. If the difference between populations is too small to be determined with 31 data from each population, then the factors involved are probably on a finer level of influence than we can expect to deal with at this time.

For nonparametric statistics, the Mann-Whitney U-test is about 90% as efficient as the t-test or a one-way anova for two samples, yet it requires almost no assumptions concerning the theoretical distributions of the data. Comparisons of such difficult-to-measure characteristics of organisms as roughness of sculpturing of shells, darkness of color, estimated aboundances, etc., that are inappropriate for parametric statistics, can be made by the Mann-Whitney U-test. The minimum sample size for each of two samples in which a two-tailed null hypothesis can be rejected by a Mann-Whitney U-test is 4. A complete correlation for a one-tailed hypothesis would also be significant with 4 data in a nonparametric Spearman rank correlation coefficient. Therefore, I always attempt to run all experiments or samples with four replicates.

For binomial-type data (male or female, success or failure, left or right, black or white, greater or lesser, etc.), a two-tailed test for a null hypothesis or equal probability of either outcome requires at least 6 trials $\{2(1/2)^6 = .03$, but $2(1/2)^5 = .06\}$. Similarly, the very powerful two-tailed Wilcoxon matched-pairs signed-ranks test requires at least 6 data.

REPORTING SAMPLE SIZES

When summary statistics are presented in papers or reports, they are occasionally given as mean ± standard deviation without including the sample size. Given the sample size, along with the mean and standard deviation, we can calculate the sum of the data, the sum of squared data, and the sum of squared deviates. This will allow us to compare results in the literature with additional results from different areas or from the same area at a future date. Descriptive statistics are of little value unless we know the number of data upon which they are based.

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3.2 CORAL REEF SURVEY METHODS IN THE ANDAMAN SEA

by

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INTRODUCTION

Because of their remoteness, reefs in the Andaman Sea were not generally known to the scientific community. Very few references in literature can be found regarding the coral reefs of this region. Scheer (1971) studied corals from the Nicobar Island during the Xarifa expedition.

Intensive studies on coral taxonomy at the Phuket Marine Biological Centre started in 1974. At present, we have identified over 200 species of corals in the Andaman Sea within Thai waters (Ditlev, 1976 and 1980). Among the reefs in this area, those in the vicinity of the Phuket Marine Biological Centre are the most studied. Ditlev (1978) described the intertidal zonation on reef flats, with emphasis on vertical zonation, in relation to tolerance to emergence. Brown and Holley (1982) have shown that, even in the vicinity of the southeastern point of the island, the locality of reefs results in different reef types, depending upon the prevailing monsoon. The reefs are dominated by coral assemblages characteristic of either exposed or sheltered conditions.

SURVEY METHOD

The reef survey reported in this paper started in 1980 as part of the project in an inventory of living resources along the west coast of Phuket Island. Since then, the same method has also been used on reefs elsewhere in the Andaman Sea. The location and extent of the reefs along the western coast of Phuket were identified from aerial photographs (1:15,000) obtained from the Army Map Department. Based on that information, field surveys were conducted.

In addition to general observations, an attempt was made to assess quantitatively reef conditions. The method used was a combination of line transects and quadrats. A location on a reef was selected, then a marked line was laid from the shore to the end of the reef in deep water. The reef profile and zonation of corals were then recorded. Along the line, transects were made parallel to the shore at 20 m intervals (unless otherwise specified, as was the case in some areas). On this transect line, a series of photographs was taken over a total area of $15m^2$ by using a $1m^2$ quadrat which was divided into 16 squares of $25 \times 25m^2$ each. An area of $15m^2$ was chosen by constructing a species area curve of the reef edge in front of the Phuket Marine Biological Centre.

The photographs were developed and duplicate prints produced. A set was kept as the record for each transect line. The other was used for identification and estimation of coral coverage of different species. One obstacle arising at this point is the difficulty or outright inability of identifying certain coral types from photographs. The two-dimensional representation resulting from photography is an additional limitation. The area of most encrusting species with small polyps is almost impossible to identify from photographs. Those corals of very similar form, such as branching Acropora, are also difficult to identify with certainty. This problem can be solved by obtaining good field records of questionable species. However, our survey team is admittedly quite handicapped in the field of coral identification. In some areas, therefore, we could identify specimens only to genus level. Others are simply included in a group termed "encrusting species". After identification, the different species in the photographs were cut out and an estimate made of their coverage expressed as a percentage of total quadrat area.

Values were accumulated for each transect line. At this point, data processing of species abundance information has not been completed in detail. For the report concerning status of reefs along the west coast, only data concerning dead, live, soft coral, and substratum coverage of each transect line are presented, as shown in Figure 1 (a reef on the north arm of Patong Bay) and Figure 2 (a reef at Bang Tao Bay).

From these two figures, comparisons can be made between the conditions of the reefs. A large part of Bang Tao corals were killed by sedimentation. The damage was more severe in the deeper part of the reef.

This technique is now used for observing any changes in the Bang Tao reef before and after the Southwest Monsoon Season. This is used to determine the prospect of reef recovery if sediments are removed during the Southwest Monsoon.

SUMMARY

The advantages and disadvantages of this method seem to be as follows:

(1) Advantages

Permanent record of the transect, which can always be scrutinised for more information or for future comparison.

Greater accuracy in estimating coverage.

More information obtained per unit of diving time, compared with other methods.

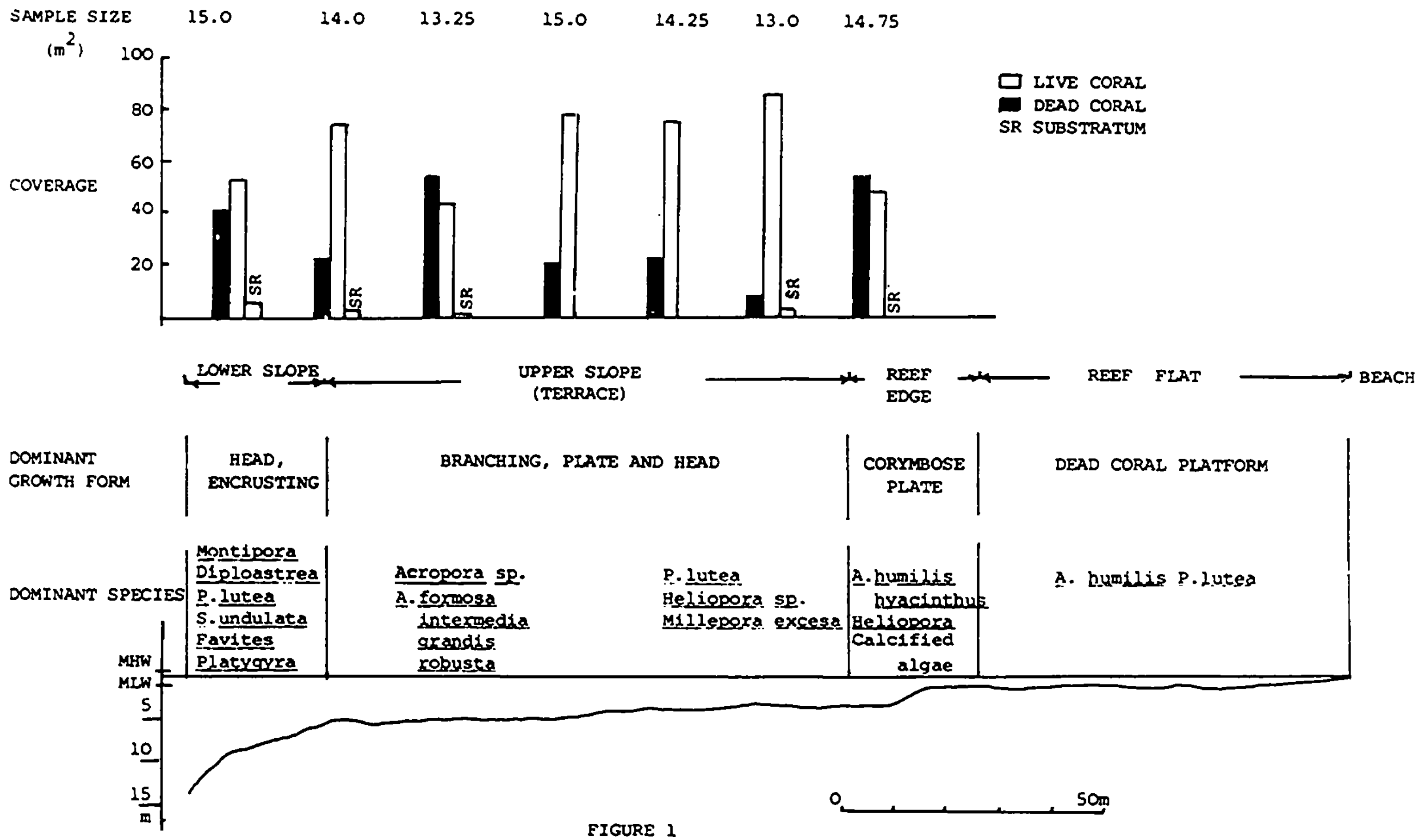

FIGURE 1

Results from North Patong reef showing reef profile, zonation, dominant growth form and dominant species. Quantitative estimate of % coverage is also presented with indicated sample size.

FIGURE 2

Results from North Bang Tao reef showing reef profile, zonation, dominant growth form and dominant species. Quantitative estimate of % coverage is also presented with indicated sample size.

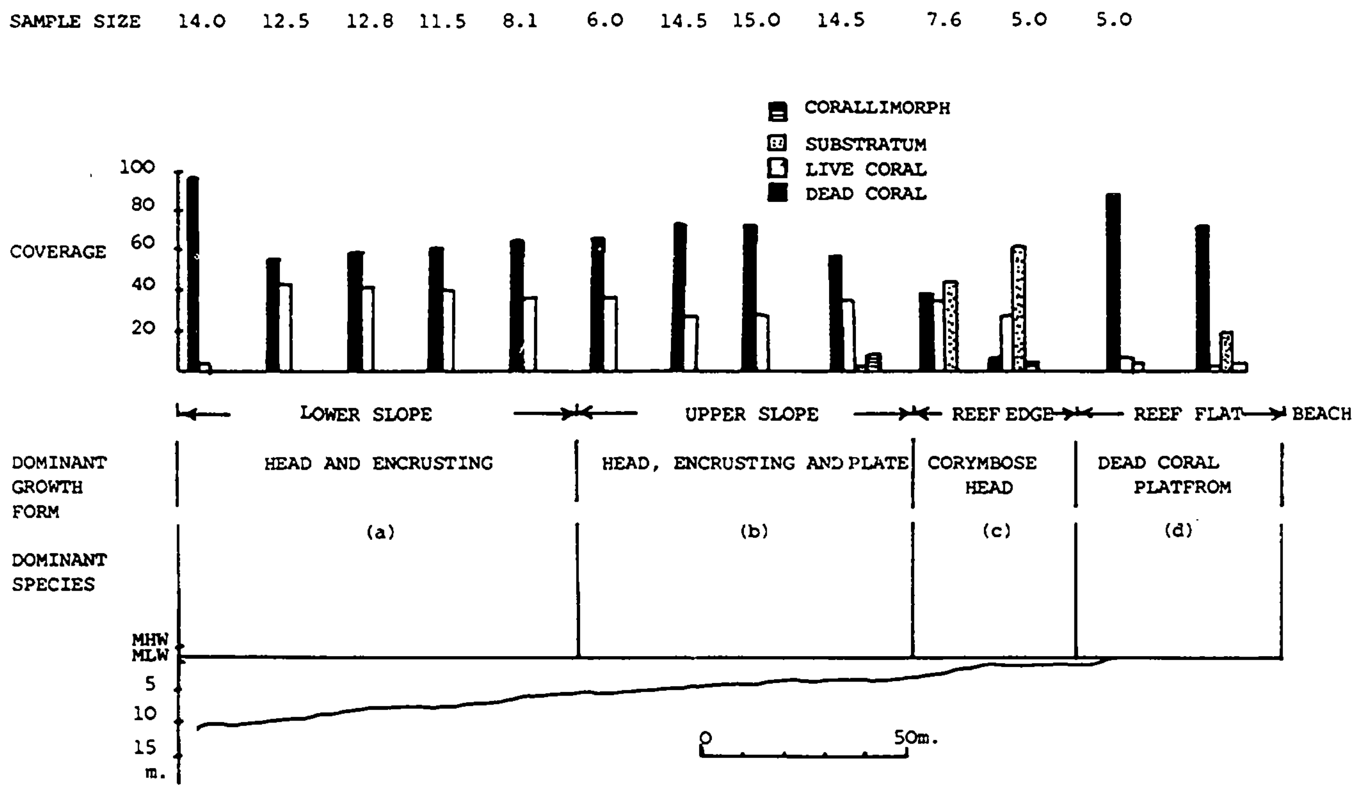

Figure 2 (cont'd.)

(a) *Diploastrea*
Turbinaria sp.
Gonipora sp.
Favites sp.
Symphyllia sp.

(b) *Acropora tenuis*
Acropora clathata
Acropora hyacinthus
Corallimorph
P. Lutea
Diploastrea

(c) *A. humilis*
P. lutea
Corallimorph
Calcified algae

(d) *P. lutea*
Montipora ramosa
Acropora aspera
Pocillopora damicornis verrucosa

Considering the lack of knowledge in coral taxonomy, photography can be useful in allowing time for identification back at the laboratory. (As shown, however, there may be limitations to our ability to identify each image.)

(2) Disadvantages

Data processing is time-consuming and rather expensive, especially for a large-scale survey.

Information obtained from photography is limited in turbid water. In many of our transect lines in the bay of the southern coast, only dead and live coverage could be distinguished.

Inconvenience of working in shallow water (less than five feet deep).

The limited view of resulting 2-dimensional projections can result in inaccurate estimates of areas covered by certain species.

REEF MANAGEMENT

By Thai tradition, reefs are public property. Any person can have access to any reef and local communities obtain food and income from reefs. No restriction or regulation exists regarding fishing rights or the collection of particular species. Certain fishing methods are, however, prohibited. Dynamite fishing is an example of an illegal act. Punishment for such infractions can be severe. However, due to problems of enforcement, damage from dynamiting can be seen in many reefs in the Andaman Sea, especially those that are far away from people. Trawling in the vicinity of reefs is prohibited as part of the law restricting trawling activity to a zone three kilometres from the coastline.

However, as populations increase, reef resources are in greater demand. Reefs are not only exploited for food, but for tourism as well. A world-wide interest in shell collecting, along with home aquarium hobbies, has resulted in the increased harvesting of non-edible reef species. There are laws in Thailand prohibiting the exportation of corals for commercial purposes and some action is now being considered regarding the export of colourful reef fishes and animals. The government has taken one step further in the prohibition of coral collection. Due to a technical interpretation, however, action can only be taken if a person is caught on the spot. Some change of this law is needed.

Aside from the above restrictions, there is no regulation of the fishing or harvesting of other reef flora and fauna. At present, the best hope of protecting or conserving the reefs would be to declare them as marine parks or protected areas. In the Andaman Sea, such action has been taken in certain selected reefs. The first marine park in Thailand, created in 1974, is Tarutao National Park in the south, next to the Malaysian border. Other parks have also been established. At present, there are two marine parks in the Andaman Sea in addition to Tarutao National Park; these are Nai Yang National Park on Phuket Island and the Similan Islands, a group of offshore islands recently declared as a National Park. Other areas, including Surin Islands, which can be said to have the best developed coral reefs in Thai waters, are also under consideration to be declared marine parks by the government. The agency responsible for marine park management is the Division of National Parks, Department of Forestry.

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POINTS RAISED DURING PRESENTATION

Dr. Hansa Chansang stated that considerable enforcement problems exist in implementing laws relating to coral reef conservation, particularly those laws relating to the prohibition of certain fishing methods, such as dynamiting. Although the possession of dynamite in a boat is an offence in Thailand, enforcement is not vigorous.

It was pointed out that Malaysia has no laws regarding coral exploitation and that reefs are mined for building material. In East Malaysia, the only law that can be applied to govern exploitation associated with coral reefs is in the Fisheries Act.

In Indonesia, there are no laws generally regulating coral exploitation; however, in certain places, such as Jakarta, local prohibitions exist.

In the Philippines, live coral is protected but coralline rock is not. Coral heads are used as traps for reef fish required for the aquarium trade. The fish are chased into shelter and then exposed to sodium cyanide or caught within a net placed over the coral complex, which is subsequently broken up. Fish caught with the use of cyanide usually die within 1-2 months, due to chemical stress.

Dr. Gomez raised the point of private coral collections and posed the question: "Should they be tolerated?"

3.3 A REVIEW OF CORAL REEF SURVEY AND MANAGEMENT METHODS IN SINGAPORE

by

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INTRODUCTION

Coral reefs within the territorial waters of Singapore are all of the fringing type. Land reclamation and industrial development have affected almost all the reefs on the mainland shores and many on the fifty-four offshore islands. Figure 1 shows the location of these reefs, including those affected either directly by land reclamation or indirectly by industry.

RESEARCH EFFORTS

Studies of coral reefs as well as of specific groups of coral reef species have been and are still being carried out, mainly by the Zoology and Botany Departments of the National University of Singapore (known as the University of Singapore prior to 1980). The Port of Singapore Authority, which is responsible for the management of the country's territorial waters, including land reclamation projects, does not conduct any research work on the coral reefs.

Research investigations conducted up to the present can be divided into two categories. The first includes studies on a selected species or a group of related species of reef organisms, such as feeding mechanisms in corals (Williams, 1976; Yeo,1976), development and ecology in Tubastrea sp. (Moll, 1977), taxonomy of the nudibranches (Chou, 1968), biology of the fungiidae (Tan, 1970), distribution and growth of the fungiidae (Goh, 1963), biology and ecology of coral reef fishes (Tay, 1978) and a survey of the hard corals at Pulau Salu (Teo, 1981).

The second includes studies on ecological distribution and zonation patterns of, and environmental effects on, the reef as an ecosystem, such as the distribution of organisms on Tanjong Teritip (Poon, 1962) and the effects of land reclamation on reef life (Chan, 1979).

Surveys are presently being conducted to study the ecology of the entire reef community at Pulau Salu (Fig. 1).

SURVEY METHODS

Most of the investigations dealing with one or a few species involved random collection and subsequent examination in the laboratory. The investigations of Tay (1978), Chan (1970), and Teo (1981), which were completely field oriented, involved the use of various ecological survey methods.

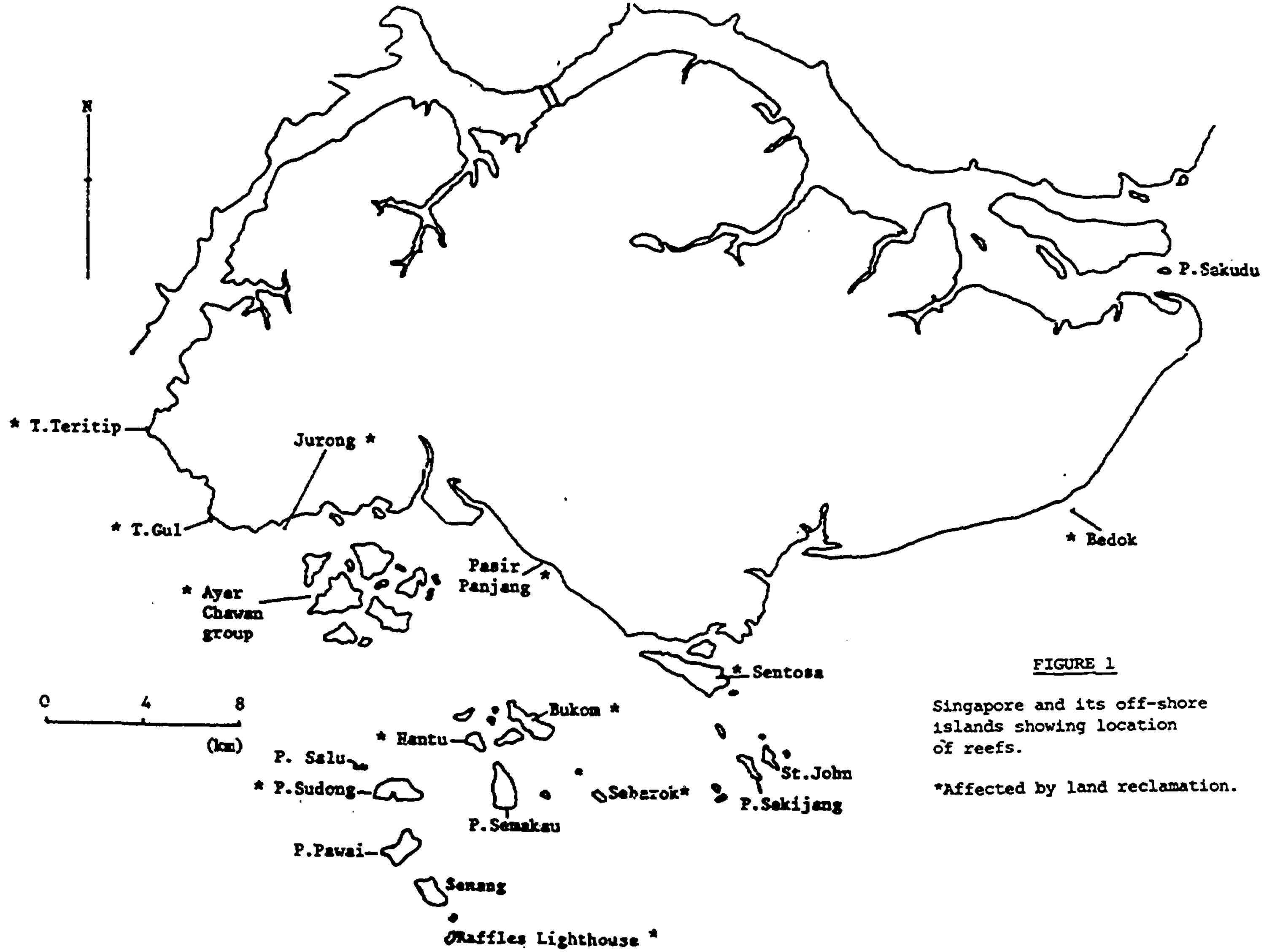

FIGURE 1

Singapore and its off-shore islands showing location of reefs.

*Affected by land reclamation.

The study by Teo (1981) and other on-going investigations indicate the importance of scuba diving as a tool in coral reef research.

Tay (1978) studied the distribution of coral reef fishes at Pulau Salu by using the common Antillean fish trap as the main sampling gear, laid in series along several transects running from the shore to the reef slope. Sampling was conducted fortnightly between 10:00 and 16:00 (between rising and ebbing tides). Other trapping techniques employed were hook and line and spear-fishing. Fish in the shallow rock pools at low tides were caught by using hand nets or poison. Direct visual-count observations taken while snorkeling along 30 to 50 metre transects were used to obtain quantitative information about the distribution of the fish. The data collected from these various methods were analysed to show the specific distribution and occurrence of the fishes in various zones, as well as the quantitative distribution and relative abundance for each species in each zone. Species diversity data were obtained by the transect and species/time random count methods. Quantitative records of the number of individuals per fish species were made along 30 metre transverse transects and 50 metre lateral transects. All fishes observed within 1 metre of either side of the transect line and 2 metres above it were counted following the method of Jones and Chase (1975). The measure of species diversity within each zone was obtained by the random count method (Thomson and Schmidt, 1977). Using snorkeling equipment and an underwater watch, random counts of fishes present in each zone within 30 minutes during the rising tide were made.

Studies by Chan (1979) and Teo(1981) made use of similar methods to plot the reef profiles along transects. These were obtained by tautly stretching a string, marked at one metre intervals, between 2 poles at either end of the transect. A spirit level was used to ensure that the string was in a horizontal position. The height of the string at each metre interval from the sea bed was measured using a plumb line. The time at which the measurements were taken was noted so that the chart datum could be determined from calculations using the predicted tidal levels. Observations by Chan (1979) were restricted to a maximum depth of 3 metres as snorkeling gear was used. He recorded the organisms within 1 metre of either side of the transect line for the reef flat and edge, and within 2 metres of either side for the reef slope.

Teo (1981) made use of scuba gear and was able to extend the transect studies down the entire reef slope. The contiguous quadrat method was chosen for his study, as it was an efficient means of acquiring data in the field when time is the limiting factor (Maragos, 1974). Quadrat sampling, due to efficiency limitations, can only cover a smaller dimension of the reef when compared to line transect techniques. However, the quadrat method allows for grouping of data, so that they can be analysed at a variety of sampling dimensions. Recording at equally-spaced points using quadrats along a transect gives a series of contiguous frequency records for each species. A one metre quadrat, sub-divided into a grid of 100 squares of equal size (each square being 10 cm^2 in area), was used in sampling along one side of the transect line.

The areas covered by the different species of corals were calculated in the following way:

(a) for corals which have a flat, horizontal growth form (e.g. Montipora), the area is estimated directly from the quadrat;

(b) for massive forms with encrusting corallities on the vertical surfaces of boulders (e.g. Diploastrea), the height of the boulders was recorded as well so that the surface area could be estimated.

Vertical (or transerve) transects were important in surveying the distribution pattern of organisms with increasing depth, while horizontal (or lateral) transects were important in surveying the distribution patterns at a fixed depth.

A survey of the ecological literature concerned with community structures reveals an interesting trend of decreasing the sample size required for an analysis of a community. There has been some attempt to replace quadrat sampling with plotless sampling, which essentially reduces quadrat measurements into linear recordings of distances among random points. The sampling unit can be reduced to a point, thus avoiding the problems of sample size or sample shape. Plotless sampling was found to be efficient and time-saving by Loya (1978).

In a present study, the "point-centered" plotless method (Loya, 1978) is employed to study the distribution of relatively sessile organisms, such as molluscs. A line transect is laid and marked at regular intervals, which form the sampling points. Each sampling point is considered a centre of four quadrants, i.e. the area around the point is divided into four 90-degree quarters. The distance from the sampling point to the nearest individual in each quadrant is measured. The mean of the four distances measured from each sampling point has been shown empirically (Cottam et al., 1953) and theoretically (Morisita, 1954) to be equal to the square root of the mean area per individual. The total density is then obtained by dividing the mean area per individual into the unit area on the basis of which density is to be expressed.

Measurements of various hydrological factors were taken in connection with these surveys. These included temperature and salinity, both measured by a Beckman Electrodeless Salinometer, pH measured by a Lovibond Comparator, and transparency measured by a Secchi disc.

The ecological indices used in these studies are shown in Appendix 1.

MANAGEMENT

There is no authority charged with the sole responsibility of managing coral reefs in Singapore. The reef flats of some of the offshore islands have been reclaimed for various uses, e.g. those of Pulau Hantu, P. Kusu, and P. Sudong were reclaimed for recreational purposes, those of the Ayer Chawan group have been reclaimed for a large petro-chemical complex. The development and management of the coastal waters is undertaken by the Port of Singapore Authority. The quality of the coastal waters is constantly monitored and strict laws govern the discharge of oil and effluents into the marine environment. The collection of reef organisms is not prohibited. Subsistence fishing occurs around the reefs, but this is mainly by small-time or sports fishermen using hook and line and Antillean traps. Collection of reef organisms for ornamental purposes was done on a wider scale in the past, when some of the southern islands were inhabited. However, with the resettlement of these people on the mainland, this problem has been reduced considerably. There is also no known instance of corals being collected on a commercial scale for use as construction materials or whitewash.

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POINTS RAISED DURING PRESENTATION

No specific studies are being undertaken in Singapore on the problems caused by the close proximity of oil refineries to coral reefs. Singapore does not experience problems caused by the dynamiting of coral reefs, but does act as a trading port for coral reef fish that have been obtained in Indonesian and Philippine waters. A participant asked whether the study of historical data would allow for estimation of the loss in fishery yield to be correlated with the loss of reef area due to industrialisation. Dr. Chou Loke Ming replied that no historical quantitative data were available on fish yields, but that the loss of reef could be estimated to exceed 50% of those present before industrial development took place. Chances for recovery of lost reef are now nonexistent, due to increased industrialisation. Recalling Singapore's role as one of the major transfer ports for marine products in this region, Dr. Gomez asked the countries to consider ways for assisting one another to regulate the coral trade. The main markets for Philippine coral are the U.S.A. and Europe. At present, two national laws prohibit the exportation of coral from the Philippines. The Lacey law prohibits import into the U.S.A. of any coral that has been illegally exported from its country of origin. However, by stocking illegally exported corals in a convenient port of transfer, smugglers often manage to bypass the law and still import their corals into the U.S.A. Concerted action to achieve harmonised and mutually supportive legislation in all ASEAN countries is, therefore, needed. Dr. Chou Loke Ming stated that the major portion of the trade in marine products through Singapore consisted of ornamental fish. Trade in corals through Singapore was negligible.

APPENDIX 1. ECOLOGICAL INDICES USED IN SURVEY STUDIES OF SINGAPORE'S CORAL REEFS

(a) Abundance

The percentage cover of the species with respect to the total area of the transect.

(b) Frequency

The number of quadrats in which the species is present.

(c) Size Index

This was calculated for individual species and quadrats.

(i) S.I. for individual species
(For comparison of colony size between species)

$$S.I. = \frac{\text{Total cover of the species (for the transect)}}{\text{Number of its colonies}}$$

(ii) S.I. for individual quadrats
(For comparison of colony size between quadrats)

$$S.I. = \frac{\text{Percentage area cover in one quadrat}}{\text{Number of colonies found in it}}$$

The size index can then be expressed as a graph.

(d) Species Richness

This is the number of species per unit area. This index is computed for quadrat sizes of 1 m^2, 5 m^2 and 10 m^2. Species richness is a measure of diversity which takes into account the number of species without considering the relative proportion of each species. This parameter is included in the Shannon-Weaver Index.

(e) Shannon-Weaver Index (Shannon & Weaver, 1949)

This index is computed using

$$Hc^1 = - \sum_{i=1}^{S} P_i \, Ln \, P_i$$

where Hc^1 is the diversity index
S is the number of species
P_i is the proportion (percent cover) of the i^{th} species in a sample.

This index has the attribute of being influenced by both the number of species present and how evenly or unevenly the individuals are distributed among the constituent species. This information function is sample size independent, and thus samples of different sizes can be directly compared. This index is computed for contiguous transects of five and ten.

(f) Evenness Index (Pielou, 1966)

This index serves to measure the dominance of one or a few species in a quadrat.

$$E.I. = \frac{\text{Shannon-Weaver Diversity Index } Hc^{1}}{\text{Maximum Diversity Index } H^{1}max}$$

The maximum value of the Shannon-Weaver Diversity Index is calculated using $H^{1}max = \text{In } S$, where S is the number of species. The diversity index is maximal when the proportion of all the species in a sample is equal. When one or a few species is much more abundant than the rest, the Evenness is low.

(g) Species Diversity

Species diversity, or species heterogeneity, is a characteristic unique to the community level of biological organisation. It measures the community structure.

(i) Simpson's index (D)
This index measures the probability that if two individuals are taken at random from a community, the two will belong to the same species.

$$\lambda = \frac{n_i (n_i - 1)}{N(N - 1)}$$

n_1 = number of individuals of speciés i.

N = total number of individuals in sample

λ = measure of dominance

A large λ implies an aggregation of individuals in only a few species and a small λ denotes a more uniform distribution of individuals among species. Thus a collection of species with high diversity will have low dominance.

$$\text{Diversity} = D = 1 - \lambda$$

$$= 1 - \frac{n_i (n_1 - 1)}{N (N-1)}$$

The maximum possible diversity can be calculated thus:

$$D \max = \left(\frac{S-1}{S}\right)\left(\frac{N}{N-1}\right)$$

This occurs when N individuals are distributed evenly among the S species.
The corresponding evennes (measure nearness of the diversity index to the maximum diversity index) index is:

$$Es = D/Dmax$$

(ii) Shannon-Weaver diversity index

This index measures how evenly or unevenly the individuals are distributed among the constituent species:

$$Hc^1 = - \sum_{i=1}^{S} P_i \log P_i$$

where $P_i = \frac{n_i}{N}$ = proportion of total number of individuals occurring in species 1.
log = base 10, base e or base 2
S = number of species

Pielou's Evenness Index can also be computed where

$$E.I. = \frac{Hc^1}{H^1max}$$

where H^1max = log S.

This also measures the nearness of the diversity index to the maximum diversity index as in the Simpson's Index.

(h) Community Similarity

There are two indices of community similarity. This enables the comparison of species composition of 2 communities. Both coefficients of community (CC) are very similar.

(i) Jaccard's coefficient (1908)

$$CC = \frac{a}{(b+c) - a}$$

where b+c = number of species in communities 1 and 2 respectively.
a = number of species in both communities.

(ii) Sorenson's index (1948)

$$CC = \frac{2a}{(b+c)}$$

where b+c = number of species in communities 1 and 2 respectively.
a = number of species in both communities.

However, these coefficients do not take into account the relative abundance of the various species.

3.4 CORAL REEF ASSESSMENT AND MANAGEMENT METHODOLOGIES CURRENTLY USED IN MALAYSIA

by

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INTRODUCTION

Malaysia consists of two geographically separated areas: Peninsular Malaysia, which lies on mainland South East Asia and East Malaysia, comprising Sabah and Sarawak on the northwest coast of Borneo. Some six hundred kilometres separate Peninsular Malaysia from East Malaysia.

Although the mainland coast of Peninsular Malaysia is extensive (approximately 1600 kilometres long), very little of it is suitable for the establishment of coral communities (De Silva, 1982a). Therefore, the majority of coral reefs, which are of the shallow water fringing type, are located around the offshore islands of the east and west coasts. De Silva (1982a) has summarised available information on the coral reefs of Peninsular Malaysia up to the year 1981. Five other reports on corals and coral reefs of Peninsular Malaysia have appeared since: they are Rashid (1980) on the Pulau Paya reef system, Betterton (1981) on the hard corals of Peninsular Malaysia, De Silva and Ridzwan (1982) on the coral reefs of Pulau Paya/Segantang group of islands, De Silva (1982b) on the human and development pressures on the coral reef ecosystem in Malaysia and De Silva and Charles (1982) on the problem of *Acanthaster planci* at Pulau Kapas, an island off the east coast of Peninsular Malaysia.

Most of the information available about East Malaysia comes from the state of Sabah. Of this information, the coral reef survey reports by Lulofs (1973), Lulofs, Langham and Mathias (1974), Mathias and Langham (1975) and Wood (1981) are among the best known. Other information on corals and coral reefs of Sabah is given by Wood (1977), Morris (1977) and Phillips (1979).

The majority of the more recent coral reef surveys in Malaysia have been undertaken to determine the suitability of reef areas to be made into marine parks (Green, 1978; Wood, 1981; De Silva and Ridzwan, 1982) or to determine their vulnerability to oil spills (Mathias and Langham, 1975; De Silva, Betterton and Smith, 1980). On the other hand, Rashid (1980) was interested in the distribution of corals and the importance of reefs to the fisheries industry. Goh and Sasekumar (1980) estimated the live coral cover and described the community structure of a fringing coral reef in Cape Rachado on the west coast of Peninsular Malaysia. Liew and Hoare (1979) made a study of coral distribution in Cape Rachado in relation to sedimentation and turbidity.

REEF ASSESSMENT METHODS

The reef assessment methods used in Malaysia fall into the following three broad categories:

(1) Line transect methods
(2) Belt transect methods
(3) General surveys

Line transect methods are most commonly employed for the study of coral community structure in terms of species composition and zonation, as well as percentage of dead and live coral cover. The method used closely follows that of Loya and Slobodkin (1971) and Loya (1972). A nylon or similar rope marked at 1 m intervals and placed on the reef is generally used to mark the transect line. Rehman (1980) used a nylon line weighted down with lead weights at regular intervals of 3 m to prevent the line from floating. Any coral species, dead or alive, which underlay the line is recorded. Its projected length, which intercepts the line, is measured to the nearest centimetre. In the case of coral colonies growing one above the other, the projected length of the largest coral colony underlying the transect rope is recorded for live/dead coverage analysis. The species of all overlapping colonies, which underlay the line, is recorded for the coral species diversity analysis, as recommended by Loya (1978). Rehman (1980) successfully used a photographic line transect method which was similar to that used by Ott (1975), as described by Loya (1978), where the entire transect marked at 1 m intervals was 'blanket-photographed'.

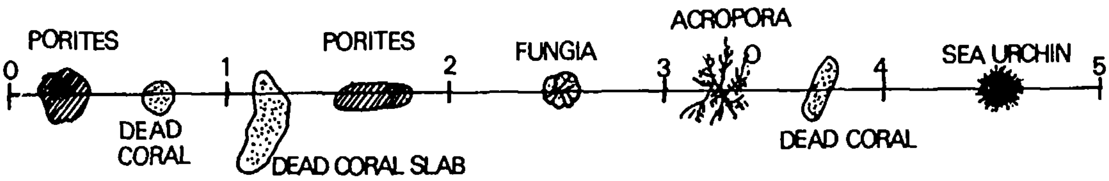
Newman (1982) is, at present, using a modified line transect method where secondary line transects of a pre-determined length (15 m) are run off at intervals of 2-5 m, perpendicular to 'a primary transect laid from the most landward point of coral growth across the reef to the most seaward edge'. Using this method should lead to a better idea of the community structure, in terms of vertical, as well as lateral, distribution of coral species.

A modified line transect method is currently used by the author and his associates for the quick assessment of coral reefs, especially during surveys where time, money and personnel are major constraints. This method provides useful information on the quality of the reefs, in terms of live and dead coral cover, presence of soft corals and dominant coral species. It also provides information on the distribution of corals, as well as coral reef relief and profile.

In this method, a nylon rope marked at intervals of 1 metre is placed over the reef. It is laid perpendicular to the shore, starting from the most leeward live coral colony and extending to the seaward edge of the reef. The approximate position and proportionate length of live corals, dead corals, soft corals, other macro-organisms and sand or rock which fall directly under the transect line are marked on lines drawn on an underwater slate to represent each metre along the transect line. Let us consider a transect line passing over some live corals, dead corals, and a soft coral on a sandy patch of the reef under investigation, as shown in Figure 1.

FIGURE 1

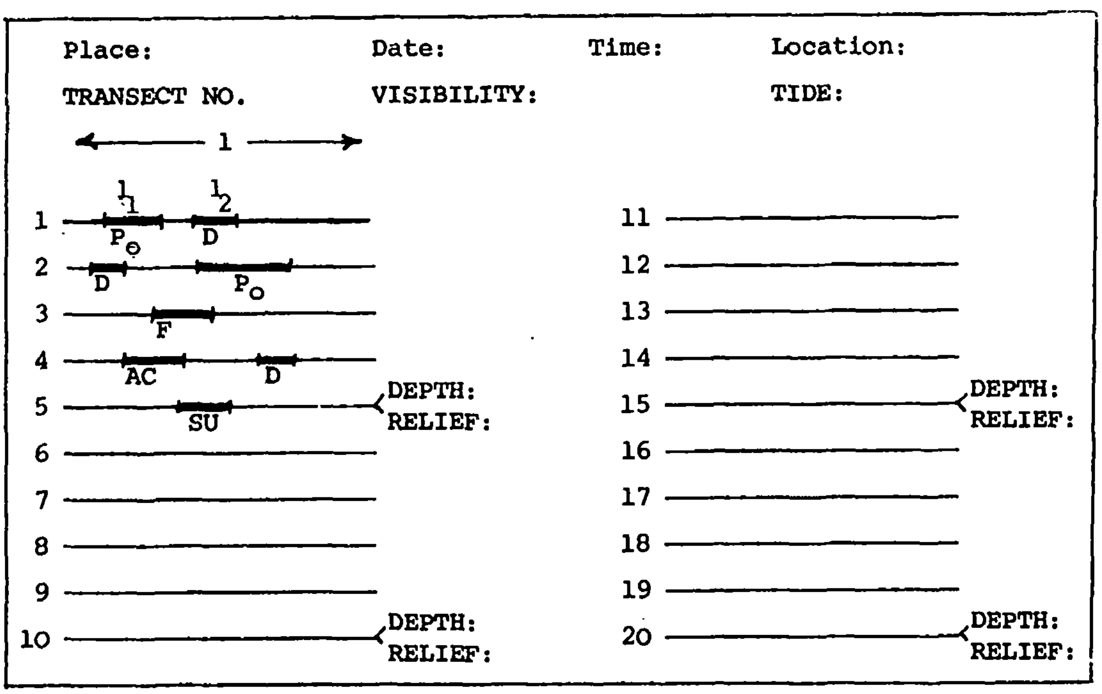
Diagrammatic sketch of a transect line marked at intervals of 1 metre passing over a coral reef with live, dead, and soft corals.



Then the recordings on the underwater slate will be as in Figure 2.

FIGURE 2

The scoring based on Figure 1 on lines drawn on an underwater slate to represent every metre along the length of the transect line laid over a reef. (PO= *Porites*, D= dead coral, F= *Fungia*, AC= *Acropora*, SU= Sea Urchin)



l_1 l_2 = length 1 and length 2 of intersected coral colonies

The percentage cover by live corals, dead corals, soft corals, sand and rocks can be computed easily from the information recorded on the underwater slate on a metre by metre basis. For example, the percentage cover by live coral in metre 1 in Figure 2 will be

$$\frac{l_1}{l} \times 100$$

while the percentage cover by dead coral will be

$$\frac{l_2}{l} \times 100$$

Although recordings are made every metre, usually the percentage cover by live corals, dead corals, and soft corals is computed on a 10 metre basis. The percentage cover for different zones of a reef could also be computed using this method.

Although corals covered by others are not taken into account for the computation of percentage cover, they are recorded for the purpose of generic diversity.

If a worker is familiar with the major coral genera of an area, he could complete work on a 100 m transect in approximately half an hour. If a worker is unfamiliar with the coral genera, each coral, whether it is the same genera or not, is given a separate number and a sample is collected for later identification. This will lead to a doubling or trebling of the time period. When studying an extensive reef, transects are taken at least every 75 m to 100 m, and where the reef is less than 100 m, usually 3 transects are taken.

Belt transect methods have been used by several workers (De Silva, Betterton and Smith, 1980; Goh and Sasekumar, 1980). However, this method proved to be time-consuming and was rejected by De Silva et al. (1980) when large reef areas were involved. De Silva, Betterton and Smith (1980) combined a belt transect with photography and came up with reasonable results when dead and live coral cover information was concerned. This method, however, had the obvious disadvantage of not being able to account for coral colonies growing under others.

General surveys are subjective and limited in use. However, they have been carried out in Malaysia to obtain basic information on dead and live coral cover, generic diversity, and the presence or absence of *Acanthaster planci*.

Two main types of general survey have been carried out by the author and his associates: one in which a time period is given for a specific task, such as collecting coral species or counting the number of *Acanthaster planci*, and the other in which time is unlimited. The limited-time technique is of some value. This is especially true when comparing two areas, for example, with respect to numbers of *Acanthaster*, etc. This technique has also been proven to be useful as a preliminary survey to obtain an idea of a reef area.

CORAL REEF MANAGEMENT

At present, the only coral reef areas in Malaysia that receive some protection are those included in three National Parks in Sabah, East Malaysia. Although these parks are not truly marine parks, the areas covered by sea far exceed the land areas (Table 1).

TABLE 1

National Parks in Malaysia which include sea areas with coral reefs. (Adapted from Davidson, 1982).

National Park	Date Gazetted	Total area in acres	Sea area in acres
Tunku Abdul Rahman	May 1974	12,185	8,345
Turtle Islands	1 October 1977	4,300	4,255
Pulau Tiga	28 June 1978	39,200	37,700

A proposal for the establishment of a marine park, the Semporna Marine Park, has been made by Wood (1980), under sponsorship by the World Wildlife Fund Malaysia. It is expected to be considered by the Sabah State Government in the near future.

Davidson (1982), referring to the marine component within the boundaries of National Parks in Sabah, East Malaysia, states that "In spite of the protection that

Sabah National Parks affords its parks, the activities of man have resulted in the severe devastation and destruction of some of Sabah's accessible coral reefs. The affected areas, as a result of such activities, are practically void of marine life." He attributes the problem of coral reef management even within the National Park boundaries to:

(1) lack of suitably qualified personnel;

(2) the public's ignorance of the concepts of conservation and the aims of the parks;

(3) the netting and dynamiting of fish within the park boundaries, due to inadequate policing of the parks's territories.

Two coral reef areas in Peninsular Malaysia, one in the east coast and the other in the west coast, have been identified by Green (1978) and De Silva and Ridzwan (1982), respectively, as being suitable for the establishment of marine parks. They have not, however, yet been declared marine parks.

De Silva (1982b) has reported that the illegal use of explosives to catch fish and land clearance practices without effective soil erosion control measures are among the major human and development pressures causing heavy damage to Malaysian coral reefs. He also stated that several other factors, such as coral mining and population explosions of Acanthaster planci, are responsible for the loss of reefs in specific areas. Tourist pressures and the anchoring of boats have also been cited as causes of coral reef damage (De Silva, 1982b and De Silva and Ridzwan, 1982).

DISCUSSION

Existing information about the coral reefs of Malaysia has been derived from less than 25% of the total coral reef areas. The majority of the survey techniques used have provided a reasonable amount of data on the quality of the coral reefs in terms of species diversity, dead and live coral cover, and, in some instances, the causes of coral reef damage.

Only a very few coral reef areas in Sabah, East Malaysia have been afforded protection by being included as National Parks. Furthermore, the management of these few coral reef areas poses problems, due to ineffective policing and lack of trained personnel.

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POINTS RAISED DURING PRESENTATION

When surveying bays, Dr. De Silva indicated that his usual strategy was to lay out three transect lines perpendicular to the shore line: one to each side and one down the centre of the bay. Headlands should be avoided since reefs do not tend to be representative in such areas.

In the case of timed surveys, Dr. De Silva felt that 30 minutes was an optimal period to use in searching out as many species of corals as possible in a particular location. Such a timed survey was also used for the collection of *Acanthaster*. In general, *Acanthaster* were removed in Malaysia, because it was felt that, since the coral reefs were relatively small, it was important to prevent the starfish from destroying the limited reef areas.

Dr. Alcala indicated that a moderate density of *Acanthaster* may favour diversity of corals and that growth by *Acropora* would reduce overall reef diversity if starfish were removed.

Dr. De Silva indicated that the removal of *Acanthaster* did not appear to have resulted in the reduction of coral diversity in the treated areas, provided the starfish were removed in time to prevent the destruction of the growing regions of the corals, especially *Acropora*.

Dr. Birkeland indicated that where *Acanthaster* outbreaks occurred in the Pacific around Guam, overall diversity of remaining corals was simplified. The survivors tend to be those species that *Acanthaster* does not like. Around atolls where outbreaks do not occur, a large diversity of corals tend to be found.

3.5 SURVEY OF PHILIPPINE CORAL REEFS USING TRANSECT AND QUADRAT TECHNIQUES

by

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INTRODUCTION

The Philippines consist of some 7,100 islands and islets located in the tropical Western Pacific. The majority of these islands are fringed by coral reefs, which, in recent years, have been subjected to more and more stresses resulting from man's activities.

Reputedly one of the most productive ecosystems (Odum, 1971), coral reefs have a direct relationship to fish production. Fish standing crops on reefs have been estimated from 490 kg/ha (Bardach, 1959) to 1950 kg/ha (Goldman and Talbot, 1976). Bardach also estimated secondary productivity at 2.2 x 10^5 kilocalories per hectare per year. This relationship between corals and fish has become apparent to some municipal fishermen in the Philippines, who complain that their fish catches over reefs that have been continually blasted have dwindled.

Because fisheries are a major source of protein for the nation, the Ministry of Natural Resources commissioned the Marine Sciences Centre of the University of the Philippines to undertake an assessment of the coral resources of the country late in 1976.

METHODS

Three survey teams of scuba divers were organised, each based on a different island. These teams used motorised outriggers ("pumpboats") to reach various reef areas from their land bases. Survey stations were chosen from topographic maps (1:50,000 scale) which indicate coral reef areas. These spots were generally spaced from two to six kilometres apart, depending on the distribution of the reefs.

At each station, a transect line, 300 m long, was laid down perpendicular to the shore, starting at a depth of five metres or at the reef front. Quadrats (Fig. 1) were laid down regularly at 20 m intervals. In this way, the vertical range of the reefs was sampled. For each quadrat, which was divided into 16 equal squares,

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*Note: This paper is an updated version of an article originally presented at Int. Symp. Mar. Biogeogr. Evol. S. Hem., Auckland, New Zealand, July 17-20, 1978, and was originally published in The Proceedings 2: 663-669, 1979.

the number of squares with live coral (both stony and soft) were recorded on slate boards, along with the number of squares with dead coral, sand and rock. Table 1 shows an outline of the Reef Survey Data Sheet that was completed for each of the surveyed reefs.

Living coral cover was arbitrarily categorised as *excellent* (75-100%), *good* (50-74.9%), *fair* (25-49.9%) and *poor* (0-24.9%). These categories included both stony and soft corals. The dominant types were also noted in each quadrat, as well as the associated organisms. Obvious causes of reef damage, such as siltation, dynamiting, destructive fishing methods, Acanthaster, etc. were recorded.

Although no concerted effort has been made to make representative collections of corals, interesting and unusual forms have been gathered incidentally for identification. In a few instances in dynamited areas, counts and measurements of hard corals were made in quadrats and samples were obtained for identification.

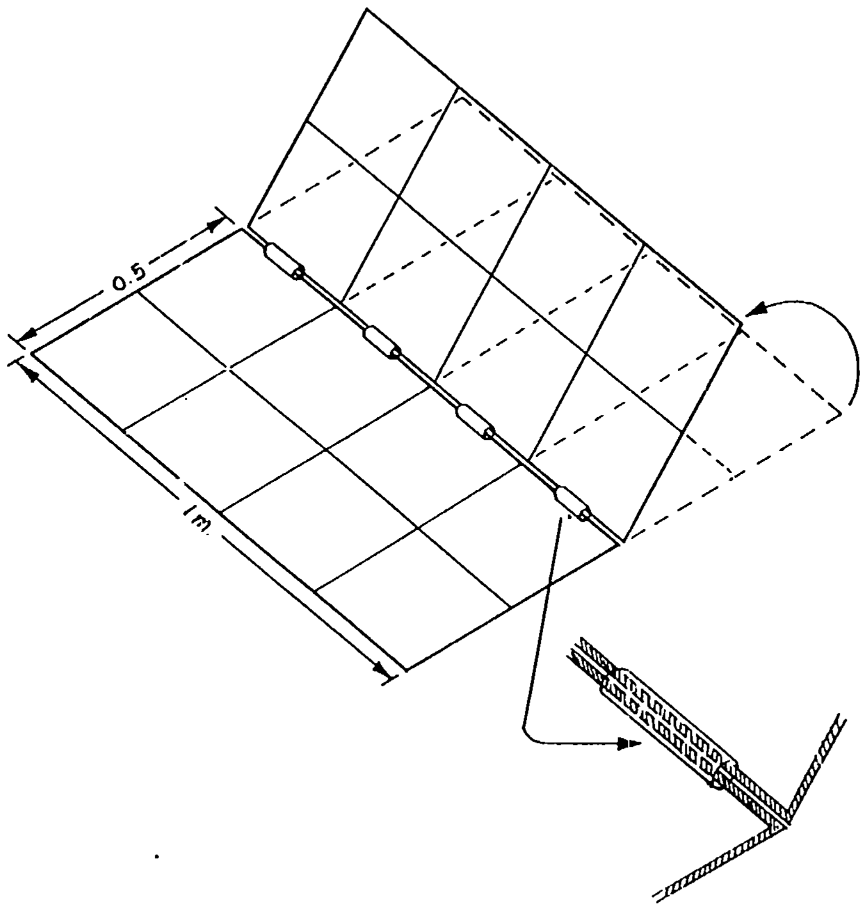
A modified method of the above coral reef survey was used in the Central Philippines. In this case, a survey team usually consisted of three to four people, one of them the "pumpboat" operator. The team was equipped with the usual diving and swimming gear and a 1 m x 1 m wire grid quadrat with 16 equal divisions (Fig. 1). The team did not use transect lines.

On arrival at a reef to be surveyed, the team marked its location on the map and made a quick inspection of the reef, noting such features as live coral cover, species richness, physical damage and topography. This preliminary inspection was for the purpose of dividing the reef into sampling "strata" (e.g. area of high diversity, area with damage, reef slope).

After the strata had been determined, the team proceeded to sample each of the strata (at least 2 or 3). One man (usually the boatman) haphazardly threw the wire quadrat to his side or back, without looking at the bottom. He made from 5 to 10 throws alternatively while on the front, rear and middle of the boat, assuring that all parts of the stratum were sampled. One diver recorded on slateboard the number of squares occupied by living coral (soft and hard), dead coral, coral rubble or rock and sand. The other diver retrieved the wire quadrat for the boatman. The data served as bases for classifying the reefs into the four categories.

FIGURE 1

Outline of a 1 m^2 quadrat having
16 subsections each measuring 25 x 25 cm.



Note: The quadrat may be constructed of brass or any other light, non-corrosive metal. Bars forming the frames are 5 mm in diameter. The grid bars may be of the same diameter or slightly smaller.

Observations of reef-associated organisms, species richness, probable causes of reef damage, etc. were written on the slate board.

RESULTS AND DISCUSSION

Figure 2 indicates the location of the coastlines surveyed from November 1976 until May 1981. During this period, nine major islands were visited. Further surveys have been carried out through the end of 1982, with the result that 35 locations have now been surveyed using a total of 632 stations (Tables 2 and 3).

The results of the initial survey, given in Table 2, are broken down into political and geographic subdivisions, generally going from north to south. It should be noted that the greatest number of reefs are located in the Visayas and the Sulu Archipelago. This last area has not been surveyed and neither has most of Palawan, another reef-rich province.

The overall pattern is quite clear. Seventy per cent of the reef areas are in the *poor* and *fair* categories, and only 5.5 per cent in the *excellent* class. In fact, more than 632 sites have been visited, but many stations that were marked as reef areas in the charts turned out to be totally or generally sandy.

Causes of reef destruction may be placed into two categories. Natural phenomena include storms, predation by Acanthaster planci L., and algal competition for space. Man-induced damage comes from siltation, blast fishing, another destructive fishing method called "muro-ami", gathering of corals for commercial purposes, and pollution.

Since the islands are situated in a typhoon zone, damaging storms occasionally visit reef areas. Predation by the crown-of-thorns starfish is equally patchy if the whole archipelago is considered. Algal competition has become apparent only in a few localities.

The most widespread cause of reef damage appears to be siltation, brought about by the denuding of forests and developing of land. Another widespread cause of destruction is blast fishing, an illegal activity which is still practised in many parts of the country. "Muro-ami" is a set-net placed adjacent to a reef and into which anywhere from several dozen to 200 swimmers drive the

FIGURE 2

Location map of the Philippines showing surveyed coral reef areas.

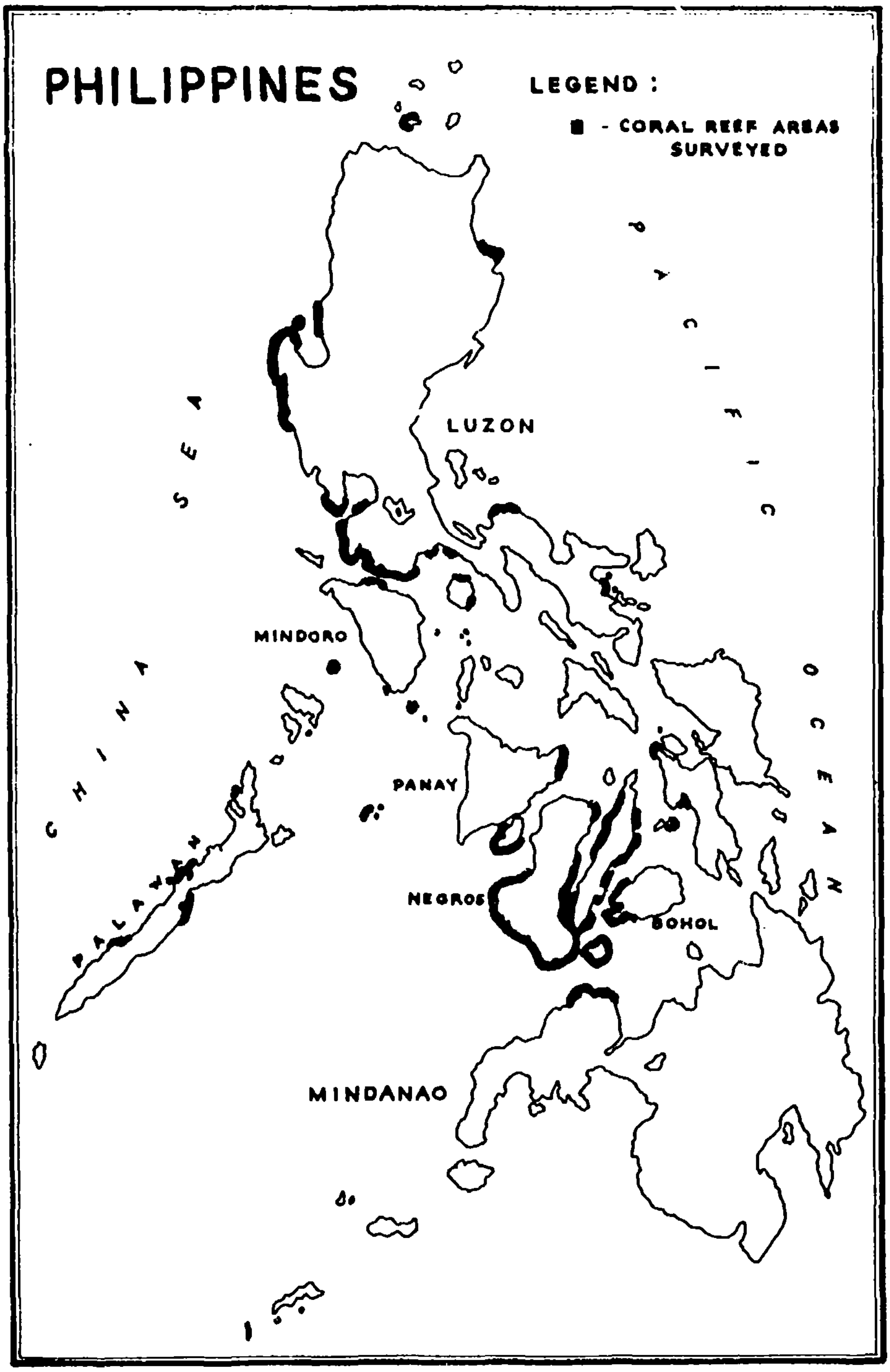


TABLE 1

Example of the Reef Survey Data Sheet used in Carrying out the Philippines Survey

Location (Island): ______________________ Observers: ______________________

Date : ______________ Time of Observation: ______ Methods : ______________________

VISIBILITY: Horizontal - m Vertical - m

LOCALITY (Specific location)	CONDITION OF REEF									DOMINANT TAXA OR FORMS
	STA	DEP	HC	SC	DC	R	S	(Optional)*	NOTES	
	300									
	280									
	260									
	240									CONSPICUOUS ASSOCIATED ORGANISMS Fish -
	220									
	200									
DISTANCE FROM SHORE	180									Invertebrates -
Shallow end ______	160									
Deep end ______	140									
	120									Algae -
	100									
CAUSE OF DESTRUCTION	80									
	60									
EXTENT OF DAMAGE	40									REMARKS
	20									
	0									
	AVG									
	%									

*This column to be used for coralline algae or other components considered important by the investigator.

TABLE 2

Summary of Reef Survey Data as of 1978
("Coral Cover" includes both soft and hard corals)

Location	Total Number of Stations	No. with EXCELLENT (75-100%) Coral Cover	No. with GOOD (50-74.9%) Coral Cover	No. with FAIR (25-49.9%) Coral Cover	No. with POOR (0-24.9%) Coral Cover
Luzon					
1. La Union	8	0	1	2	5
2. Zambales	4	0	0	1	3
3. Pangasinan	11	0	4	4	3
4. Bataan	6	0	3	2	1
5. Batangas	38	1	7	12	18
6. Mindoro Oriental	13	1	2	6	4
7. Mindoro Occidental	31	1	8	15	7
8. Palawan	5	0	3	2	0
Subtotal	116 (100%)	3 (2.5%)	28 (24.2%)	44 (37.9%)	41 (35.4%)
Visayas					
9. Bohol Island/Islets	22	0	8	7	7
10. Cebu Province	57	3	15	18	21
11. Negros Island	100	4	24	37	35
12. Siquijor Island	31	0	9	9	13
13. Guimaras Island	32	8	8	11	5
Subtotal	242 (100%)	15 (6.2%)	64 (26.4%)	82 (33.9%)	81 (33.5%)
Mindanao					
14. Zamboanga del Norte	8	0	3	2	3
15. Aliguay Island	8	2	3	2	1
16. Selinog Island	7	0	0	1	6
Subtotal	23 (100%)	2 (8.7%)	6 (26.1%)	5 (21.7%)	10 (43.5%)
TOTAL (Percentage)	381 (100%)	20 (5.2%)	98 (25.7%)	131 (34.5%)	132 (34.6%)

TABLE 3

Status of Philippine Coral Reefs - 1982: 632 Stations in Four Categories of Living Coral Cover - Excellent (75-100%), Good (50-749%), Fair (25-49.9%) and Poor (0-24.9%)

Location	No. of Stations	Excellent		Good		Fair		Poor	
		#	%	#	%	#	%	#	%
LUZON									
1. Albay	9	0	0	1	11.1	5	55.6	3	33.3
2. Bataan	10	0	0	0	0	0	0	10	100.0
3. Batangas	25	0	0	6	24.0	11	44.0	8	32.0
4. Cagayan	4	0	0	2	50.0	2	50.0	0	0
5. Camarines Norte	13	0	0	1	7.7	7	53.8	5	38.5
6. Camarines Sur	2	0	0	0	0	2	100.0	0	0
7. Cavite	9	0	0	0	0	6	66.7	3	33.3
8. Isabela	3	0	0	2	66.7	1	33.3	0	0
9. La Union	5	0	0	1	20.0	2	40.0	2	40.0
10. Marinduque	5	0	0	0	0	4	80.0	1	20.0
11. Mindoro Occidental	31	1	3.2	8	25.8	15	48.4	7	22.6
12. Mindoro Oriental	11	1	9.1	2	18.2	4	36.4	4	36.4
13. Palawan	49	6	12.2	17	34.7	20	40.8	6	12.2
14. Pangasinan	37	0	0	8	21.6	14	37.8	15	40.5
15. Quezon	4	0	0	2	50.0	2	50.0	0	0
16. Zambales	12	0	0	2	16.7	3	25.0	7	58.3
Subtotal	229	8	3.5	52	22.7	98	42.8	71	31.0

TABLE 3
(Cont'd.)

Location	No. of Stations	Excellent #	Excellent %	Good #	Good %	Fair #	Fair %	Poor #	Poor %
VISAYAS									
1. Antique	12	2	16.7	10	83.3	0	0	0	0
2. Bohol	22	0	0	8	36.4	8	36.4	6	27.2
3. Cebu	64	6	9.4	14	21.9	27	42.2	17	26.6
Hilutangan Island	4	0	0	1	25.0	0	0	3	75.0
Mactan Island	15	1	6.7	3	20.0	3	20.0	8	53.3
Olango Island	7	0	0	1	14.3	4	57.1	2	28.6
Sumilon Island	4	0	0	3	75.0	0	0	1	25.0
4. Iloilo	64	9	14.1	18	28.1	27	42.2	10	15.6
5. Leyte	12	0	0	0	0	6	50.0	6	50.0
6. Negros Occidental	18	1	5.6	2	11.1	5	27.8	10	55.6
Refugio Island	4	0	0	1	25.0	1	25.0	2	50.0
7. Negros Oriental	98	5	5.1	20	20.4	41	41.8	32	32.6
Apo Island	5	0	0	5	100.0	0	0	0	0
8. Siquijor	31	0	0	9	29.0	9	29.0	13	41.9
Subtotal	347	23	6.6	94	27.1	123	35.4	107	30.8
MINDANAO									
1. Misamis Occidental	9	0	0	0	0	4	44.4	5	55.6
2. Misamis Oriental	1	0	0	0	0	0	0	1	100.0
3. Zamboanga del Norte	18	1	5.6	3	16.7	6	33.3	8	44.4
Aliquay Island	8	2	25.0	3	37.5	2	25.0	1	12.5
Selinog Island	7	0	0	0	0	1	14.3	6	85.7
Subtotal	43	3	7.0	6	14.0	13	30.2	21	48.8
T O T A L	632	35	5.5	152	24.0	242	38.3	203	32.1

SOURCE: Marine Sciences Centre. 1982. Investigation of the coral resources of the Philippines. Phase III (Terminal Phase) Final Report with Project Publications. Report submitted to the Ministry of Natural Resources. Quezon City: University of the Philippines (Unpublished).

fish by repeatedly dropping boulders or weights onto the reef. Many coral heads are smashed in the process. Although not as widespread as blast fishing, its tell-tale signs cannot be missed. Another selective method of reef damage is due to the gathering of corals for commercial and construction purposes. While coral traders and exporters tend to choose the branching and flower-like shapes, others collect the boulder or massive encrusting types for use in road and dike filling. Finally, a few reefs have been placed under stress by pollution from shipping and from sugar mills.

It is interesting to note that Langham and Mathias (1977) spoke of similar problems with respect to the coral reefs of neighbouring Sabah.

In line with the identification of the causes of destruction or damage to reefs, studies have been initiated on the growth and regeneration of corals.

A broad-ranging survey such as this has demonstrated to the authors the rich variety of corals in the country, with no clear pattern of zonation discernible at present. The five sub-orders of Scleractinia are all represented, as well as the non-scleractinian orders of Milleporina (Millepora), Coenothecalia (Heliopora), and Stolonifera (Tubipora). The soft corals are also well represented on shallow reefs. In contrast with Caribbean reefs, however, the gorgonians only become moderately abundant at lower levels.

The most conspicuous associated organisms are the reef fishes. Among the invertebrates, the echinoderms are well represented, along with the crustaceans and the molluscs. On some reefs, coralline algae are abundant.

All this indicates the need for more studies on Philippine coral reefs. It may be stated that coral reef ecology is a new discipline in the Philippines, inviting researchers to study the myriad problems of these marine resources.

Incidental to the surveys, some corals have been collected for identification purposes. The project is fortunate in having Emeritus Professor Francisco Nemenzo as a consultant. His monographs (1955-1971) on nearly 400 species of shallow-water scleractinia of the Philippines are known to coral researchers studying the Indo-Pacific. Although he made a comprehensive study during his most active years, he and his collectors were limited by the lack of scuba gear. The present project is bringing up specimens from greater depths which are either new morphs of known species, new records for the Philippines, or entirely new species which are being described.

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POINTS RAISED DURING PRESENTATION

Dr. Gomez indicated that reefs are classified into four categories: poor, fair, good and excellent, depending on their coral cover. Surveys are based on the transect/quadrat method. The 300 m transect has recently been abandoned in favour of a method using an underwater compass bearing and a short line. With this method, a first diver studies a certain quadrat while the second diver takes a compass bearing and swims 20 m away. After obtaining his readings, the first diver follows the line to the second diver, positions his quadrat and starts again. Dr. Alcala explained that atmospheric and hydraulic conditions in the southern and central Philippines made it nearly impossible to use the transect line method. He opted for a method whereby 1 m^2 quadrats were tossed over the side of a boat riding at anchor.

The authors further stated that the studies described above concern only one type of survey and that fixed transects and permanent quadrats are in place on certain reefs to permit ongoing surveys.

The 1 m^2 quadrat size was chosen for reasons of maneuverability (when folded) and because it is a standard dimension for zoological studies. Several participants expressed doubt as to whether it would be possible to develop a standardised quadrat size, in view of the high species diversity in coral reefs.

Regarding management procedures, Dr. Alcala informed the meeting that marine parks in the Philippines are established under the authority of the Ministry of Natural Resources, in cooperation with the Natural Resources Management Centre and the Bureau of Fisheries and Aquatic Resources. However, it is generally left to the individual town councils to set up a part of their coastline as a marine park. One island which is regularly surveyed has 20% of its water proclaimed a marine reserve. This is sufficient to serve as a replenishment area for the waters adjacent to this protected zone.

3.6 PROBLEMS IN THE STUDY OF CORAL COMMUNITIES

by

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&
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INTRODUCTION

Coral reef study including surveys has been concentrated within these past few years. It should be noted, from the beginning, that coral reefs in Thailand can be categorised according to their occurrence in two areas: the Andaman Sea and the Gulf of Thailand. This distinction results from differences in the natural environment that the reefs in these two areas encounter.

REEFS IN THE GULF OF THAILAND

In the Gulf of Thailand, which is mainly a semi-closed water body, reefs are associated mainly with islands. This distribution is caused by run-off from rivers and streams within the Gulf area.

The Gulf of Thailand can be divided into three areas: the inner Gulf, the east coast, and the west coast. The Gulf is shallow, with a maximum depth of about 85 metres. Reefs are not well established.

At present, one can find fossilised coral within marble in the province of Saraburi. This indicates that the shoreline within the Gulf is extending. This may explain the present lack of true coral reefs with layer after layer of coral in the same area. It is possible that the reef is extending into the Gulf by the same process that governs shoreline extension. Therefore, reefs within the Gulf might better be considered as a community of corals, rather than as true reefs.

Geomorphological phenomena are not the only limits to the growth of coral reefs in the Gulf of Thailand area. Many other environmental factors also contribute.

Within the inner part of the Gulf, problems result from the amount of fresh water discharging into the area from the four major rivers. This discharge creates a muddy substratum in most of the inner Gulf and, consequently, there is very little coral growth in the inner portion of the inner Gulf. Toward the outer portion of the inner Gulf, coral reefs can be found along the rocky shore or adjacent to certain sections of most of the islands.

Along the west coast of the Gulf, the shoreline extends from the inner Gulf. Here, islands are found in more southern latitudes than on the east coast. Coral reefs are found associated with these islands.

Within the Gulf of Thailand, research on coral reefs has been carried out by Chulalongkorn, Srinakarinvirot and Kasetsart Universities. Most of the work has been concentrated on surveys of reefs on various islands. Some work on various organisms associated with corals has also been carried out.

Coral reefs within the Gulf suffer from illegal dynamite fishing. Certain areas are faced with domestic pollution, which changes the composition of the reef drastically. Problems arising from trawling and coral collecting can also be found.

CORAL REEF SURVEY METHODS

The methodology used in coral reef surveys differs slightly among the various research groups. The technique generally used is as follows:

(1) Since the coral reefs in the Gulf are not very broad, an estimation study of species diversity is done by swimming and searching for various species.

(2) In order to study the density and distribution of coral species, a 1 sq. m quadrat is deployed perpendicular to a transect line. At each selected point, an optimum area of about 10 sq. m is surveyed, perpendicular to the transect line. If this optimum coverage is doubled, the number of species occurring in the area is increased by less than 10%.

Coverage area is determined by using small-scale (10 cm x 10 cm) subsections within the 1 sq. m quadrat. In certain cases, underwater photographs are also obtained.

(3) The reef profile along the transect line from the outer edge to the inner part of the reef is obtained by recording the depth of water and the time of day at 1 m intervals and making corresponding adjustments using the tide table.

(4) Type of substrate, percentage of living and dead coral, and exposure time are also recorded.

DISCUSSION

Many problems emerge from applying such techniques. In particular, use of the quadrat technique seems ill-advised because corals in the Gulf do not show much vertical zonation. Various species of coral are found grouped together within clumps, with Porites lutea as the dominant species. Since a quadrat may or may not cover such clumps, this method could result in biased figures.

Distribution of coral in the Gulf can easily be classified into two vertical zones: the submerged zone and the exposed zone (indicated by low water). The extent of an intermediate area between these two primary zones varies by location.

It is suggested that aerial photography be used to plan transect lines in a given area so that the line will depict a representative picture of the reef. Another technique must, however, be devised to thoroughly study the coral clumps referred to above.

FUTURE WORK

Presently, members of diving clubs have been invited to give information about their diving spots. An easy checklist is now in the process of being developed. Divers will be asked to help in a preliminary survey of corals in the Gulf of Thailand. The checklist has been developed from "Coral monitoring handbook", edited by A.L. Dahl, South Pacific Commission, New Caledonia.

3.7 A REVIEW OF CORAL REEF SURVEY AND ASSESSMENT METHODS CURRENTLY IN USE IN INDONESIA

by

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INTRODUCTION

Indonesia lies in the part of the world which is noted for harboring the highest degree of coral reef development and diversity. It is one of the richest coral reef areas of the world (Molengraff, 1930).

As a maritime habitat, coral reefs serve as feeding, breeding, and nursery grounds for indigenous and transient aquatic populations. In addition, organisms inhabiting the reef benefit from physical protection from the destructive forces of the sea. Coral reefs also contribute to marine farming and recreation.

Coral reefs are, however, extremely vulnerable to destructive factors. Their deterioration is proceeding at an alarming rate in many parts of Indonesian waters. In the last ten years, as a result of Indonesian efforts in development, coral reef ecosystems have experienced severe pressures, both directly and indirectly. Generally, if reefs are not subjected to heavy pollution by domestic and industrial waste from the centre of human settlements, people directly destroy the reefs by removing tons of sand and hundreds of coral heads daily for road and building construction.

In order to maintain the high productivity characteristic of reefs, as well as to ensure continuity of their ecological processes, to preserve genetic diversity and to allow for the development of relevant sustained economic potential, there is now an urgent need for rational management of such resources. Any effective management scheme, however, must begin with a sound knowledge of the extent and condition of the subject resources. In order to accumulate such knowledge, sufficient information must be obtained on the distribution, type structure, and species composition of reefs throughout the Indonesian archipelago. The present paper provides a review of coral reef survey and assessment methods currently used in Indonesia.

METHODOLOGY

The Indonesian government commenced studies on marine resources in eastern Indonesian waters in 1964 through the first Baruna Expedition. The objective of the expedition was to obtain information about marine resources available in the eastern Indonesian waters, including species composition, distribution, and ecological conditions. The primary focus of the expedition was on economically important marine resources such as molluscs, shrimp, fishes, and seaweed. Methods used during the expedition, to date, have been extremely simple. Molluscs, crustaceans, and seaweed were observed and collected by snorkeling, while fishes were collected by gill net.

For the preceding "Five Year Development Plan" (PELITA), the National Institute of Oceanology (NIO) developed a programme to "Inventory marine resources in Indonesian waters". The objective of this programme was to determine marine resources in Indonesian waters, both qualitatively and quantitatively, and to assess distribution and ecological conditions. The information thus obtained should serve as a basis for management decisions, as well as for more comprehensive studies to be conducted in the future.

To obtain information on percent area covered by corals, species composition, distribution, and ecological condition, quantitative surveys were made on traverses selected around various islands. Corals on the traverses covering the reef were sampled at five-metre intervals with a metre square quadrat. A 1 m x 1 m frame was subdivided to form a grid of 16 meshes (25 cm x 25 cm). Samples were taken from the low water levels to the reef slope parallel to the depth contour, not exceeding 6 metres. The depth of each quadrat was measured to make a profile of the bottom along the traverses and to show the physical conditions across the traverses surveyed. Information on the length of the traverses, occurrence of other invertebrates, economically important algae and the characteristics of the substrate were recorded on a survey data sheet (see Table 1). The foregoing method was used to study the influence of Mount Krakatau on the community structure of hermatypic corals in terms of species composition, percent area covered by living corals, zonation, and diversity patterns in different zones of reefs around the eruption site and the Sunda Strait. From the quantitative data gathered, various indices can be calculated with the formula presented in Odum (1971), briefly described below:

(1) Index of Dominance (C)

$$C = \Sigma \ (n_i/N)^2$$

where n_i = importance value for each species (number of individuals, biomass production, etc.)

N = total of importance values

(2) Index of Similarity (S) between two samples

$$S = \frac{2C}{A+B}$$

where A = number of species in sample A
B = number of species in sample B
C = number of species common to both samples

Note : Index of dissimilarity = 1-S

(3) Indices of species Diversity

(a) Three species richness or variety indice (d) were used :

$$d_1 = \frac{S-1}{\log N} \qquad d_2 = \frac{S}{\sqrt{N}} \qquad d_3 = S \text{ per } 1000 \text{ ind.}$$

where S = number of species
N = number of individuals, etc.

(b) Evenness index (e)

$$e = \frac{\bar{H}}{\log S}$$

where $\bar{H}$ = Shannon index (see below)
S = number of species

(c) Shannon index of general diversity ($\bar{H}$)

$$\bar{H} = - \Sigma \left(\frac{n_i}{N}\right) \log \left(\frac{n_i}{N}\right) \text{ or}$$

$$- \Sigma P_i \log P_i$$

where n_i = importance value for each species
N = total of importance values
P_i = importance probability for each species = n_i/N

In studying density of stony corals in the reef slope and lagoon of Air Island (Sukarno, 1977), a form of continuous recording line transect method was used. Line transects were run underwater to a depth of 6 or 7 metres. Any coral species that was found to underlay the line was recorded and its projected length intercepting the line was measured to the nearest centimetre. In cases where an individual colony was clearly separated into two or more portions by the death of the intervening parts, the separate parts were considered as one individual. In the case of two or more colonies growing one above the other and underlying the transect, the projected length of the largest colony was recorded for live coverage analysis. The density of stony coral/soft coral was calculated from this equation:

$$\text{Density} = \frac{\text{the total length of intercepted line}}{\text{the total length of the transect line}} \times 100\%$$

With this method, the density of soft coral along the transect was also determined. Results were presented in the form of histograms (see Figures 1 and 2).

A final method used for quantitative assessment of the composition and health of reefs was the plotless line transect. This method was used in an environmental reconnaissance survey of candidate sites for a liquified natural gas project on Natuna Island in 1981. A 100-metre line, marked prominently at intervals of one metre, was strung out randomly over the sample area. The identity of organisms or substrate falling directly beneath the marked points was recorded. Areas falling under points were categorised as either bare substrate or organisms. A substrate was characterised as bare if no macro-organisms were living on it. Two subcategories of bare substrate were chosen: sand and dead coral. A dead coral was recorded if the substrate still retained the obvious form of a coral, but was not covered with living tissue. Organisms were divided into two main categories: soft coral and scleractinian, or hard coral. The hard corals were further subdivided into major families and species, when possible. Transect data were later tabulated to find percentage composition and distribution of the various categories. A quantitative assessment of the health of the reefs was then based on the ratio of dead versus live organisms.

The kinds of sampling methods used in the Indonesian programme are illustrated in Figure 3.

CONCLUSION

Several methods have been used for recording the state of corals on reefs in Indonesia. However, the results so far are not readily comparable, even on a local basis.

The main problems raised in quantitative transect work are more acute at the level of the field recording

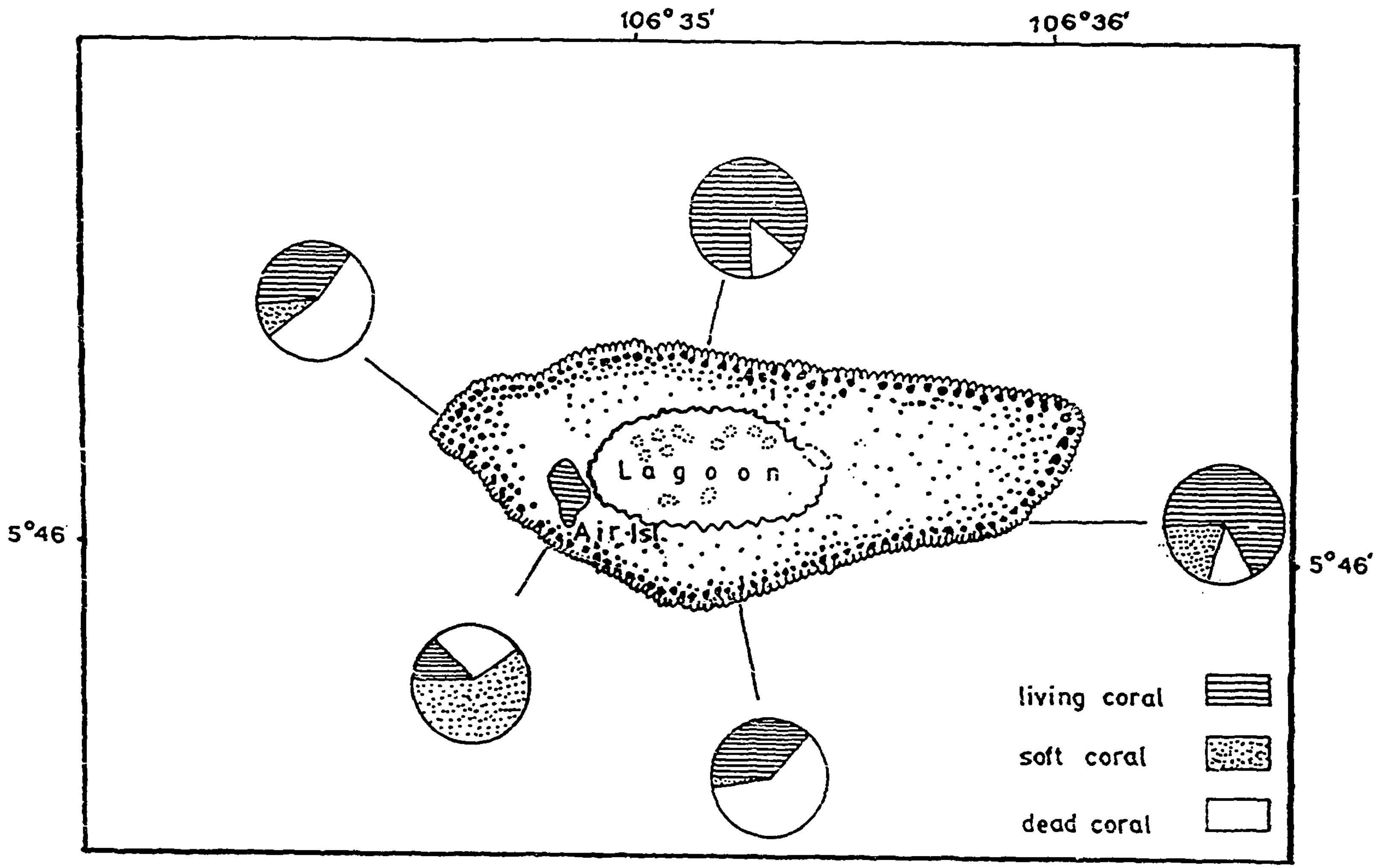

FIGURE 1

Location of transects and corresponding density of living stony coral, soft coral and dead coral in the reef slope of Air Island.

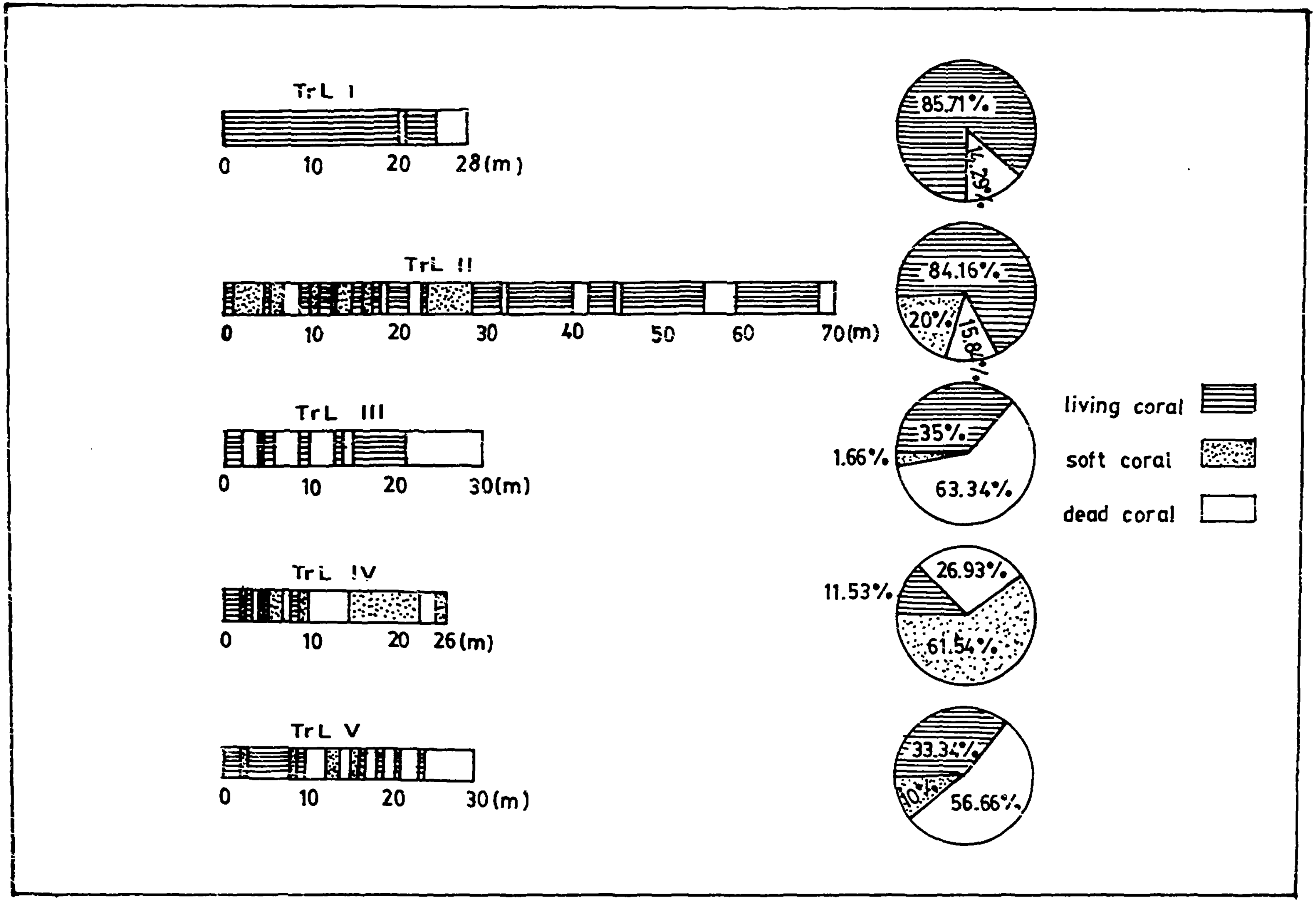

FIGURE 2

Density of stony coral for all transects
taken on the reef slope of Air Island

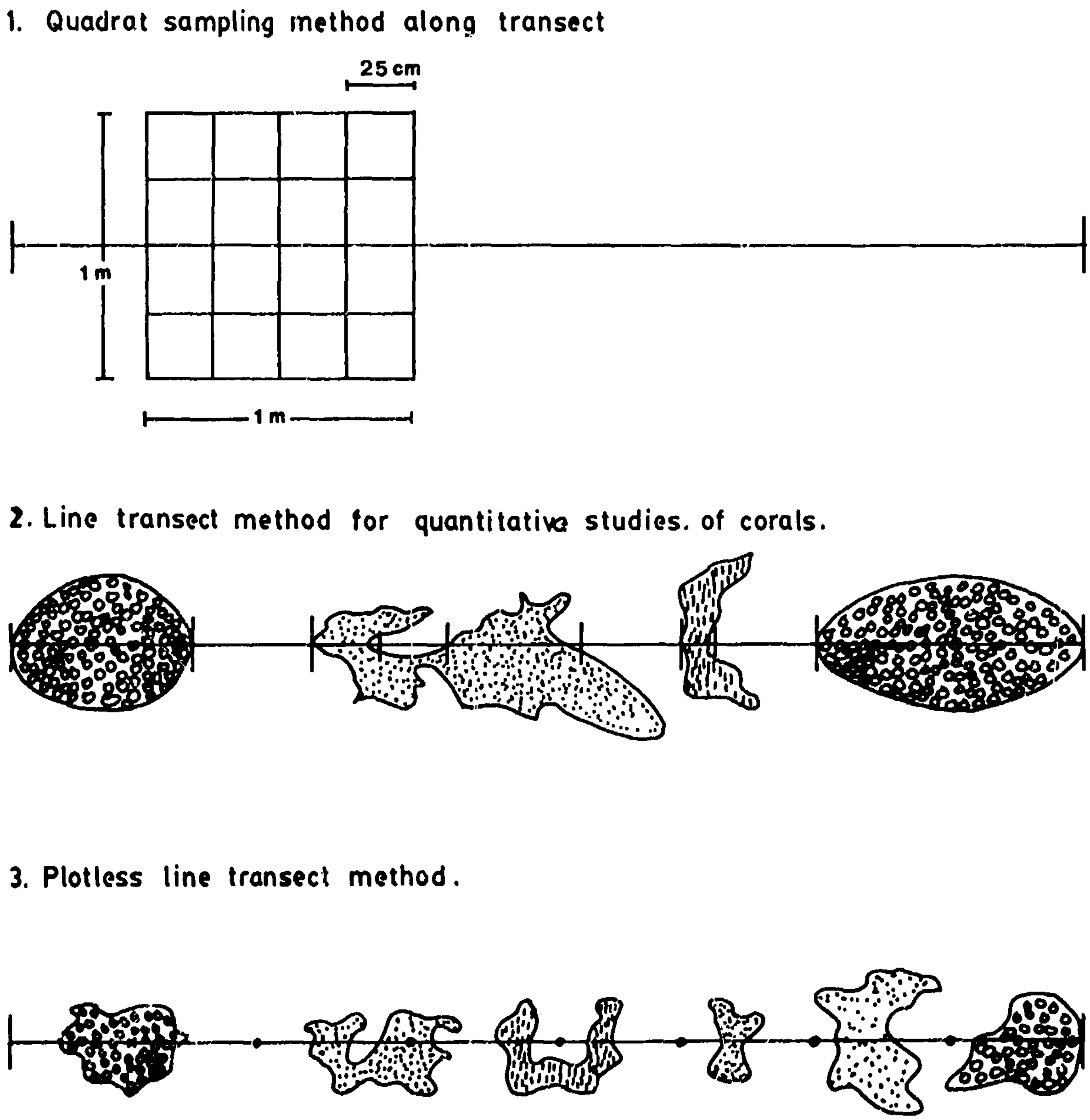

FIGURE 3

Field method and quantitative studies of hermatypic coral and invertebrate communities procedure. This is due to a lack of experience in using scuba gear. On reef slopes having irregular substrates and characterised by the occurrence of different colony sizes, the use of metre square quadrat is particularly difficult.

Because of the problems involved with identification, it has proved impossible to make meaningful counts of individual colonies in the field. For an environmental reconnaissance survey to estimate composition and health of reefs, the plotless line transect method is probably the most reliable.

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3.8 RAPID SURVEY TECHNIQUES TO DETERMINE DISTRIBUTION AND STRUCTURE OF CORAL COMMUNITIES

by

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INTRODUCTION

Stony corals are generally believed to be absent or rare in the northeast section of the Persian Gulf, particularly around the region of Bandar Abbass and Bandar Lengeh on the Iranian coast. A survey was carried out around the island of Hormoz (Fig. 1), situated on the northern side of the Straits of Hormoz, in order to determine the occurrence of coral communities in that region. The following is an account of survey methods and results obtained from a comparatively isolated area, for which no systematic information existed prior to the investigation.

METHODS

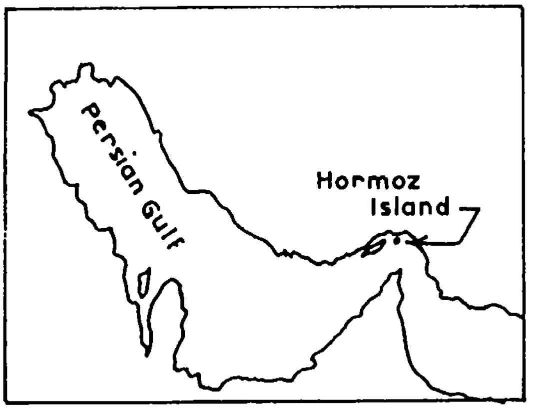
Between June and December 1976, a series of day-trip surveys was carried out around the perimeter of Hormoz Island, using a motor launch. It was found that the use of successive anchor stations, with associated spot dives, to determine the extent and distribution of the coral communities around the island was extremely time-consuming. Accordingly, a towed diver technique was substituted to make a preliminary estimation of the distribution of coral communities.

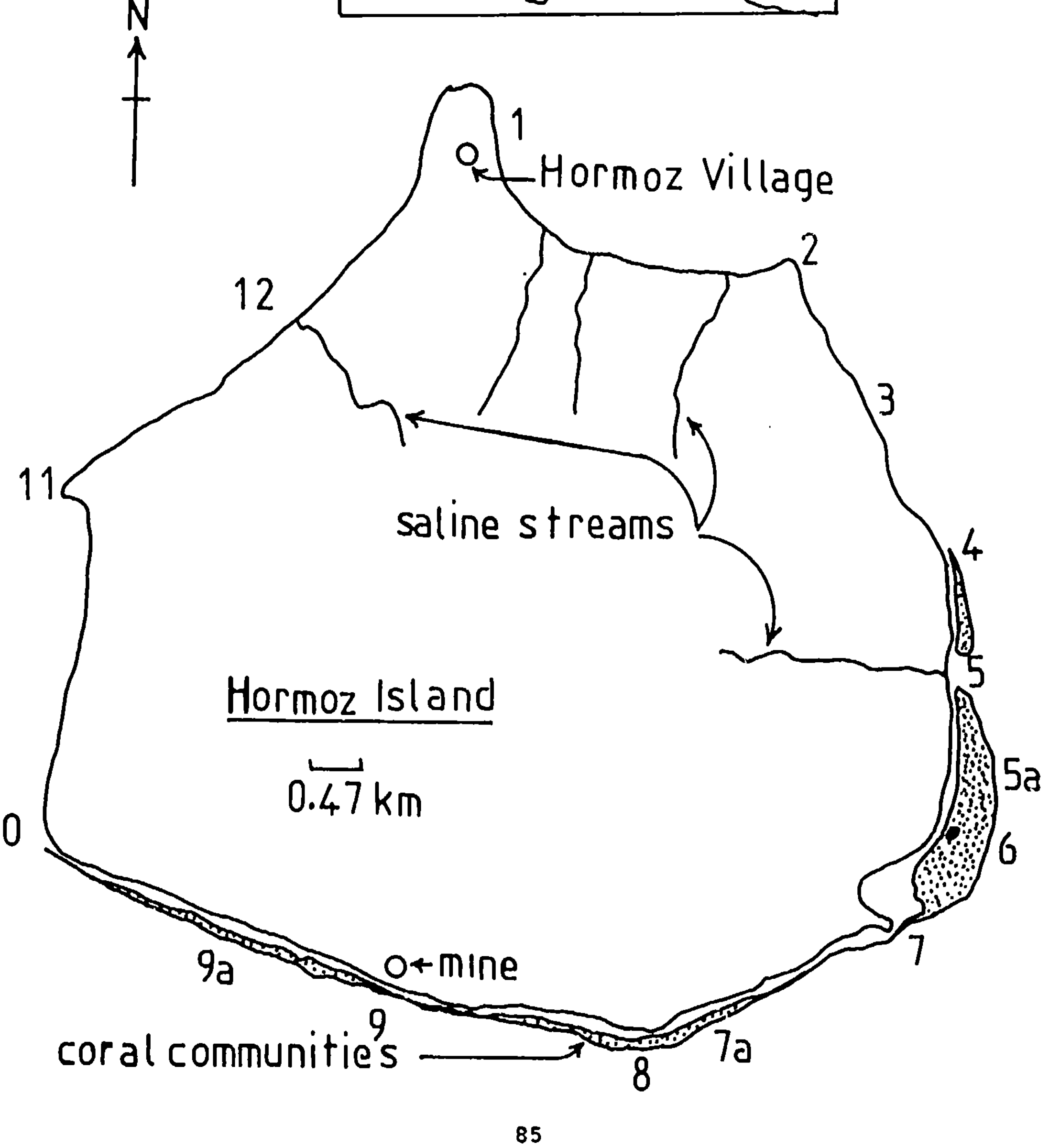
A small outboard motor boat was used to pull a diver at the end of a 20 metre length of 3 cm diameter polythene rope, with a loop on the outside end. The rope can be hand-held during the tow or, alternatively, the observer may stand one foot in the loop. A speed of approximately one knot was found to be most convenient. Higher speeds increased diver discomfort and resulted in a form of sensory overload that prevented a subsequently adequate description by the observer of the coral community covered by tow. In essence, this method is similar to that reported by Kenchington (1978), using a manta board at the end of the tow line. Surveys are restricted to water depths of 6-15 metres, depending on visibility. Development of observer fatigue is a further limiting factor. Although it is possible to cover distances of up to 20 km in a day, continuous activity at this level is not possible without rest periods.

After determining an outline of coral distribution patterns, a series of stations was set up around the island perimeter (Fig. 1). Three surveys of physical and chemical factors relating to sea water at each station were undertaken on October 17, 1976, October

FIGURE 1

Location map showing position of sampling stations and general distribution of coral communities on Hormoz Island. Hormoz Island is situated close to the mainland of Iran at the mouth of The Persian Gulf. The south of the island faces the Straits of Hormoz whereas the north and west face the mainland and the straits inside adjoining Qesham Island respectively.





31, 1976, and December 13, 1976.

Factors monitored were salinity (ppt), temperature (^{o}C), hydrogen ion concentration (pH), dissolved oxygen (ppm) and water transparency (% light transmission). For the first two surveys, measurements were obtained from both the surface and the bottom of the water column in locations of about 2-3 metres depth at low tide, above coral communities where they occurred and as close to the shore as possible. The final survey was confined to surface water. Occurrence of corals at each station was checked by free diving for one hour at low tide from an anchored boat, in order to locate and sample as many hard coral species as possible.

A Martek XMS *in situ* transmissometer was used for measuring sea water transparency and a Martek MK III water quality monitoring package was used for salinity, temperature, oxygen and pH measurements.

RESULTS

In aggregate, salinity, temperature, dissolved oxygen concentration and pH differed little around the circumference of the island (Table 1). Sea water transparency, however, varied greatly. Values around 10% light transmission were obtained from the northern side, as opposed to over 35% from the southern side (Table 1).

Due to the shallow nature of the water and the occurrence of currents and wave action, the surface and bottom readings for all variables did not differ significantly from each other during the sampling periods examined. This justified the pooling of data from each station.

The greatest number of stony coral species and also the best coral reef development was found on the southeastern margin of the island. In general, corals coincided with the region of highest water transparency and were distributed from the low water spring tide level to a maximum depth of 4-5 metres. Coral communities were found in a narrow band, approximately 10-15 metres in width, except in the area of maximum development, i.e. stations 5a-6 (see Fig. 1), where the maximum extent of the reef was approximately 50 metres seaward from the spring tide low water mark. There was a gradual tapering off in horizontal extent toward the northern and western limits of the coral communities. The communities on the southern edge of the island are discontinuous, being interrupted by patches of sand.

TABLE 1

Summary values for physical factors measured around Hormoz Island, October-December 1976

Sta.	Depth (m) at low tide	No. coral spp.	Salinity o/oo			Temperature °C			Dissolved oxygen (ppm)			pH			% Light transmission		
			N	$\bar{Y}$	S	N	$\bar{Y}$	S	N	$\bar{Y}$	S	N	$\bar{Y}$	S	N	$\bar{Y}$	S
1	2.5	0	5	37.7	0.4	5	29.0	2.5	1	4.7	-	5	8.3	0.2	5	13.2	5.4
2	2.5	0	4	38.2	1.0	4	29.3	2.9	3.	4.2	0.6	4	8.3	0.2	4	12.0	4.1
3	2.5	0	4	37.4	0.4	4	28.0	2.9	3	4.0	0.5	4	8.3	0.2	4	27.0	3.8
4	1.5	2	5	37.6	0.4	5	29.0	2.6	3	3.9	0.6	5	8.3	0.2	5	23.2	1.8
5a	2.5	10	5	37.6	0.5	5	29.1	2.7	3	4.1	0.5	5	8.3	0.2	3	22.5	3.3
6	2.0	14	5	37.5	0.3	5	28.9	2.5	3	3.9	0.6	5	8.2	0.2	5	30.0	10.2
7a	1.5	8	5	37.6	0.3	5	29.0	2.7	3	3.8	0.6	5	8.2	0.2	5	33.0	5.8
8	2.5	7	4	37.5	0.5	4	28.5	2.8	2.	4.0	0.8	4	8.2	0.2	5	36.0	4.3
9	1.5	3	4	37.5	0.5	4	28.1	3.6	2	4.2	1.0	4	8.2	0.1	4	37.8	5.6
9a	2.0	7	1	36.6	-	-	-	-	1	4.8	-	-	-	-	1	39.0	-
10	2.0	1	4	37.5	0.4	4	27.6	3.2	2	3.5	1.8	4	8.0	0.2	4	20.6	5.5
11	3.0	0	4	37.5	0.6	4	27.5	3.2	2.	4.3	0.7	4	8.0	0.3	4	13.4	3.4
12	2.5	0	3	37.6	0.8	3.	28.2	3.3	2.	3.9	1.3	3	8.4	0.1	3	9.0	3.5

Except for one interruption at station 5, caused by discharge of a super saline stream (360 ppt), the reef on the eastern edge is continuous.

A total of 19 different species of stony corals were found around Hormoz Island. As mentioned, species diversity was greatest on the southeast section (14 species) and tapered off to the northern and western limits of the communities.

Several specific nonconformities to the general pattern were seen, particularly at station 5 (already mentioned), where a super saline stream discharged from the island's salt dome core enters the sea. Such streams are postulated to arise as the result of hygroscopic action of the salt in absorbing moisture from the usually humid atmosphere (relative humidity consistently 99.9% during summer months). At station 7 (one species), a further nonconformity was found, presumably due to relatively heavy wave action. Also, at station 9 (three species), few corals were found, presumably due to heavy discharges of haematite-contaminated sediments from an adjacent mine. To the west of the mine at station 9a, seven species were found and to the east, at station 7a, eight species.

DISCUSSION

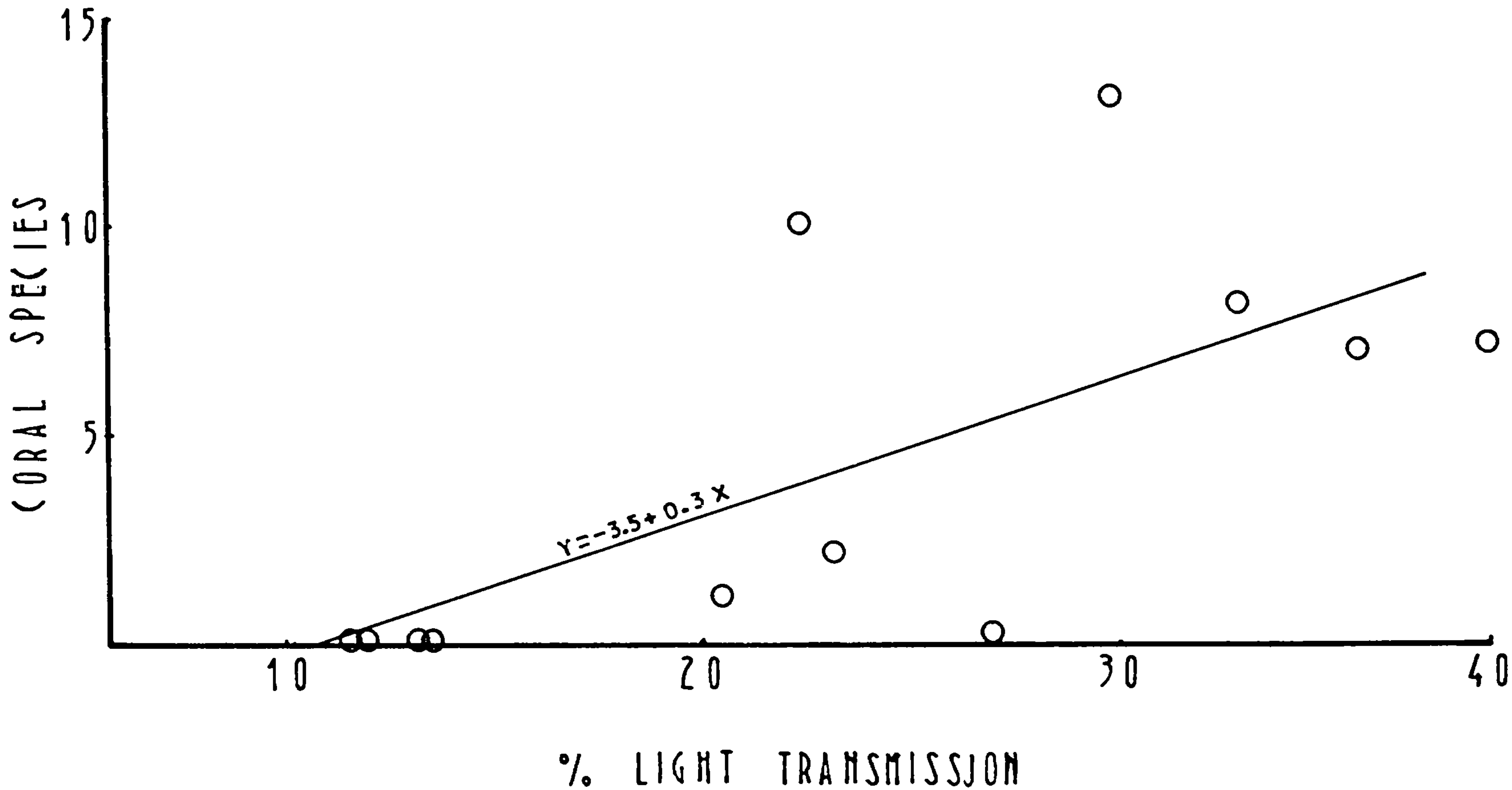
The maximum development of corals around station 6 coincides with both the region of clear water and with comparative shelter from prevailing winds, and, therefore, wave action, created by the headland at station 7. Because the southern coastline is often heavily wave beaten, it is difficult to operate a small boat in the area.

In Figure 2, the number of coral species found in a one hour search is plotted against percentage light transmission (station 5, 7 and 9 are omitted from this plot). As mentioned, station 5 is clearly affected by discharge from a super saline stream, station 7 is a rocky exposed promontory and station 9 is exposed to haematite debris discharged from the adjacent mine. The resulting pattern shows a clear and positive relationship between light transmission and diversity of corals. Below 20% light transmission, no corals are to be found. Above this figure, a roughly proportionate response in diversity to increasing light transmission can be seen. A significant and positive correlation can be obtained from these data: $r = 0.67$, $n = 12$ ($p < 0.001$, $r = 0$).

<u>FIGURE 2</u>

Relationship between diversity in coral communities and percentage light transmission at Hormoz Island.

Note: c = 0.67, n = 12 95% confidence limit for r is 0.15–0.90 r is significantly different from 0 ($p < 0.001$)



The relatively high spread of points may be associated with the interacting effects of shelter and water clarity.

In comparison to coral reefs reported from the Red Sea by Loya and Slobodkin (1971) in the Gulf of Eilat where 99 species were recorded, Hormoz Island shows a markedly depauperate fauna with only 19 species. Seasonal variation of physical factors may, in part, be responsible since sea water temperatures range from a 38°C peak towards the late summer to 21°C by the end of winter. Salinity ranges from 38 ppt in the summer to 34 ppt in winter.

The apparently significant effect of both water transparency and exposure on the occurrence of stony corals around Hormoz Island suggests that these organisms exist close to or at the edge of their tolerance range to one or more major environmental factors in this area of the Persian Gulf.

In effect, the clear waters on the south and south-east sections of Hormoz Island arise as the result of an inflowing surface current from the adjacent Gulf of Oman, which replaces evaporative loss and loss by heavier, more saline, deeper counter current flow from the Persian Gulf back to the Gulf of Oman. The cloudy, usually warmer and sometimes a little more saline waters from the north side of the island have been subject to coastal contact with Iran and may contain detritus from nearby mangrove stands.

CONCLUSION

A towed diver can provide a relatively fast method for determining coral distribution in a broad sense, although the factor of observer fatigue must be taken into account when planning surveys.

Species counts obtained from a fixed time search at stations spanning a gradient in light transmission were used to identify a relatively consistent positive relationship between coral diversity and increasing water transparency. This relationship, in turn, suggests that fixed time species search techniques may provide an easily applied and convenient tool for coral reef survey work where quantification of community responses to factors causing disturbances is required.

ACKNOWLEDGEMENTS

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3.9 LARGE AREA SURVEYS OF CORAL REEFS

by

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INTRODUCTION

A fundamental difficulty of reef assessment is that of selecting an appropriate operational scale. This has been discussed by Kenchington (1978). In essence, the problem is that in areas covered by water, we have no equivalent of aerial, or even vehicular, reconnaissance to obtain a rapid understanding of the general ecological characteristics of a large region. This problem is compounded by the fact that studies carried out by divers are severely limited in time. Thus, detailed study sites tend to be extremely small and replication for comparative purposes tends to be restricted.

These problems apply to determining the representativeness of sites for ecological investigations. They are particularly important in the context of studies or investigations related to management of coral reefs.

MANTA TOW TECHNIQUES

The manta board, a simple diving plan upon which a snorkel or scuba diver may be lowered at speeds of up to 2.5 knots, was first introduced for reef survey by Endean and Stablum (1973) in studies of distribution of *Acanthaster planci* on the Great Barrier Reef. The technique was refined by Kenchington and Morton (1976). This enabled detail of the condition of surveyed reefs to be recorded in a form suitable for statistical analysis. Further development toward a standard methodology for planning and evaluation survey in connection with the Great Barrier Reef Marine Park is described by Done, Kenchington and Zell (1982). Refinement of the technique continues, with the objectives of making it easier to operate and improving the reproducibility of results.

The essential elements of the technique are herein described and discussed.

A BRIEF DESCRIPTION

The diver, using snorkel or scuba equipment, holds on to the manta board, which is towed behind an outboard powered boat. By tilting the leading edge downward, the diver can be towed down to a depth proportional to the length of the tow rope, but in snorkel operation rarely exceeding 10 metres. To surface, the board is tilted upward. The technique is less physically demanding than rope towing without a board.

The course of the survey is determined by the boat driver. Depending on conditions, a speed of 1-2 knots is usual. A considerable area or length of reef face can be covered in a short period of time. It is usual for the driver to zig-zag, so that the tow will cover areas from the reef top - determined by the state of tide and the drift of the tow board - to the maximum depth achieved by rope length, boat speed and diver endurance.

The observer is towed over an area of reef, often covering several vertical ecological zones, until either a major change in the horizontal zone characteristics is noted or a set time has elapsed.

The observer is then debriefed, reporting on the various vertical zones. The information required is set out on a data sheet (Fig. 1) with explanatory debriefing notes (Fig. 2). Most observers find their initial tows difficult because of the volume of information. However, a training programme and systematic debriefing normally lead to reasonably consistent reporting within two or three days.

The main information categories are explained in the data sheet and debriefing notes (Figs. 1 and 2). Two elements are discussed briefly here.

Assessment of area coverage uses the semi-logarithmic scale developed by Kenchington (1978). This scale is based on the fact that observers generally find the task of estimate absolute percentage cover to be difficult. The intervals developed equate to terms such as none, very little, sparse, moderate, abundant, and very abundant. Laboratory and field trials reported by Kenchington (1978) indicate that there are few occasions on which two observers will differ by more than one scale interval.

The most demanding task in the survey is the assessment, whilst moving, of the major visually dominant organisms (VDOs). The list (Fig. 3) was developed on the basis of major visually distinct forms such as massive corals, branching corals, encrusting corals. At the simplest level, indicated by the first digit of the code, an untrained observer can identify those categories and the information is useful to the analyst. At the next level, indicated by the second code digit, an observer can be trained to recognise a number of subdivisions. The information available to the analyst is, thus, increased. At the finest level, a specialist with a reasonable level of taxonomic competence can identify some distinctive genera and species.

GREAT BARRIER REEF MARINE PARK AUTHORITY

BENTHIC REEF SURVEY DATA SHEET MANTA TOWS

Reef Name .

Observer Name

Date / /

Times :

No. [ ] No. [ ] Tow No. [ ]

	Site Desc'n	reef top	reef crest				
	Site No.	1	2				
	Aesthetics, 1-6						
	Slope, 0-6						
Substrate/Sediment	Mud						
	Sand						
	Gravel						
	Stag Rubble						
	Sm Blocks 50cm						
	Lg Blocks 50cm						
	Platform						
	Depth, ft						
COVER	Hard Coral						
	Soft Coral						
	Dead Stand Hard Coral						
	Macro Algae						
	Other						
	Colony Size, 1-3						
	Diversity, 1-4						
Crown of Thorns	Number						
	Grouping						
	Scars						
	V.D.O.'s						
	Benthos Code with						
	% hard coral, 1-6						
	% soft coral, 1-6						
	% other, 1-6						
	Reliability Index						

Code	%
0	0
1	1-5
2	5-15
3	15-30
4	30-50
5	50-75
6	75-100

FIGURE 1
Manta Tow Survey data sheet

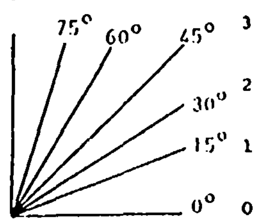
GREAT BARRIER REEF MARINE PARK AUTHORITY
SHEET for MANTA TOW SURVEY

1 AESTHETICS

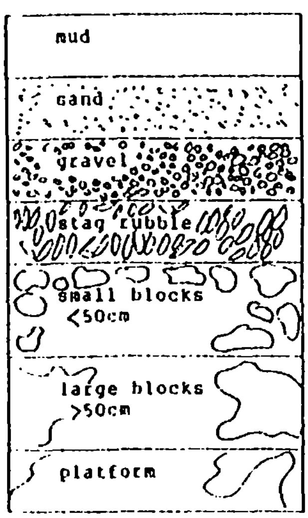
code	
1	R.S.
2	POOR
3	AVERAGE
4	GOOD
5	VERY GOOD
6	OUTSTANDING

2 SLOPE

code



3 SUBSTRATE



4 Depth (Range in feet).

5 Hard, Soft, Dead Standing
Hard and Macro Algae
(% Cover of colonizeable substrate

6 COLONY SIZE

1	SMALL
2	MEDIUM
3	LARGE

PERCENTAGES

code	%
0	0
1	1-5
2	5-15
3	15-30
4	30-50
5	50-75
6	75-100

7 DIVERSITY

code	Diversity
1	monoculture
2	Low
3	Medium
4	High

8 C.O.T. NUMBER

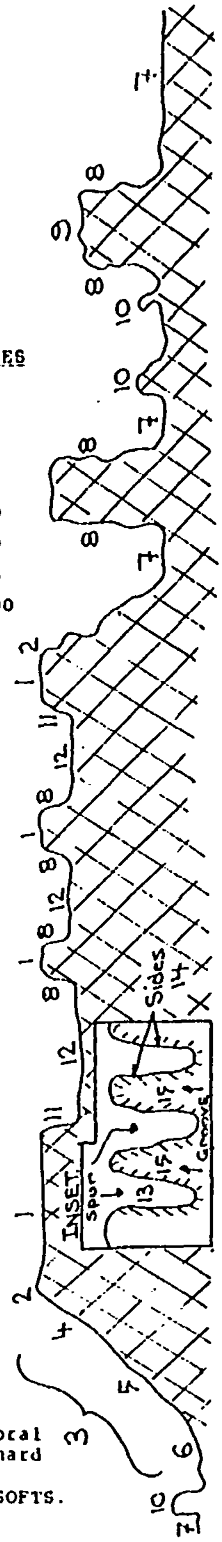
0	NONE
1	1-9
2	10-39
3	40+

9 C.O.T. GROUPING

0	NONE
1	Together
2	Uniformly Scattered

10 FEEDING SCARS

0	NONE
1	1-9
2	10-39
3	40+



11 V.D.O.'s
Growth form and % of hard coral or soft coral cover e.g. 310-6 = 310 is 75-100% of the hard coral coral cover which may only be 5-15%
DO NOT RECORD MORE THAN SIX HARDS OR SIX SOFTS.

12 Reliability Index. 1-6 (i.e. as per aesthetics categories)

FIGURE 2
Manta Tow Survey explanatory notes for debriefing

GREAT BARRIER REEF MARINE PARK AUTHORITY

CORAL IDENTIKIT CODES

FOR MANTA TOW SURVEY

MASSIVE COLONIES

- 211 PORITES LARGE HEADS 30cm
- 212 PORITES SMALL HEADS 30cm

220 SMALL CORALLITES (Unspecified)

230 CERIOO PLOCOID (Unspecified)
- 231 DIPLOASTREA

240 FINE MEANDROID (Unspecified)
- 241 LEPTORIA
- 242 PLATYGYRA

250 FLESHY MEANDROID (Unspecified)
- 251 LOBOPHYLLIA
- 252 SYMPHYLLIA

260 MASSIVE WITH KNOBS or DENTS (Unspecified)
- 261 FAVIA STELLIGERA
- 262 PAVONA CLAVUS
- 263 HELIOPORA
- 264 SYNAREA
- 265 MILLEPORA
- 266 PSAMMOCORA
- 267 GALAXEA
- 268 CARDINOSERIS
- 269 PAVONA MINUTA

Code	%
0	0
1	1-5
2	5-15
3	15-30
4	30-50
5	50-75
6	75-100

ACROPORA

310 TABULATE (Unspecified)
- 311 A.HYACINTHUS TYPE

320 A.HUMILUS

A. PALIFERA
- 331 SHEETS
- 332 RIDGED
- 333 CLAVIFORM
- 334 COLUMNAR

STAGHORN
- 341 HIGH THICKETS (>2 FEET)
- 342 LOW THICKETS (<2 FEET)
- 343 HIGH CLUMPS (>2 FEET)
- 344 LOW CLUMPS (<2 FEET)
- 345 A.FLORIDA
- 346 A.'ROBUSTA' GROUP

350 BUSHLIKE ACROPORA (Unspecified)
- 351 BUSHY DENSE
- 352 BUSHY OPEN

360 BOTTLEBRUSH ACROPORA (Unspecified)
- 361 A.ECHINATA
- 362 XMAS TREE TYPE

BRANCHED CORALS

410 NEEDLE CORAL SERIATOPORA

420 FINGER THICK BRANCHING
- 421 MILLEPORA
- 422 ANACROPORA
- 423 HYDNOPHORA RIGIDA
- 424 CLAVARINA
- 425 ECHINOPORA
- 426 ACRHELIA
- 427 PORITES
- 428 MONTIPORA
- 429 PALAUASTREA
- 431 STYLOPHORA PISTILLATA
- 432 TUBASTREA
- 433 CAULASTREA

440 CLUB-LIKE BRANCHES (Unspecified)
- 441 POCILLOPORA EYDOUXI

450 STUBBY BRANCHES (Unspecified)
- 451 POCILLOPORA VERRUCOSA

460 POCILLOPORA DAMICORNIS

470 DENDROPHYLLIA NIGRANS

SHEET CORALS

510 ENCRUSTING-NO FREE LIP (Unspecified)
- 511 MILLEPORA
- 512 MONTIPORA
- 513 PORITES
- 514 FAVIDS (CERIOD PLOCOIDS)
- 515 TURBINARIA
- 516 ECHINOPORA

520 ENCRUSTING WITH VERTICAL PROJECTIONS (Unspecified)
- 521 HYDNOPHORA EXESA
- 522 MONTIPORA
- 523 GALAXEA

530 EXPLANATE - WITH FREE LIP (Unspecified)
- 531 MYCEDIUM/ECHINOPHYLLIA/OXPORA
- 532 MONTIPORA
- 533 TURBINARIA
- 534 PODABACIA/LITHOPHYLLON
- 535 PACHYSERIS
- 536 LEPTOSERIS
- 537 ECHINOPORA
- 538 MERULINA

540 EXPLANATE WITH VERTICAL PROJECTIONS (Unspecified)
- 541 SCAPOPHYLLIA
- 542 MERULINA
- 543 ECHINOPORA HAMMIFORMIS
- 544 PORITES LICHEN TYPE
- 546 MONTIPORA
- 547 PAVONA DECUSSATA
- 549 PECTINIA
- 551 PACHYSERIS RUGOSA

560 LEAFY EXPLANATE (Unspecified)
- 561 PAVONA CACTUS
- 562 LEPTOSERIS
- 563 PECTINIA

570 VASES/ROSES (Unspecified)
- 571 MONTIPORA
- 572 TURBINARIA
- 573 ECHINOPORA
- 574 PODABACIA
- 575 LEPTOSERIS

610 HARD CORALS WITH POLYPS EXTENDED
- 611 GONIOPORA/ALVEOPORA
- 612 EUPHYLLIA
- 613 PHYSOGYRA
- 614 TUBIPORA MUSICA
- 615 CATALAPHYLLIA

SOLITARY FREELIVING CORALS

710 ECONCATE FUNGIIDS (Unspecified)
- 711 HELIOFUNGIA ACTINIFORMIS
- 712 CYCLOSERIS
- 713 DIASERIS

720 ELONGATE FUNGIIDS (Unspecified)

730 SINGLE FLESHY POLYP
- 731 SCOLYMIA
- 732 TRACHYPHYLLIA
- 733 CYNARINA

740 BASKET CORALS (Unspecified)

SOFT CORALS

810 ERECT FLESHY CORALS
- 811 TUFTY LOW (Unspecified)
- 812 MASSIVE BRANCHING
- 813 SARCOPHYTON
- 814 SPIKEY SOFTS
- 815 XENIIDAE

820 PROSTRATE FLESHY CORALS
- 821 MASSIVE PROSTRATE
- 822 THIN ENCRUSTING
- 823 ZOOANTHIDS

SEA FANS AND WHIPS
- 831 FAN
- 832 WHIP
- 833 COMB
- 834 PUMPHELLA
- 835 BLACK CORAL BUSH

910 SPONGE
- 911 ENCRUSTING RIDGED SPONGE
- 912 VERTICAL LEAF SPONGE
- 913 VASE/CUP
- 914 ENCRUSTING (Unspecified)

STINGING HYDROIDS
- 921 BROWN FEATHER
- 922 WHITE FINE

ASCIDIANS

930 ASCIDIANS (Unspecified)
- 931 SMALL WHITE COLONIAL

FIGURE 3

Manta Tow Survey list of visually dominant organisms

Current development is aimed particularly at refining the VDO recording, so that the task of the observer is simpler and the reliability of the data is improved. Analysis of replicate samples reveals:

(1) that observers find some second order indicators difficult to discriminate;

(2) that there is a high level of correlation between some second order variables; and

(3) that some third order indicators which are visually distinct may be useful indicators of particular benthic communities.

The hope is that, by working closely with coral ecologists, it will be possible to redevelop the VDO categories, so that they focus particularly on indicative species and growth forms which can be used to record distribution of major community types.

ANALYSIS

The data can be used directly to describe the characteristics of reef sites, which can be readily plotted in map form or used for statistical analysis.

The data sheet is designed for easy data coding for computer classification analysis. Using strategies such as those discussed by Lance and Williams (1967a and b) can be valuable in analysis of the relative similarity of sites. Figure 4 presents such an analysis, conducted on data of the Great Barrier Reef Marine Park Authority by Mr. Gordon Bull of James Cook University of North Queensland (pers. comm.).

APPLICABILITY

For reconnaissance, the objective is to achieve descriptive coverage of large areas of reefs. The manta board technique can meet this objective and produce a reasonable understanding of the nature and extent of characteristics such as morphology, coral cover, condition and variability.

The precision of the technique is limited. For any substantial management or research initiative, the reconnaissance should be followed up by more detailed survey of representative or significant sites. The merit of the reconnaissance technique is, in part, that it enables the 'representativeness' of more detailed study sites to be seen in the context of the wider variability of the reef environment.

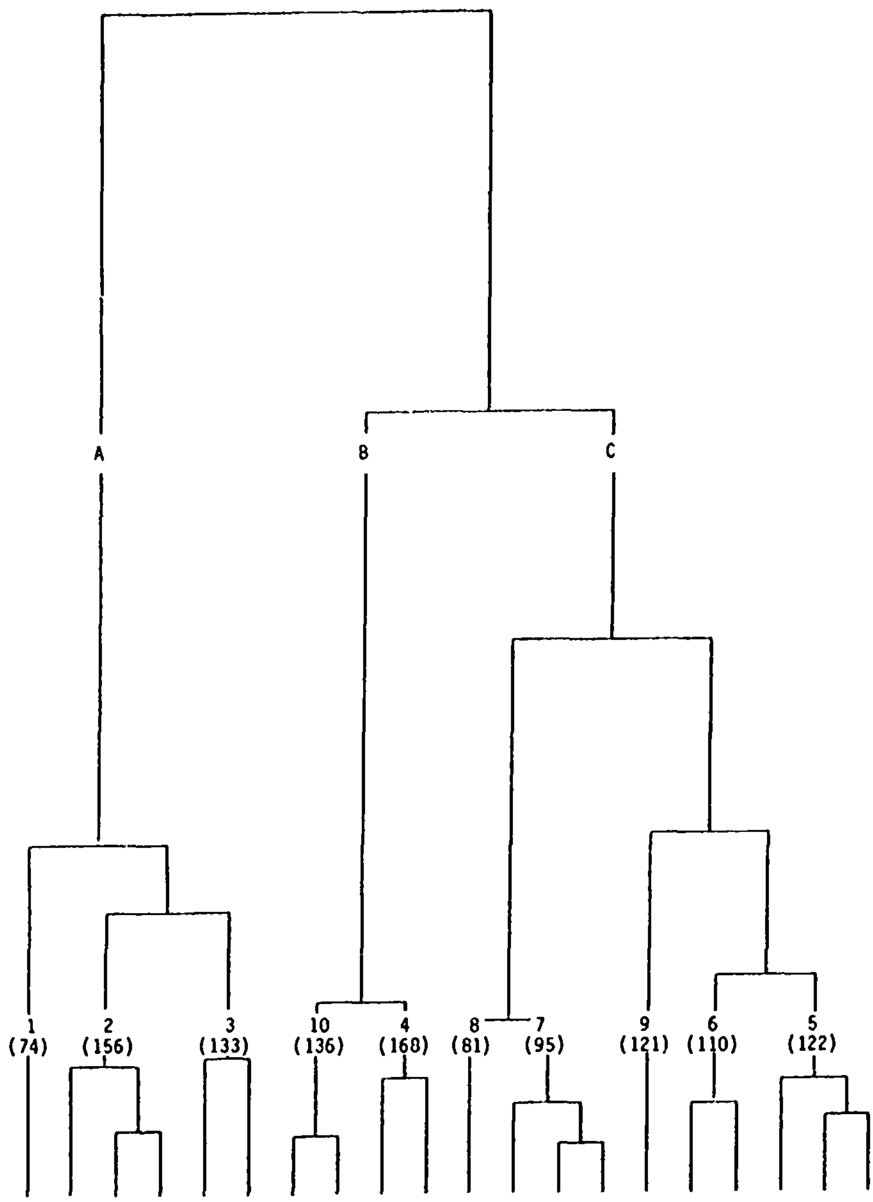


FIGURE 4

Denrogram showing fusion of the final 20 groups from classification of all 1196 sites. The ten site groups discussed are numbered (the number of sites in each group is in parentheses).

SATELLITE IMAGERY TECHNIQUES

The need to have a general description or condition over many square kilometres of isolated areas is shared by many agencies with responsibilities for planning or management of coral reefs and other tropical shallow sea environments. Even with techniques such as manta board reconnaissance, substantial and regular coverage is difficult, if not impossible.

The Great Barrier Reef Marine Park Authority, through a research arrangement of the CSIRO Division of Land and Water Resources, has had developed a number of analytical programmes for use of LANDSAT satellite data (Jupp et al.). These encompass:

(1) Geometric rectification to produce images at a scale of 1:250,000, acceptable under International Mapping standards.

(2) Indicative bathymetry with depth bands 0-0.5m, 0.5-2m, 2-5m, 5-15m, 15m.

(3) Broad-scale morphological or ecological maps based upon calibration or ground truth data for some sites within the satellite image scene.

Further analysis of the data can lead to production of 'exposure/depth' images (Fig. 5) and other specialised interpretations which may be of interest in planning or research investigations.

The exotic nature of spacecraft and the radiometric data which they sense remotely tends to lead to two phenomena.

The first is an expectation that they can solve all problems, which is unrealistic. This is often followed by the second, which is a reluctance to believe that data collected in space can be applicable to assessment of coral reefs.

The experience of the Great Barrier Reef Marine Park Authority is that satellite remote sensing offers valuable means of obtaining synoptic data over large areas. Interpretation of that data requires collection of on-site calibration, or ground truth, data. The combination provides an effective coverage of large areas and can be used to plan more detailed site investigations.

Other satellite systems with different spectral sensitivity, different data unit size (pixels) and different frequency of orbit offer a variety of potential applications, summarised in Figures 6 and 7 from Jupp (1983).

CONCLUSION

The limitations imposed by the marine environment, even in shallow water, are such that detailed studies can cover only very limited sites and time spans. Generally, the level of skill and training needed for detailed study are not readily available. Manta board and satellite data analysis techniques can provide the means to relate detailed study of small areas to the broader context for environmental studies and management.

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Lance, G.N. and W.T. Williams. 1967b. A general theory of classificatory sorting strategies. I. Hierarchical systems. Comp. J. 9: 373-380.

FIGURE 5

Exposure/Depth Images

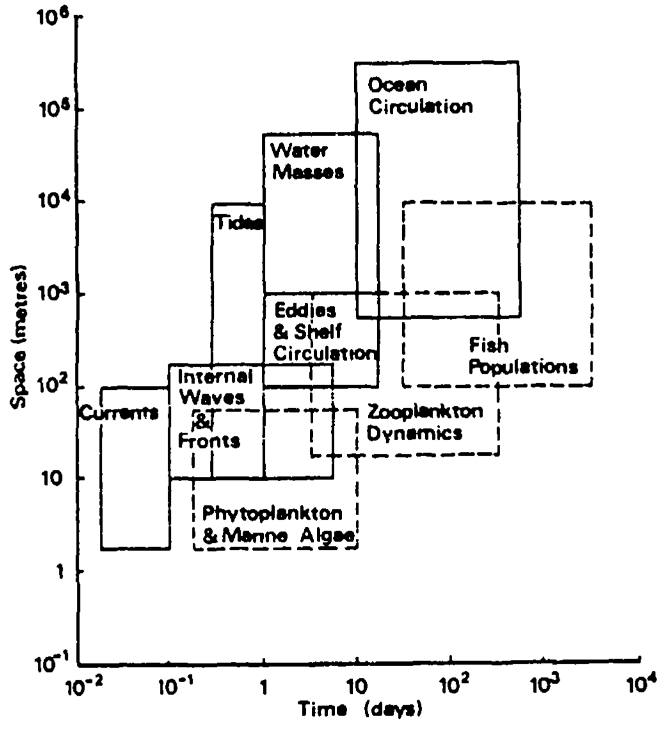


FIGURE 6
Time and space resolutions and extents for GBR phenomena

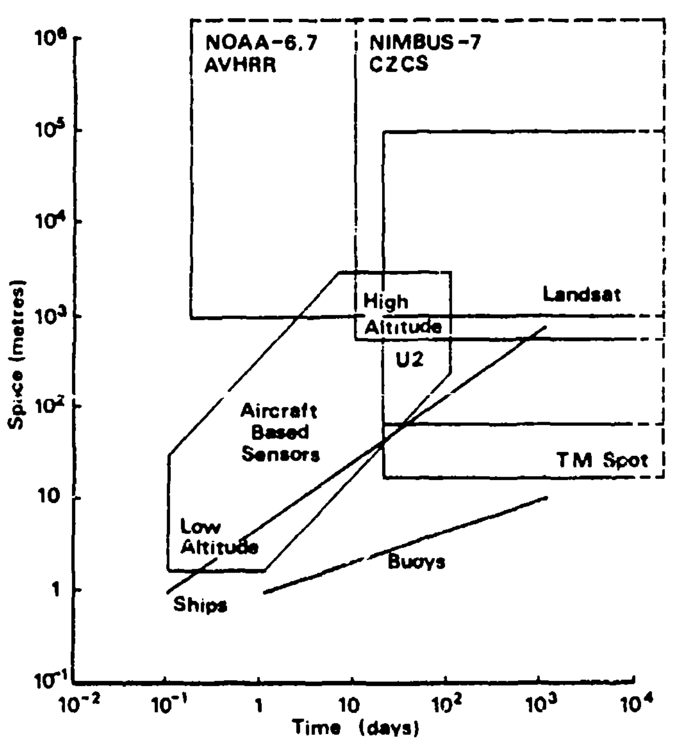


FIGURE 7
Time and space resolutions and extents for data platforms

4. CORAL REEF ASSESSMENT GOALS

Following the presentation of reports, participants evaluated the different survey procedures.

It was felt that general useful survey methodologies should conform to the following criteria:

(1) Not time consuming
(2) Inexpensive
(3) Operable with a small number of people.

In general, surveys should be classified as either shallow (to 15 metres depth) or deep (to 20 metres or beyond). This classification depends, essentially, on whether snorkeling and free diving or scuba diving are used. Regardless of the methods chosen, the essential goals of the survey should be similar or the same in both cases. It was pointed out that a scale permitting inter-reef comparisons in terms of quality should also be involved.

4.1 Terminology

Considerable discussion took place concerning the terminology used in the description of the geomorphology of coral reefs (Fig. 1). It appeared that "flat" and "slope" were used by all participants, but that the "rim" of a reef could also be called "crest" or "margin", with the understanding that a margin is essentially above water. Reefs in South East Asian countries were felt to consist of a "flat", a "rim", and a "slope", while reefs in the Pacific around Guam consist of a "flat", a "margin", a "reef front", a "terrace" and a "slope" (Fig. 1).

In surveying reefs, three main areas should be considered:

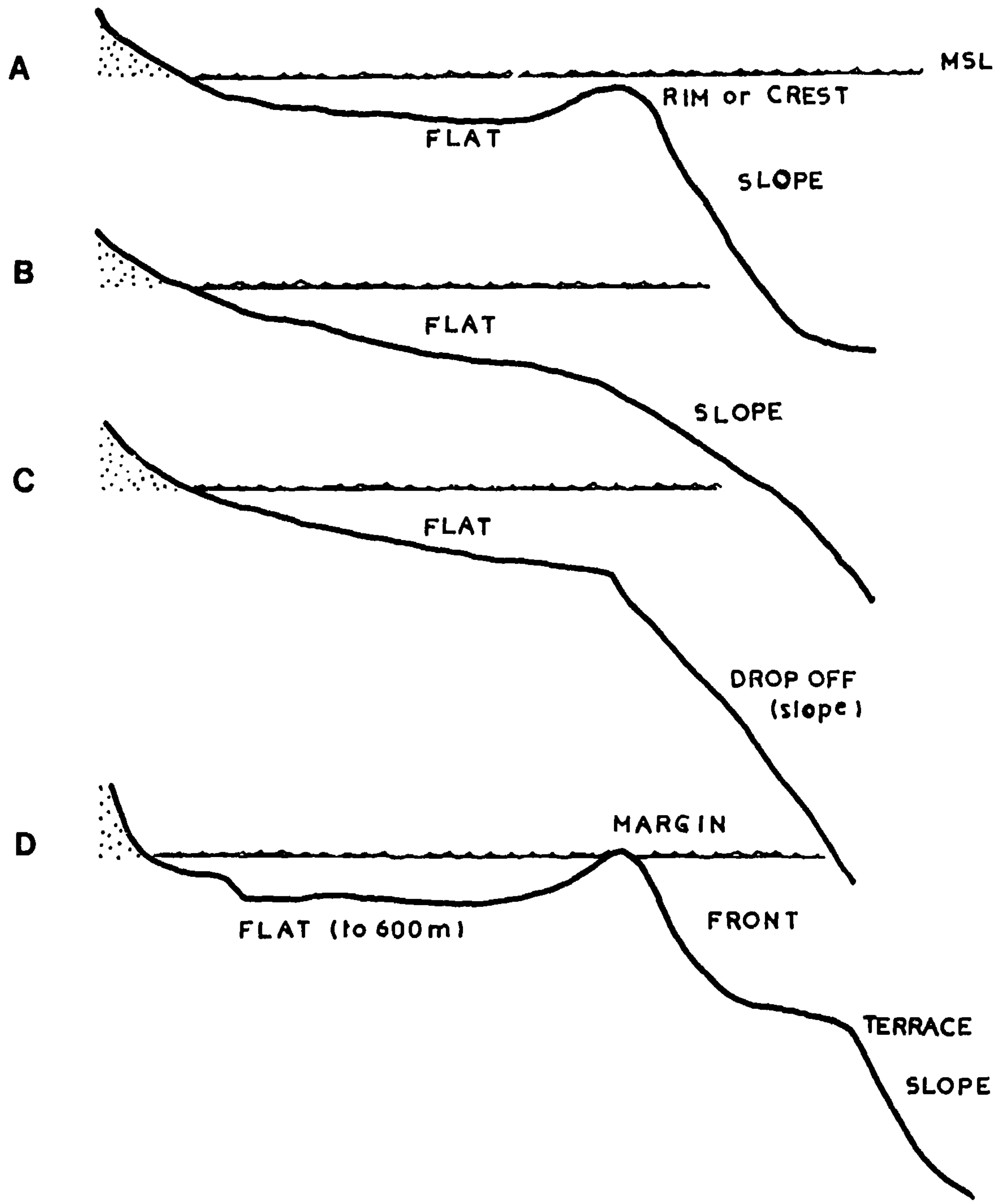
(1) the reef flat compared to the rim, especially with regard to run-off effects;
(2) the reef margin and front slope; and
(3) deep coral.

4.2 Survey Goals

It was agreed that a survey should be undertaken in two parts. First, a preliminary survey lasting at least 30 minutes should be undertaken to provide information on general descriptive characteristics of a reef. Second,

FIGURE 1

Commonly-encountered reef types in South East Asia and the Pacific. Types A, B and C are found commonly in South East Asia, whereas type D is characteristic of areas around Guam. The flat in type A may also contain a lagoon.



a detailed survey should be carried out.

The preliminary survey should include estimates of: area extent; general state of the reef (flourishing or stressed); type of reef (fringing, barrier, patch reef); zonation, if distinctive enough; predominant communities (algae or coral); type of substrate (silt, sand, rubble, rock, etc.); existence of major geomorphological features, such as lagoons; proximity of mangroves or seagrass beds to the coral reef; quality and abundance of fish life.

A detailed survey should then be undertaken to address the following questions, listed in order of priority:

(1) percentage coral cover
(2) species diversity
(3) growth form and relief
(4) percentage of algal coverage on dead coral
(5) quantitative assessment of fish life
(6) size distribution of corals
(7) associated fauna
(8) distribution patterns
(9) importance of reef as breeding and nursery area
(10) physicochemical parameters (temperature, salinity, turbidity).

4.2.1 Percentage Coral Cover

Participants tried to identify the most suitable survey method to assess each of the above questions. It was felt that percentage coral cover might best be addressed by one of the three following methods: line transect, quadrat estimate or point-centered quarter method.

The first method was considered suitable for the study of the distribution of sand, dead coral and rubble, as well as percent cover of live coral. The last method was considered more appropriate for the study of size distributions of live coral.

4.2.2 Species Diversity

Surveys to determine species diversity should normally be undertaken, in addition to studies of the percentage live coral cover. A 30-minute survey was recommended. Such half-hour surveys should be aimed at the discovery of as many species as possible, undertaken by several observers, and results averaged. A minimum reporting index for species diversity would consist of the absolute species number. The information, index H' was favoured. However, several species diversity indices should also be reported where possible. In cases where observers are unable to assess diversity at the species level, identification of genera could be accepted as a back-up system.

4.2.3 Growth Form and Relief

Growth form of coral reef can be assessed by classifying organisms into height categories, according to deviation above the substrate (e.g., 0.5; 1; 1.5 m). The mean height above the substrate, together with the standard deviation for the different life forms, should be reported. Part of the characterisation for this factor can be obtained from the species list. However, some reefs are very irregular, having overhangs and other cave-like features. These should be noted.

4.2.4 Percentage Algal Cover (Health Form)

The percentage of algal cover on dead coral can best be assessed by visual observations during a 30-minute swim or with the help of a towed observer with or without a manta board. Tow speed should not exceed 1 knot. An estimated cause of damage noted should be supplied. Freshly eaten corals (whitish patches) should be noted, together with numbers of *Acanthaster*, if present.

4.2.5 Fish Life

The quantitative assessment of reef-associated fish life should normally be limited to commercially important species. Participants discussed methods such as visual observation (Unesco Monograph in Marine Science No. 5), catching fish with gill nets and traps, and use of photography. To be consistent with procedures previously suggested, participants recommended that observations to determine the identity and density of fish should be carried out during 3 ten-minute swims, with the averaged result being reported. Both horizontal and vertical components of the reef should be covered.

4.2.6 Size Distribution

The point-centered quadrat method was generally recommended for studies of size distribution of corals, since it appeared to be less biased than most other techniques.

In the case of bombed reefs, corals settling on small fragments should not be reported, as they are unlikely to survive.

4.2.7 Associated Fauna

Associated fauna, such as commercially important invertebrates, should be reported as part of the results obtained by use of the transect/quadrat method. Animals of interest include echinoderms, holothurians, *Tridacna*, etc.

4.2.8 Distribution

The distribution pattern of corals in reefs should be defined by application of transect methods. Where transect methods are not used, a schematic description of the reef should be given.

4.2.9 Further Considerations

After discussion, participants felt that the assessment of the reef as a breeding and nursery area might better form part of the preliminary assessment. It was felt that no advice should be given on the selection of equipment for measurement of physico-chemical parameters.

Participants also agreed that coral reef survey and assessment studies should try to identify linkages between major on- and off-shore ecosystems, with specific regard to the principal energy and material exchanges.

4.3 East Asian Regional Seas Programme

Dr. E. Gomez presented the meeting with a review of the UNEP East Asian Regional Seas Programme concerning coral reef work. Additional details of this programme were given by Dr. D. Elder.

The University of the Philippines was proposed as a focal point where all literature, including graduate theses relating to coral reefs, from the South East Asian region, could be assembled. Copies of scientific articles could be distributed free of charge. The centre would also determine whether monographs in national languages could be included, provided that a translation of the title and the abstract are given in English. A particular attempt would be made to collect and disseminate any articles on coral reefs that could be described as falling under the category of "grey literature": i.e. articles produced outside of formal research and academic structures and appearing in journals without a "referee" system of selection.

5. FIELD ASSESSMENT OF SURVEY METHODS

After two days' discussion on the theoretical aspects of coral reef surveys, participants and observers travelled to Phi Phi Island to conduct field assessments of methods. Phi Phi Island is located about 30 miles southeast of Phuket in the Andaman Sea (Fig. 1).

The majority of work was carried out on a reef (the main reef) situated to the east of South Bay on Phi Phi Island (Ko Phi Phi Don). Secondary surveys were also applied to a reef on the west side of the bay (Fig. 2). These reefs are termed, respectively, the main reef and the west side reef for the purposes of this report.

Field work was divided into three sections:

(1) Preliminary survey;
(2) Systematic application of alternate quantitative procedures;
(3) Analysis and Summary.

5.1 Preliminary Survey

Preliminary surveys of each of the two reefs mentioned above were made by all participants to determine and then analyse the resulting range of subjective responses. Surveys were carried out by both snorkeling and scuba diving. Since the maximum depth at which coral occurred in the bay was about 12 metres, both forms of investigation were believed to be adequate.

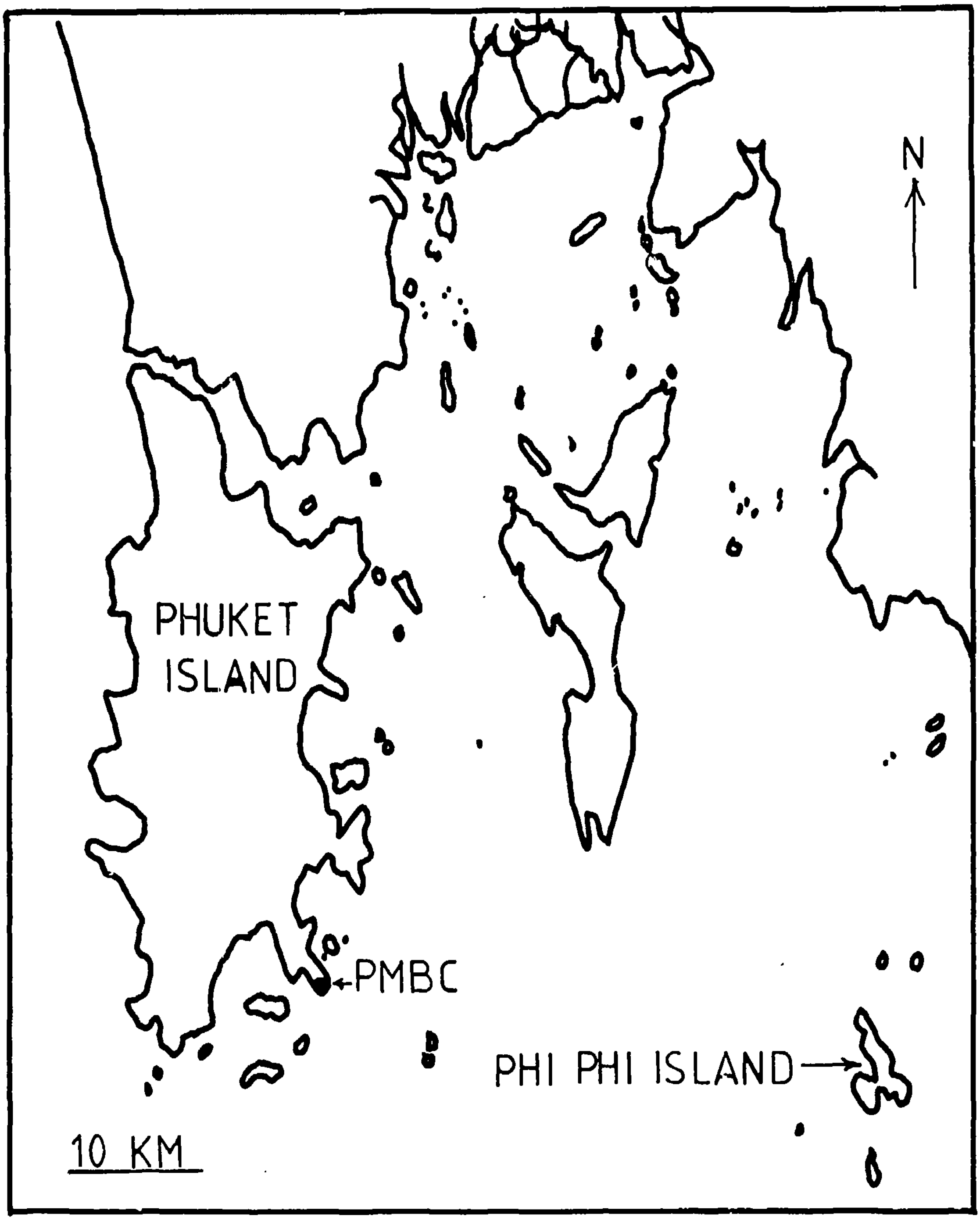
Visual estimates were generated for each of the factors listed in section 4. Results were recorded individually and independently (after dinner in the evenings) and then subjected to group discussion and analysis.

5.1.2 Reef Profile

Participants agreed that the main reef had the profile indicated in Figure 3.

The west side reef was similar in structure to the main reef, except that the overall lateral extent was foreshortened to about 20 metres. The west side reef flat was only about eight metres wide, as opposed to 30 metres on the main reef, and the slope was steeper.

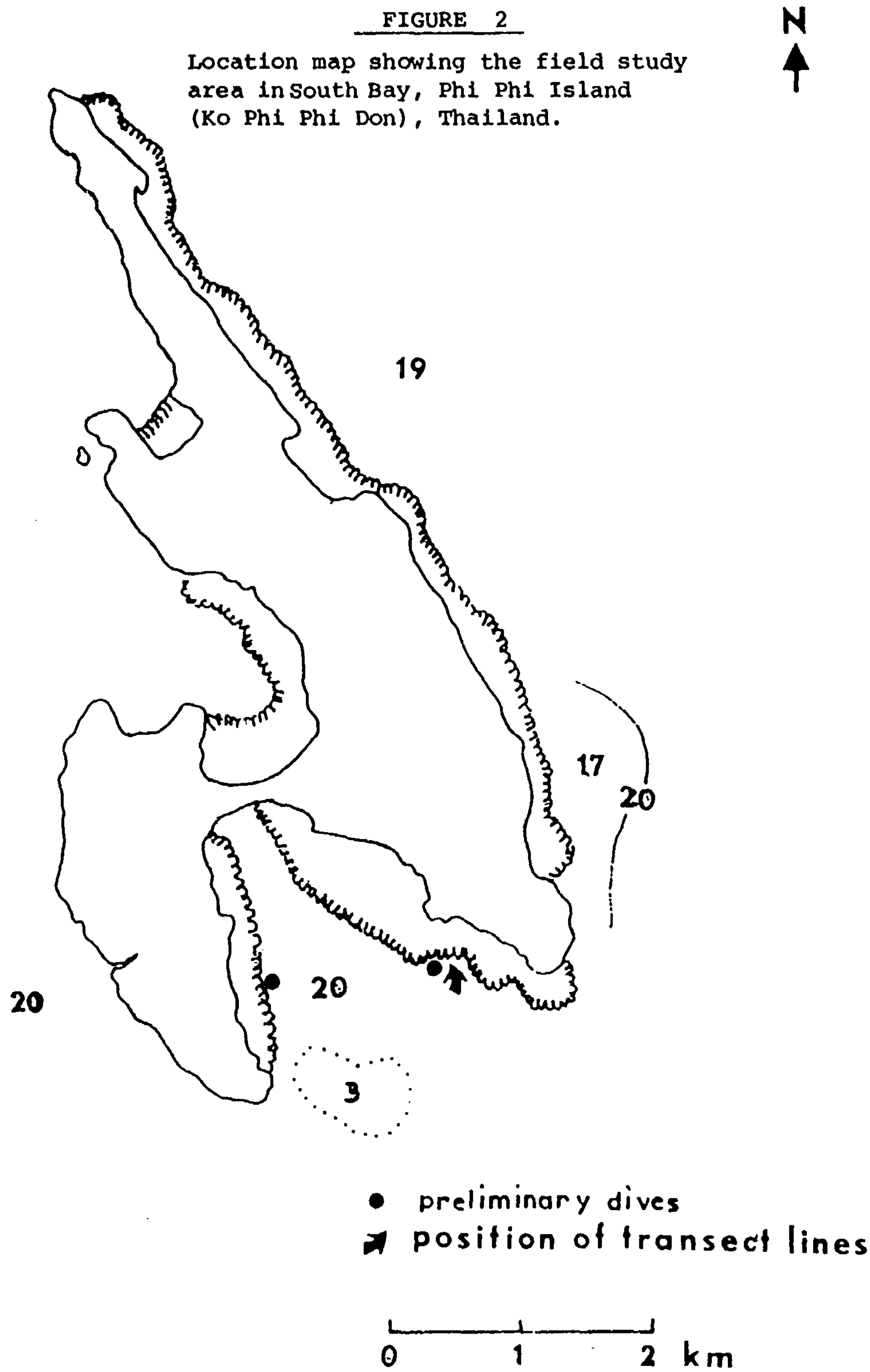
FIGURE 1



General location map of South West Thailand showing Phuket Island, the Phuket Marine Biological Centre (PMBC) and Phi Phi Island (Ko Phi Phi Don).

FIGURE 2

Location map showing the field study area in South Bay, Phi Phi Island (Ko Phi Phi Don), Thailand.

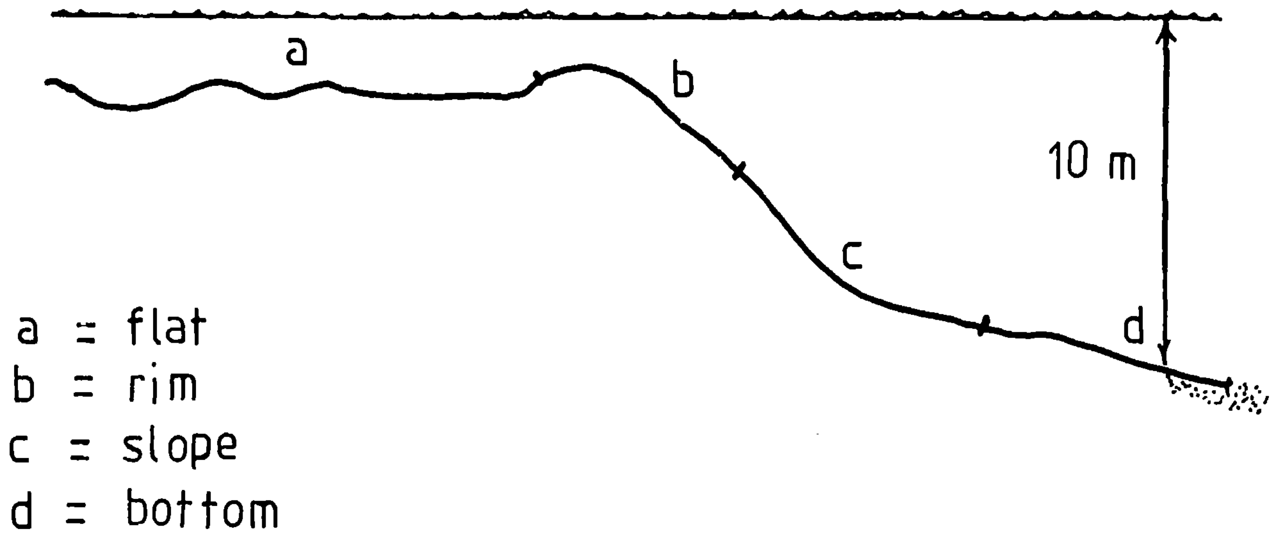


KO PHI PHI DON (scale 1:50,000)

Lat 7°45' Long 98°45'

FIGURE 3

Schematic cross-section of "main reef"
South Bay Ko Phi Phi Don, Thailand.



In all, the main reef, including all coral bearing sections on the flat, was approximately 60 metres wide by measurement, excluding a stretch of sand between the shore line and the start of the coral growth, which was 300 m in width.

5.1.3 Percentage Coral Cover

The width of the main reef from rim to bottom was estimated by a limited number of the participants as 30 m, 33 m, 50 m. One participant estimated the slope to be about 7 m. Percentage coral cover reported for the main reef is indicated in Table 1.

TABLE 1

Visual estimates of percentage live coral cover

Reef area (zone)	a	b	c	d	
Participants					
1	50	70	30	?	
2	60	75	80	?	
3	60	70	50	50	
4	-	65	-	-	
5	40	70	?	?	
6	?	85	70	30	
7	60	80	75	20	
8	70	85	30	?	
	56.7	75.0	55.8	33.3	Mean
	10.3	7.6	22.5	15.3	Standard Deviation

\- = participant did not swim over the area
? = participant unable to quantify the factor under consideration

5.1.4 Zonation

Table 2 indicates the dominant genera estimated to occur in each zone of the main reef.

TABLE 2

Visual estimates of genera dominating the main reef by zone

Reef area (zone)	a	b	c	d
Participants				
1	Porites	Porites	?	?
2	Porites	Porites	Lobophyllia	
		Acropora		
3	Porites	Acropora	Pectinia	Plerogyra
				Lobophyllia
				Fungia
4	Porites	Porites	Pectinia	Fungia
5	Porites	Porites	?	?
		Acropora		
6	Porites	Porites	Pectinia	Pectinia
		Lobo-phyllia	Plerogyra	Fungia
7	Porites	Porites	Pectinia	?
8	Porites			
	Acropora	Acropora	?	?

5.1.5 Diversity

Because of the comparatively short nature of the preliminary survey (one half hour), participants generally estimated coral diversity in terms of genera only.

Most participants gave one number to account for all areas combined for the main reef (Table 3). They agreed however that there were probably more genera present on the reef than the ones they observed and that most were to be found on the reef rim or crest.

TABLE 3

Visual estimates of the numbers of coral genera in zones a, b and c of the main reef

Reef area (zone)	a	All areas
Participants		
1	6*	25
2		25
3		24
4		
5		
6		35
7		25
8		23

mean = 26

* refers to number of species on the reef flat (one participant)

When participants drew up a pooled list of coral genera observed (Table 4), it appeared that the total number recorded was significantly higher than the number reported by any individual. It can, therefore, be concluded that, on this reef, an increase of the number of observers by a factor of 4 resulted in a 20% increase in the number of observed coral genera in a 30-minute swim.

TABLE 4

Pooled list of coral genera observed during preliminary survey of main reef

Acropora *	Plerogyra +	Heliopora
Fungia *	Millepora *	Euphyllia +
Herpolitha *	Symphyllia *	Polyphyllia
Porites *	Hydnophora *	Merulina *
Favites *	Pocillopora +	Pectinia *
Goniopora *	Diploastrea	Physogyra
Distichopora	Pavona *	Pachyseris *
Lobophyllia +	Echinopora *	Goniastrea *
Favia *	Montipora *	Synaraea
Platygyra *	Galaxea *	Montastrea
	Total = 30	

+ = Verified on transect survey only
* = Verified by subsequent collection

Commenting on the west side reef, five participants felt that it exhibited a diversity similar to the main reef. One felt the diversity was reduced because of the narrower reef form and two were of the opinion that a more diverse coral community was to be found there.

One participant felt that the fact that table Acropora occurred in higher numbers on the west side reef than on the main reef could be used as an indication of a more diverse and healthy community. Another participant pointed out that the west side reef showed a decrease in diversity toward the head of the bay.

5.1.6 Reef Condition

Participants evaluated the condition of the reef in relation to their accumulated experience from other reefs. On an arbitrary scale of 0 to 100, where 100 refers to a reef in optimum condition and 0 to a dead reef, the following terms were used:

Excellent	100-76
Good	75-51
Fair	50-26
Poor	25- 0

Results of the review are presented in Table 5.

TABLE 5

Summary of visual estimates of quality made for the main reef

Participants	Quality of Total reef area	Points allocated	
1	Poor	25	
2	Good	60	
3	Good	60	
4	Good	75	
5	Excellent	80	mean point score = 59.0
6	Good	65	
7	Good	60	
8	Fair	50	

Commenting on the west side reef, two observers felt that conditions were excellent and better than those at the main reef. The rest were of the opinion that conditions on the west side reef were similar to, if not less healthy than, the main reef.

5.1.7 Growth Form and Relief

Relief of the reef was assessed in three categories: low (0-10 cm), medium (10-50 cm) and high (>50 cm). Participants agreed that reports on reef relief should contain only data on the actual condition of the reef. They should not refer to a known or suspected potential for growth. Thus, when high growing corals are limited in growth by tidal action, the actual height should be reported. The results of the individual assessments are presented in Table 6.

TABLE 6

Summary of relief for main reef developed from visual estimates

Reef area (zone)	a	b	c	d
Participants				
1	M	M	H	?
2	M	M	H	?
3	M	M	H	L
4	?	H	H	M
5	M	H	?	?
6	M	H	H	L
7	M	H	H	L
8	M	H	?	?

5.1.8 Reef Damage

Damage of the reef was reported in two categories: natural and man-made (Table 7). All participants agreed that whatever damage they observed was slight in comparison to conditions they know exist on other reefs. The results of the survey are as follows:

TABLE 7

Visual estimations of damage to the main reef

Participants	Man made	Natural
1		Silt
2	Anchor	
3	Anchor	
4	Fishing	
5	General	
6	Anchor	Storm
7	Fishing, Anchor	
8	Fishing	

5.1.9 Fish Life

Abundance and diversity of fish life on the reef was estimated by the same 100 point scale used in section 5.1.6. The results are shown in Table 8.

TABLE 8

Summary of visual estimates relating to quality of fish life associated with the main reef

Participants	Fish life
1	Poor
2	Good
3	Fair
4	Good
5	-
6	Good
7	Fair
8	Poor

5.2 Field Assessment Quantitative Surveys

Three approximately parallel transects were laid out by the junior staff of the Phuket Marine Biological Centre, starting approximately 300 m from the shore line at the inward edge of the reef. The transects then ran 60 metres from the shoreward to the seaward edges of the main reef (see Chapter 5, Fig. 2 for location). The transects were set at right angles to the beach. The seaward end terminated approximately 10-15 metres from the foot of the slope.

A number of survey methods were then applied, using the transects as guidelines. These were, respectively, the point-quarter method used in Guam and Singapore, the intercept line transect method used in Malaysia and Singapore, the transect/quadrat method used in the Philippines, and the photographic transect method used in Thailand. Additionally, two 20 metre line transects, as used in Indonesia, were also set up parallel to the shore line on the margin and within the reef flat. This survey is referred to as a plotless line transect, using spaced point intercepts. Each survey was performed under the guidance of the investigator most familiar with the procedure in question. In the case of the photographic transect survey, the work was carried out by junior staff of the Phuket Marine Biological Centre.

As a further exercise, all participants applied the point-quarter method on the reef rim in zone b, while following the central transect line.

Finally, as many coral species as possible were collected for later positive identification during a half-hour scuba swim down and up one transect and across the reef slope, rim and flat, separately, on both the main reef and on the west side reef.

5.2.1 The Point-Quarter Technique

The basic concept of the point-quarter method is that the average abundance of coral species or other species of sessile organisms can be measured by the average distances from random points to the centre of colonies or individuals. The shorter the average distance from a random point to the nearest colony, the more colonies there are per unit area. When the average distance is squared, an average square area in which one individual or colony occurs is obtained. If this average occupied area is divided into the unit area, the abundance or density or number of individuals per unit area will be obtained. The average surface coverage for each species can then be obtained by multiplying the average surface area of colonies of each species times their average abundances.

5.2.1.1 Application

The random points from which measurements are made can be obtained by laying a transect, by randomly tossing an object with right angles in its structure, or by a combination of both (tossing an object at points along a transect). Four measurements must be made from each random point, one and only one in each quadrant. The four quadrants can be visualised as marked by the transect line and an imaginary line running perpendicular to the transect line through the point (Fig. 4a), one line running along the handle of the hammer and another perpendicular to the handle, through the blade. The imaginary point from which measurements are made is the intersection of the handle with the blade (Fig. 4b). Or, imaginary lines at right angles to each other could be determined by any other object tossed at random, i.e. a diving knife (Fig. 4c).

The first measurement to be made in each quadrant is the distance from the sample point to the centre of the nearest colony or to the centre of the nearest item being sampled (Fig. 4). The next two measurements are the length (or longest dimension) and the width (or longest dimension at right angles to the length). Data should be recorded in the field in an organised manner, in order to facilitate later computations (Table 9).

The area of each colony is estimated by multiplying the length times the width and taking the square root (the geometric mean diameter). The mean diameter is then divided by 2 to obtain the radius which is squared and multiplied by π to obtain an estimate of the area, i.e., $\pi\left(\frac{\sqrt{L \times W}}{2}\right)^2 = A$.

If the colony is not roughly circular but is, instead, somewhat rectangular, triangular, L-shaped, or of some other configuration, the area may be estimated however the observer believes is best, without spending too much time (Fig. 5).

It is important to remember to measure to the nearest colony centre. The borders of some colonies may be nearer than the centres of other colonies, but the measurement should be made to the nearest centre (Fig. 5b).

FIGURE 4

An illustration of the point-quarter sampling technique as described and explained in the text. ▬▬▬▬▬▬ indicates imaginary lines determining the 4 quadrants; — — — — — indicates direction of measurements for distances between the random point and the centre of the nearest coral colony in each quadrant; >———< indicates length or width measurements of the coral colony.

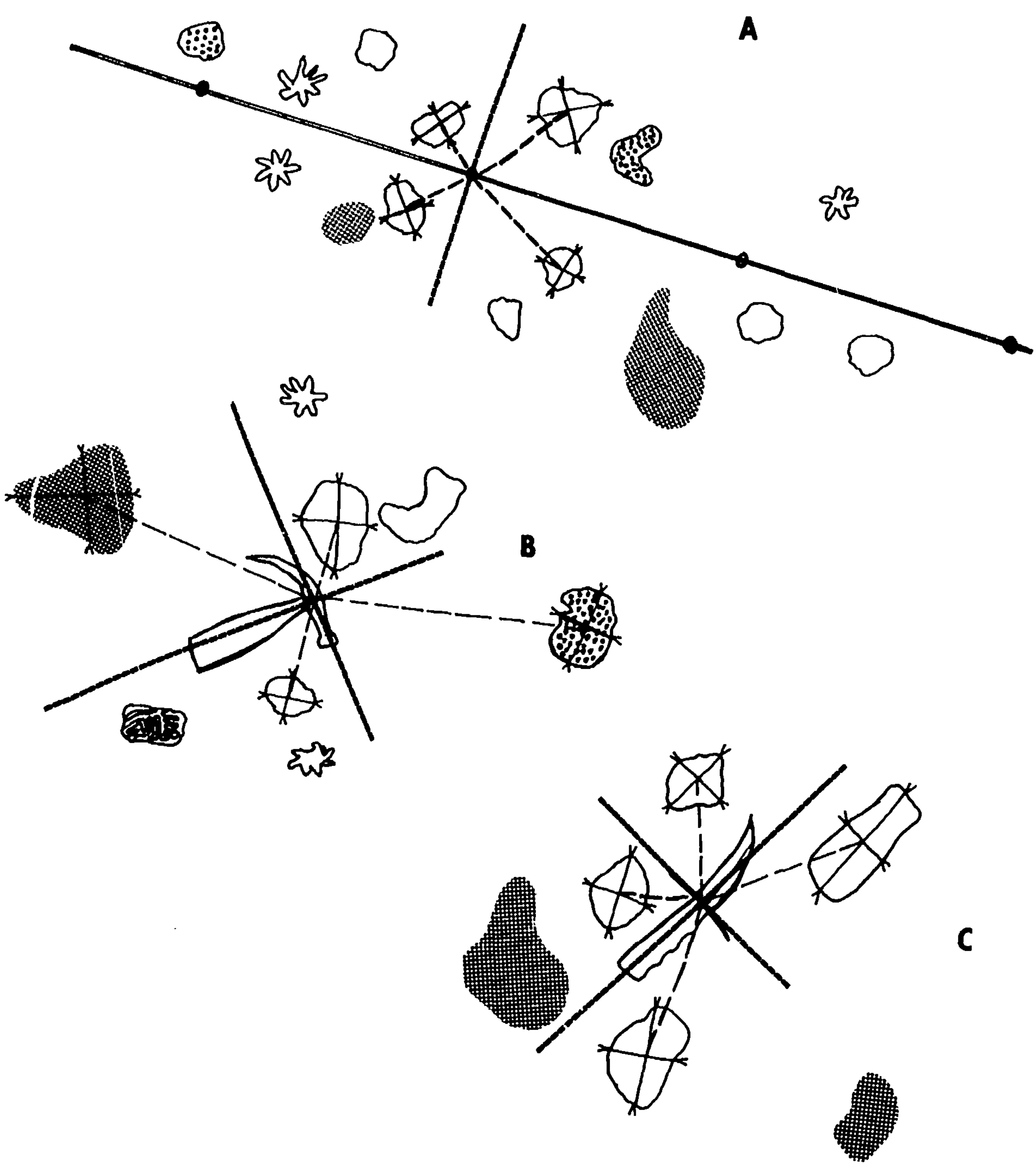


TABLE 9

An example of an efficient format for recording field data from the point-quarter method. The areas would be calculated later, but a column is included on the same paper for efficiency. The means of each four distances and areas taken from the same point could be calculated separately for an additional level in nested analysis of variance. If the subject being sampled is not found in a quadrant, there are methods for taking zero-quadrants into account (Warde and Pertanka, 1981), but it is better to attempt to find a coral in each quadrant no matter how far the search must be extended (within the limits of time available).

Date:

Location:

Zone:

Distance	(Length x Width)	Species	Area
	(x)		
	(x)		
	(x)		
________	(x)		
	(x)		
	(x)		
	(x)		
________	(x)		
	etc.		

The formulae for computations are:

$$\text{abundance (density) of all species} = \frac{\text{unit area}}{(\text{mean distance})^2}$$

$$\text{relative abundance of a particular species} = \frac{\text{frequency of a particular species}}{\text{total number of individuals measured}}$$

$$\text{abundance (density) of a particular species} = \left(\text{abundance of all species}\right) \times (\text{relative abundance})$$

$$\text{percent cover of all species} = \left(\text{average area of all species}\right) \times \left(\text{abundance of all species}\right)$$

$$\text{percent cover of a particular species} = \left(\text{average area of a particular species}\right) \times \left(\text{abundance of a particular species}\right)$$

$$\text{relative percent cover of a particular species} = \left(\frac{\text{percent cover of a particular species}}{\text{percent cover of all species}}\right)$$

The original presentations of this method (Cottam *et al.*, 1953; Cottam and Curtis, 1956; Cox, 1972) provide formulae for calculating indices of "dominance" or "importance value". In this treatment, compund indices of this form are omitted since it is felt that they have little statistical validity or strength and the otherwise accompanying terminology invites subjective conclusions or interpretations.

5.2.1.2 Results of the surveys with the point-quarter method at the Ko Phi Phi Don, South Bay main reef

Samples were taken in Zone b with the point-quarter method by a participant who regularly uses this method as his primary sampling technique. The point-quarter method was also used in Zone b by six other participants who had not previously used the technique. Results are compared in Table 10. Although samples obtained by the experienced participant more often fell near *Porites lutea* and the samples of the others more often fell near *Fungia fungites*, the overall percent cover by living coral is quite similar in the two estimates. Perhaps this is partly because, even though small *Fungia fungites* were encountered more frequently than the larger *Porites lutea* in the second series, the size distributions of corals help reduce the effects of sampling error when the size of each coral encountered is taken into account.

FIGURE 5a

Area of coral colonies should be estimated by as efficient an approximation as possible. The great range in sizes of coral colonies determines that the number of colonies measured is more important than the precision of the measurements.

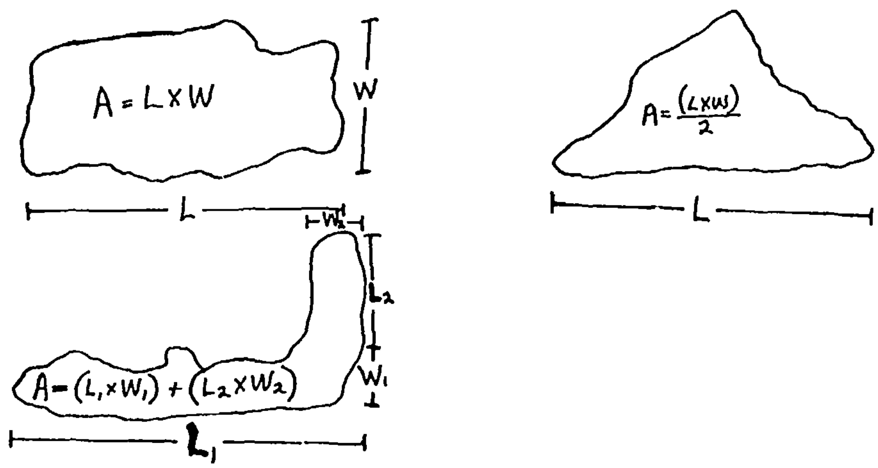


FIGURE 5b

Measurements should be to the nearest colony centre rather than to the nearest colony edge.

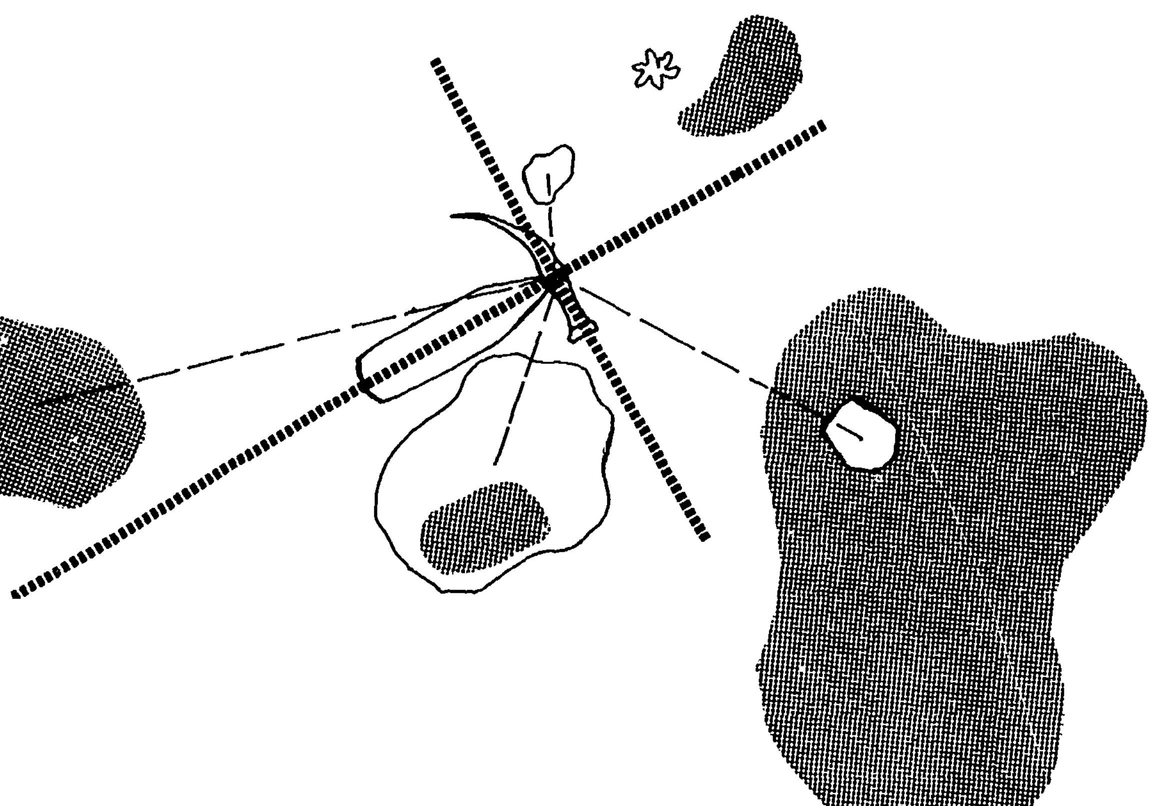


TABLE 10

Results of the point-quarter survey in Zone b by Birkeland in comparison with results from another six persons who were using the sampling technique for the first time. For each species or genus of coral, the percent of living surface cover (open numbers) or percent of numbers of colonies (numbers in parentheses) are given as a proportion of living coral cover, not of total substratum surface.

	Birkeland	six others
(number of distances or colonies measured)	74	24
Percent cover by living coral of total substratum surface	83.2	86.5
Number of colonies per m^2	5.07	11.2
Stylocoeniella armata	0.01 (1.34)	
Acropora sp.	15.86 (9.59)	4.01 (8.33)
Montipora sp.	9.93 (13.70)	11.24 (25.00)
Fungia fungites	0.20 (6.85)	3.10 (25.00)
Herpolitha limax	0.58 (4.11)	
Porites lutea	47.18 (24.66)	76.98 (16.67)
Porites (Synaraea) undulata	0.14 (1.34)	
Favia sp.	2.92 (1.34)	
Favites sp.		0.55 (4.17)
Goniastrea sp.	0.21 (4.11)	
Leptoria phrygia	0.77 (1.34)	

TABLE 10 (Cont'd.)

	Birkeland	six others
Diploastrea heliopora	1.49 (4.11)	
Leptastrea sp.	0.05 (1.34)	
Echinopora lamellosa		0.17 (4.17)
Merulina ampliata	0.55 (2.74)	0.97 (4.17)
Lobophyllia sp.	4.56 (2.74)	
Symphyllia sp.	0.67 (4.11)	2.11 (4.17)
Pectinia lactuca	12.26 (10.96)	0.86 (8.33)
Euphyllia sp.	0.08 (1.34)	
Plerogyra sinuosa	0.77 (1.34)	
Sinularia sp.	0.55 (1.34)	
Millepora sp.	0.92 (1.34)	

By taking both distance (abundance) and colony size into account, the point-quarter technique is relatively robust. Of course, few samples were taken and the best way to reduce sampling error is to take more samples.

A description of the coral community structure in the three zones, as determined by the point-quarter method, is given in Table 11. In terms of both surface cover and frequency, the predominant coral in Zone c was Pectinia lactuca. Zone b had, by far, the greatest diversity of corals, whether determined in terms of surface cover or numbers of colonies. It would have been far better to have identified all the corals to the species level. This should be done on any real survey.

5.2.1.3 Discussion and Conclusions

The mechanical procedures of the point-quarter technique tend to eliminate subjective decisions on the part of the person collecting the data. Cottam and Curtis (1956), Crockett (1963), and Weinberg (1981) each compared results from various sampling techniques and found the point-quarter technique to be the least susceptible to subjective bias. Although Weinberg (1981) preferred drawing a map of colonies within a grid and estimating areas from the drawing, he also admitted that the point-quarter method was the least subjective. Cottam and Curtis (1956) further noted that the point-quarter technique was more efficient and easier to use than any of three other distance measures. Dix (1961) and Penfound (1963) found that the point-quarter technique was much faster and, at the same time, just as accurate as any other sampling method. Dodge et al. (1982) found the point-quarter method to be reliable and had the advantage over many other techniques of providing additional information on absolute abundance and size distributions.

An additional advantage of the point-quarter method over the transect methods is that it provides data on size distributions of each species in terms of area. Size distribution data can provide insight into the nature of the population dynamics of each species. Also, if colonies are widely spaced, the point-quarter method allows one to precisely measure the distance to the nearest colony in each quadrant, no matter how far it may be. The transect method might only allow the accumulation of zeros. If only zeros are accumulated, we might have no idea of the order of magnitude of the scarcity of a species. However, the point-quarter method is best used for discreet colonial organisms, such as hard corals, soft corals, anemones or large sponges. The point-quadrat, the line-intercept, or the wire-grid-quadrat-count method would be better in recording the nature of any indiscreet or amorphous substratum encountered, such as sand, dead coral, filamentous algae, filmy sponges, or detritus, if it is desired to sample these as well as corals.

As mentioned above, the point-quarter survey provides us with size distribution data which, if we assume size relates directly to age, allows us to speculate on community dynamics in the various zones. As an example, let us take the size distribution data for *Porites lutea* (27 from Zone a and 22 from Zone b). *Porites lutea* was much larger, on the average, in Zone b (Table 12 and Figure 6). This suggests that Zone b is a more suitable or secure habitat for *P. lutea* than the reef flat, since the species generally either lives longer, has a greater probability of survival, or grows faster in the former, as opposed to the latter, location.

TABLE 11

Description of the three zones of the Ko Phi Phi Don South Bay Main coral reef from a survey using the point-quarter method. Zone B data were compiled by combining the two sets in Table 10. As in Table 10, for each species or genus of coral, the percent of surface cover (open numbers) or the percent of colonies (numbers in parentheses) are given as a proportion of living coral cover rather than of total substratum surface area.

	Reef Flat (a)	Zone b	Zone c
N (number of distances or colonies measured)	52	98	16
Percent cover by living coral of total substratum surface	20.2	84.0	28.6
Number of colonies per m^2	1.5	6.6	4.2
Stylocoeniella armata		0.01 (1.01)	
Pocillopora damicornis	0.23 (4.17)		0.12 (6.25)
Acropora sp.	2.36 (4.17)	12.96 (9.28)	
Montipora sp.	5.24 (8.33)	10.25 (16.47)	
Fungia fungites		0.91 (11.29)	
Herpolitha limax		0.44 (3.10)	
Porites lutea	86.59 (56.25)	54.48 (22.70)	
Porites eridani	0.07 (2.08)		
Porites (Synaraea) undulata		0.11 (1.01)	
Favia sp.	0.44 (2.08)	2.20 (1.01)	
Favites sp.	0.22 (4.17)	0.13 (3.15)	

TABLE 11 (Cont'd.)

	Reef Flat (a)	Zone b	Zone c
Goniastea sp.	1.99 (6.25)	0.16 (3.10)	
Leptoria phrygia		0.58 (1.01)	
Hydnophora sp.	0.26 (4.17)		5.79 (6.25)
Diploastrea heliopora		1.13 (3.10)	
Leptastrea sp.		0.04 (1.01)	
Cyphastrea sp.	0.23 (2.08)		
Echinopora lamellosa		0.04 (1.01)	
Merulina ampliata	0.89 (2.08)	0.65 (3.09)	
Lobophyllia sp.		3.44 (2.07)	
Symphyllia sp.	0.23 (2.08)	1.02 (4.12)	2.06 (6.25)
Pectinia lactuca		9.47 (10.32)	92.03 (81.25)
Euphyllia sp.		0.6 (1.01)	
Plerogyra sinuosa		0.58 (1.01)	
Sinularia sp.		0.40 (1.01)	
Millepora sp.	1.18 (2.08)	0.69 (1.01)	

$H' = \Sigma p_i \log_2 p_i$

for surface cover	0.9275	2.3297	0.4753
for numbers of colonies	2.4779	3.5524	0.9934

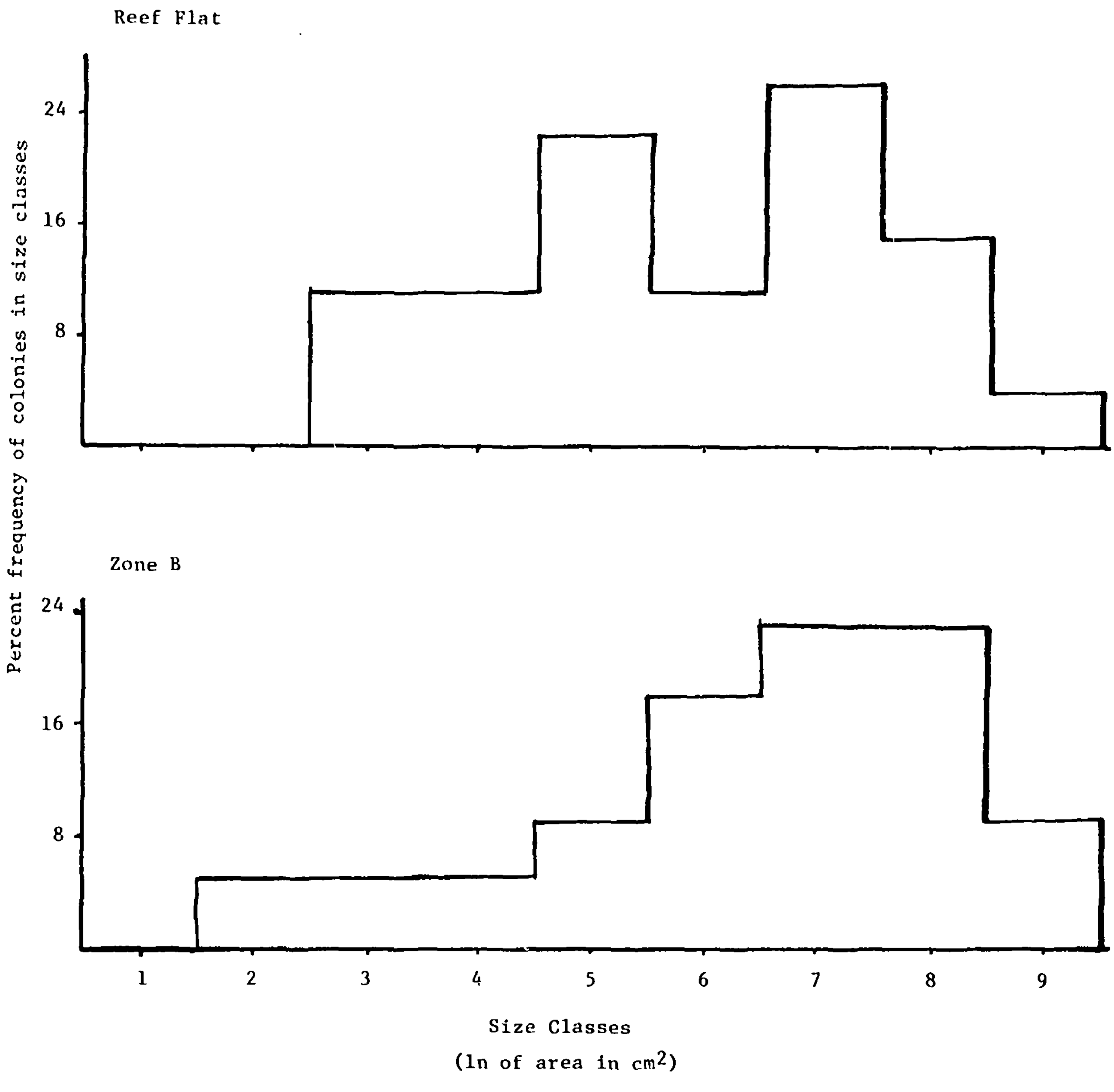
TABLE 12

Some aspects of the size distribution (in cm^2) of Porites lutea on the Reef Flat and in Zone b.

	Reef Flat (a) (n= 27)	Zone b (n = 22)
Mean size	2078	3625
Median size	565	1233
Smallest in samples	32	9
Largest in samples	17,671	18,600

FIGURE 6

Size classes of *Porites lutea* on the reef flat and in Zone b at Ko Phi Phi Don. The size classes are converted to natural logs because areas are in squared units.



On the other hand, the smallest *P. lutea* was also found in Zone b (Table 12) and the size distribution was more evenly spread out (Figure 6). This suggests that recruitment may be more regular in Zone b. The size distribution in Zone b more closely resembled a normal distribution, while the size distribution on the reef flat was more irregular and dominated by two particular size classes (Figure 6). The size distribution suggests that Zone b is not only more secure and suitable for *P. lutea* than is the reef flat, but it is, perhaps, also more stable, with relatively regular mortality and compensatory regular recruitment. Of course, this is speculation, but the size distribution data from the point-quarter methods allow potentially greater insight for generating hypotheses along these lines.

5.2.1.4 References

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5.2.2 Transect/Quadrat Survey

The survey was conducted following the general methodology used in the Philippines for a nation-wide assessment of coral resources. The method has been reported previously (see section 3.5, Gomez and Alcala, 1979). Here, it is described with the modifications employed.

5.2.2.1 Methods

Instead of setting down new transects, the three parallel transects laid out at Phi Phi Island by the staff of the Phuket Marine Biological Centre were utilised (section 5.2). A metal quadrat, measuring one square metre and subdivided into sixteen smaller squares, was laid down at the head (shallow end) of each transect. The depth was recorded and the substrate under each of the small squares was noted. If at least half of the square was occupied by live coral (or some other substrate such as sand, rubble, algae), that square was tallied as one under the appropriate column on the writing slate used by the observers. Thus, each row on the slate would have a total of sixteen subdivisions.

After each completed set of observations, the quadrat was moved ten metres down the transect and the observations repeated. This process continued down the reef until the end of the reef was reached.

General observations on dominant coral taxa and conspicuous organisms were also noted. Horizontal and vertical visibility was recorded. Any damage to the reef was also assessed and noted.

The data thus recorded on underwater writing slates were transcribed to data sheets at the end of the day. Averages were computed and the percentage coral cover (both hard and soft) was determined. The results are given on the three data sheets accompanying this report.

5.2.2.2 Results

When the three transects were averaged, the overall coral cover appeared in the fair to good range, above 45%. (See summary in Table 13a).

TABLE 13a

Summary of coral cover estimates obtained by the transect/quadrat survey method for transects 1, 2, and 3

Transect	1	2	3
Live coral cover	53.1%	38.4%	45.5%
Mean overall coverage (live coral) = 45.6%			
Mean coverage (live coral) for two areas A and B = 44.5%			

As carried out, the survey did not address the question of species diversity. However, this can be done by mapping the corals on the quadrats, instead of merely determining coral cover. Mapping entails more time, but yields more information. It would necessitate modifying the writing slates to include grids in addition to, or instead of, columns. The method used required about 15 minutes for each transect. Mapping would require about double or treble that time. It is estimated that a broad reef tract may require one tankful of air for an experienced observer to survey. Consideration of the time involved will determine the detail to be included in the survey for particular circumstances.

Data records for the individual transects are shown in the following three tables (Tables 13b, c, and d) for the transect/quadrat survey. The observations were obtained from transects 1, 2, and 3, respectively. Note:

stations 0-30 cover section a (reef flat)
station 40 covers section b
station 50 covers section c
station 60 covers section d.

TABLE 13b
Transect 1

Location (Island): Phi Phi Dong, Thailand Observers: E. Gomez and P. Boonyanate

Date : December 16,1982 Time of Observation: 11.00 A.M. Methods : Scuba

VISIBILITY: Horizontal - 6-8 m Vertical - 6 m

LOCALITY (Specific location): South channel, east reef

I. South transect

CONDITION OF REEF

STA	DEP	HC	SC	DC	R	S	(Optional)	NOTES
60	35'	-	-	-	-	16		No reef
50	25'	15	-	-	1	-		
40	15'	8	-	-	4	3	1 (Petrosia)	
30	8'	15	-	-	1	-		
20	7'	9	-	-	7	-		
10	7'	-	-	-	-	16		
0	6'	4	-	-	11	1		
		51/6**						
AVG		8.5						
%		53.1						

DISTANCE FROM SHORE
Shallow end 100 m
Deep end 160 m

CAUSE OF DESTRUCTION
Anchor

EXTENT OF DAMAGE
Slight

DOMINANT TAXA OR FORMS
Porites, Acropora

CONSPICUOUS ASSOCIATED ORGANISMS
Fish -
Damsels, anthiids, etc
Invertebrates -
Diadema
Algae -
None

REMARKS

**Since the reef ended before the deepest quadrat, the divisor is only 6 which equals the number of quadrats scored.

Note: The numbers entered in columns HC, SC, DC, R and S represent the number of quadrat subdivisions (possible total of 16) occupied by the elements under consideration at each station.

STA: Station (metres from shallow end); DEP: Depth (feet); HC: Hard Coral; SC: Soft Coral; DC: Dead Coral; R: Rock; S: Sand; AVG: Average; % percentage cover live coral.

TABLE 13c
Transect 2

Location (Island): Phi Phi Dong, Thailand   Observers: E. Gomez and P. Boonyanate

Date : December 16, 1982   Time of Observation: 11.15 A.M.   Methods : Scuba

VISIBILITY: Horizontal - 6-8 m   Vertical - 6 m

LOCALITY (Specific location): South channel, east reef

II. Middle transect

CONDITION OF REEF

STA	DEP	HC	SC	DC	R	S	(Optional)	NOTES
60	35'	3	-	-	-	12	1(Sponge)	
50	25'	9	-	-	4	3		
40	12'	3	-	-	13	-		
30	6'	4	-	-	12	-		
20	6'	8	-	-	1	7		
10	6'	8	-	-	2	6		
0	6'	8	-	-	-	8		
		43/7						
AVG		6.14						
%		38.4						

DISTANCE FROM SHORE
Shallow end 100 m
Deep end 160 m

CAUSE OF DESTRUCTION
Anchor

EXTENT OF DAMAGE
Slight

DOMINANT TAXA OR FORMS
Porites, *Acropora*

CONSPICUOUS ASSOCIATED ORGANISMS
Fish -
Damsels, anthiids, etc.

Invertebrates -
Diadema

Algae -
None

REMARKS

TABLE 13d
Transect 3

Location (Island): Phi Phi Dong, Thailand   Observers: E. Gomez and P. Boonyanate

Date : December 16, 1982   Time of Observation: 11.30 A.M.   Methods : Scuba

VISIBILITY: Horizontal - 6-8 m   Vertical - 6 m

LOCALITY (Specific location): South channel, east reef
III. North transect

DISTANCE FROM SHORE
Shallow end 100 m
Deep end 160 m

CAUSE OF DESTRUCTION
Anchor

EXTENT OF DAMAGE
Slight

CONDITION OF REEF

STA	DEP	HC	SC	DC	R	S	(Optional)*	NOTES
60	33'	5	-	-	-	11		
50	20'	11	-	-	2	3		
40	12'	12	-	-	1	3		
30	7'	4	-	-	12	-		
20	6'	2	-	-	-	14		
10	6'	8	-	-	-	8		
0	6'	9	-	-	2	5		
		51/7						
AVG		7.28						
%		45.5						

DOMINANT TAXA OR FORMS
Porites, Acropora

CONSPICUOUS ASSOCIATED ORGANISMS
Fish -
Damsels, anthiids, etc.

Invertebrates -
Diadema

Algae -
None

REMARKS

*This column to be used for coralline algae or other components considered important by the investigator.

(OVERALL: 45.6%: FAIR TO GOOD)

5.2.3 Plotless Line Transect (Parallel to Shore line)

A short (20 m) transect was laid out on the reef flat, Zone a, and on the rim in Zone b, both parallel to the shore line. A point intersect survey was then conducted along each of the transects, in accordance with the method outlined in section 3.7. The total time for application on both transects was 55 minutes. Results are shown in Table 14.

TABLE 14

Results obtained from application of the plotless line transect (point intercept) method for reef areas a and b

	Reef Area	
	Zone a	Zone b
Percent cover:		
Live coral (all)	53.0	64.7
Dead coral	21.0	23.3
Sand	26.0	12.0
Porites	46.4	48.1
Acropora	17.8	29.1
Montipora	12.5	2.5
Others	23.3	2.5
Dead Coral and Sand	47.0	35.3
Non living Substrate percent cover		
Sand	55.1	34.1
Dead coral	44.9	65.1
Elapsed Survey Time	25 minutes	30 minutes
Number of points in transect	105	122

5.2.4 Line Intercept Transect Method

This survey was carried out on the main reef, according to the directions given in section 3.4.

5.2.4.1 Results

The average percentage cover by live corals, dead corals, sand, sponges and soft corals at 10 m intervals along each of the three transects set up on the coral reef at Phi Phi Island is summarised in Table 15. This table shows that 25 genera of hard corals were recorded for the area. For convenience of representing the results pictorially, as in Fig. 7, the average percentage cover was computed for every 10 m of the transect, although recordings were made at 1 m intervals along the transects.

Figure 7 shows the reef profiles along the three transects studied. In these, the following reef regions were recognised:

(1) 0-30 metres, which approximately correspond to the area of the reef flat,

(2) 30-40 metres, which approximately correspond to the area of the reef rim,

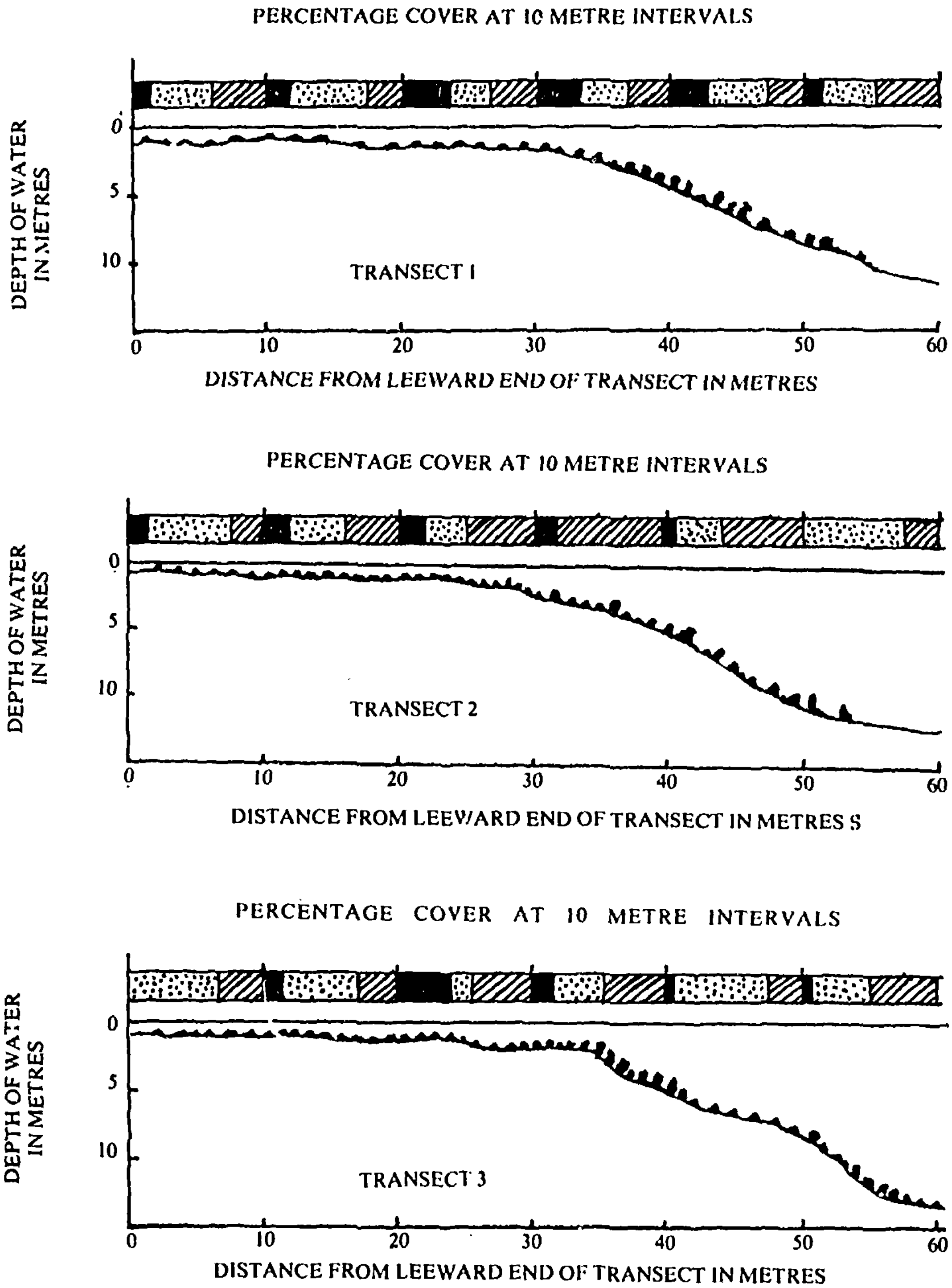
(3) 40-50 metres, which approximately correspond to the area of the reef slope, and

(4) 50-60 metres, which was taken to correspond to the bottom region of the reef.

5.2.4.2 Overall Assessment of the Reef

The results for the overall assessment of the different regions of the reef, in terms of average percentage cover by live corals, dead corals, sand, soft corals and sponges, are given in Table 15. This indicates that the greatest amount of live coral (57.0%) occurs in the 30-40 m region of the transects, which corresponds to the reef rim area. As can be seen in Table 16, this region is also one of the richest in terms of coral diversity.

FIGURE 7



Assessment of the percentage cover by dead corals, live corals, sand, sponges and soft corals at 10 metre intervals on *diagrammatic reef profiles along 3 transects taken* perpendicular to shore on a coral reef at Phi Phi Island, Thailand.

Dead corals, live corals, sand, sponges and soft corals

TABLE 15

The percentage cover by live corals, dead corals, sand, sponges and soft corals on different regions of the reef at Phi Phi Island (computed by averaging the results of the three transects considered on the reef).

Zone	Region of Reef	Percentage Cover			
		Live Corals	Dead Corals	Sand	Sponges & Soft Corals
a	0 - 30 m	36.4	17.4	46.0	0.2
b	30 - 40 m	57.0	17.9	24.7	0.5
c	40 - 50 m	37.9	10.9	48.7	2.5
d	50 - 60 m	41.8	3.2	55.0	-

5.2.4.3 Dominant coral genera

The dominant hard coral genera found in different regions of the reef are listed as percentages of the live coral cover in Table 17. With respect to the different zones of the reef:

(1) Porites (44.2%), Acropora (21.0%) were the dominant hard coral genera in the 0-30 m regions of the transects, which can be considered as the area of the reef flat,

(2) Porites (44.9%), Acropora (12.2%) and Montipora (11.9%) were the dominant hard coral genera in the 30-40 m regions of the transects, which approximately corresponded to the rim area of the reef,

(3) Porites (25.9%), Symphyllia (20.0%), and Pectinia (19.3%) were the dominant hard coral genera in the 40-50 m regions of the transects (corresponding to the slope area of the reef), and

(4) Pectinia (44.0%), Symphyllia (11.5%), Favia (9.3%) and Porites (8.4%) were the dominant hard coral genera in the 50-60 m regions of the transects (corresponding to the seaward edge of the reef).

TABLE 16

Average percentage cover at intervals of 10 metres by live corals, dead corals, sand, soft corals and sponges on three transects perpendicular to the shore on the coral reef at Phi Phi Island, Thailand.

DISTANCE IN METRES FROM LEEWARD END	PERCENTAGE COVER																													
	TRANSECT	DEAD CORAL	SAND	Acropora	Porites	Pocillopora	Millepora	Favia	Favites	Montipora	Hydnophora	Symphyllia	Pachyseris	Pavona	Platygyra	Psammocora	Lobophyllia	Fungia	Pectinia	Merulina	Cyphastrea	Genus 1	Genus 2	Goniastrea	Echinopora	Plerogyra	Diploastrea	Herpolitha	Soft Corals	Sponges
10 m	1	10.5	50.2	6.5	17.0	0.5	2.0	2.5	1.5	3.0	3.5	2.0										0.8								
	2	12.0	62.0	6.0	13.0						3.0													4.0						
	3		69.0	4.5	4.0																			22.5						
20 m	1	15.5	59.5	8.0	8.0					1.0	4.5	2.0	1.5																	
	2	16.0	42.5	11.0	23.0	2.5			3.0															2.0						
	3	13.0	57.0	8.0	20.5			1.5																						
30 m	1	32.2	28.0	7.3	20.0			3.5		1.5				2.0	4.0	1.5														
	2	19.5	30.0	9.0	20.5	4.5		4.5		4.5	4.0	2.0											1.5							
	3	37.5	15.5	11.0	19.0			6.5		3.5					3.0								2.0							2.0
40 m	1	31.0	34.8	5.5	15.5	2.0					10.0							1.2												
	2	10.5	0.5	7.0	48.0	1.0		3.5	2.0	10.5		3.0							3.0				3.0		1.5	2.5	2.5		1.5	
	3	12.0	39.0	8.3	17.5			5.5		10.0		2.5			3.5	2.0		2.0					2.5							
50 m	1	25.8	40.7		12.5						3.0	1.0	2.5					3.0	5.0	2.0	2.5	2.0								
	2	1.5	35.5	1.0	1.0	1.5				4.0		22.0						1.5	14.0						4.0	4.0		2.5	7.5	
	3	5.5	70	4.5	16.0			1.0											3.0											
60 m	1	7.7	43.2					7.3		1.5	1.2					1.5	1.2		36.4											
	2		74						10.5			8.0							5.0							2.5				
	3	2.0	47.9	2.5	10.5			4.5	6.5			6.3							13.8							3.5	2.5			

TABLE 17

Dominant coral genera in the different regions of the reef represented as percentage of live coral cover (Percentages computed as the averages of the 3 transects)

Region of reef	PERCENTAGE OF LIVE CORAL COVER									
	Acropora	Porites	Favia	Montipora	Symphyllia	Hydnophora	Fungia	Goniastrea	Pectinia	Plerogyra
0-30 m	21.0	44.2	4.6	3.8	1.6	4.9	-	8.5	-	-
30-40 m	12.2	44.9	5.3	11.9	3.2	5.8	1.8	-	1.8	1.4
40-50 m	4.7	25.9	0.8	3.4	20.0	2.6	4.0	-	19.3	3.4
50-60 m	1.9	8.4	9.3	1.2	11.5	1.0	-	-	44.0	4.8

5.2.4.4 Other Comments

The times spent on studying the three transects were as follows:

Transect 1 : 34 minutes
Transect 2 : 15 minutes
Transect 3 : 21 minutes

Since the transect lines were marked at 10 m intervals, quite a bit of time was spent measuring 1 m intervals when transect 1 was studied. Due to the use of a metre measure, the studies on transects 2 and 3 were faster. If the lines were marked at 1 m intervals, the time taken for transects 2 and 3 would have been further reduced.

The transect ropes were tied to massive corals, especially at the seaward edge. This created a systematic bias in scoring such massive corals. Relatively high percentages of massive corals were, therefore, scored in Zone d.

5.2.5 Photographic Transect

This survey was carried out on the main reef, according to the directions given in section 3.2.

5.2.5.1 Methods

As previously, the transect lines were designated transect 1, 2, and 3, from the east. The reef area was divided into a reef flat (0-30 metres), upper reef slope (30-50 metres), and lower reef slope (50-60 metres), which are comparable to zones a, b, and c referred to earlier. Photographs of 1 x 15 m^2 transect were taken parallel to the shore line at 20 metre intervals on each line. The area used for interpretation is indicated as a number in brackets, due to the selection of photographs after development.

The profiles of the reef are as shown in Figure 8. There is some slight variation in each transect. The reef extends down to about 12 metres depth. Further down, there are coral patches on sand.

5.2.5.2 Results

The percentage cover by sand, dead corals, live corals and the sea urchin *Diadema setosum* at each station is shown in Figure 8.

5.2.5.2.1 Reef flat

The percentage cover of live coral at the beginning of transect 2 and 3 was low (24.4% and 22.3%), the remaining surface being sandy bottom. Both in this area and further inshore, the corals grew in the form of microatolls on a sandy bottom. The live coral coverage increased at the outer reef flat (47-60%). Here, Porites was the dominant coral genus and the main building block of the reef. Besides Porites, certain species of Acropora also dominated the area, i.e. A. humilis and A. hyacinthus. Among 11 species of Acropora identified on the reef flat, A. humilis and A. hyacinthus represented approximately 54.26% and 9.39% of live coral cover, respectively. The sea urchin Diadema setosum was common on this reef and could be found down to the end of the reef slope on one transect. On the reef flat, Diadema represented about 2.11% of area cover.

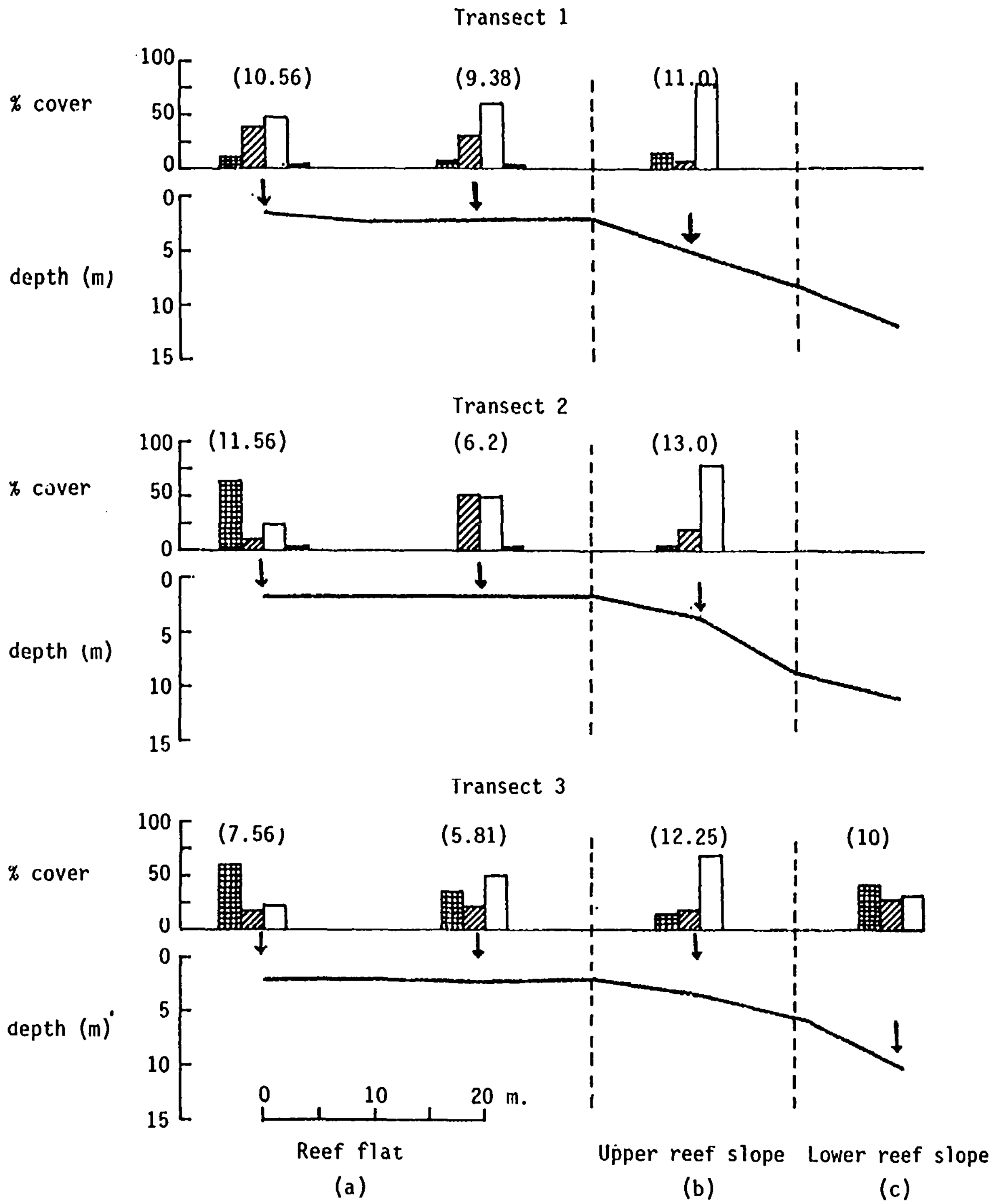
Dead coral areas on the reef flat ranged from 9.7% to 49.5% of the total quadrat area. Most of the dead areas were found on top of the microatolls formed by Porites colonies.

Other living organisms found in the area were soft corals (0.06% of total quadrat area). The reef flat showed the highest diversity of coral species found, as indicated in Table 19. Of 23 genera reported in all transects, 20 were found on the reef flat. The transect area near the reef edge showed the highest variety of coral species.

5.2.5.2.2 Upper reef slope

In terms of species composition, the upper slope was, more or less, a continuation of the outer reef flat. The area was also dominated by Porites. The percentage coral cover increased significantly (68.4-77.3%) in the three transects, when compared to the reef flat. The live coral cover was highest in this zone. Consequently, the area covered by sandy substrate and dead corals was less than in other zones. Diadema setosum was present in the zone, but in much smaller numbers than on the reef flat (0.2-0.4% of total coverage). Soft corals and sponges, although present only in small amounts (1.6% and 0.05%) in each transect, were more common in this zone than in either the reef flat or the lower reef slope.

FIGURE 8



Percentage cover by sand ▦, dead coral ▨, live coral □, and sea urchin (*Diadema setosum*) (■). (←) indicates position of quadrat-transect at 20 meter interval. The number in bracket is the area (m^2) interpreted for percentage cover.

5.2.5.2.3 Lower reef slope

The lower reef slope was composed of clumps of low relief form scattered on a sandy slope. On line 3, live coral cover was only 31.8%. The sandy bottom constituted about 40.2% of the total area. The most abundant species was Pectinia lactuca (29.2%). The percentage of dead coral cover was quite significant (27.4%), in comparison with live cover. The fragility of the Pectinia structure makes it more susceptible to physical damage than those corals occurring in other zones. Data in line 2 were not analysed, due to poor photograph quality. The photos were taken in late afternoon, when the light intensity was poor. At the end of the lower slope of line 1, no quadrats were recorded, since the bottom was mainly a sandy substrate. The total number of coral species in this zone was lower than in the previous zones. Diadema setosum was also present in lower numbers than in other areas (0.6%). Only six species were found within the 10 square metres covered by quadrats in this zone. Echinopora lamellosa and Lobophyllia sp. were seen in the region, but were not recorded on the transects.

5.2.5.3 Discussion

In comparing the three transect lines, it can be seen that the results are similar in the region of the upper reef slope and the outer part of the reef flat in terms of sand, dead coral, and live coral cover. This indicates that the area sampled by each of the individual transects was adequate for the region. However, the variation on the inner part of the reef flat was not adequately covered. The transect sample at the beginning of line 1 was quite similar to the samples taken from the reef flat near the reef edge. This may have been due to local variation in reef growth.

Table 18 shows results obtained by combining data from all three transect lines. Live coral cover was highest on the upper reef slope, Zone b (74.26%), and lowest on the lower reef slope (32.17%). Diadema setosum was most abundant on the reef flat and decreased further down the slope. Sponges were abundant on the upper reef slope area. When comparing data sets obtained either by the same method or by use of different methods, the sample size utilised should be considered. On the lower slope, if the data of transect 1 and transect 2 are pooled, the overall result differs from the picture obtained by looking at either transect alone.

The abundance of various genera in each zone is shown in Table 19. The proportion of the overall live coral coverage represented by each genus was calculated as a percentage. Favia sp., Favites sp. and Goniastrea,

TABLE 1.8

Percentage cover of live corals and other organisms on different regions of the reef (pooled data three transects)

	Reef flat (Zone a)	Upper reef slope (Zone b)	Lower reef slope (Zone c)
Size of Sample area (m^2)	51.07	36.25	10
% Coverage of total area			
Sandy substrate	30.21	10.34	40.2
Dead coral	26.57	14.57	27.4
Live coral	41.08	74.26	32.17
Diadema setosum	2.11	0.25	0.6
Others (soft coral and sponge)	0.06	0.50	-

however, were combined. The identification of certain corals to the species level poses a difficulty. This is especially so for the genus Acropora, although A. humilis, A. hyacinthus and A. formosa were found to be common. Certain species that were seen during the survey were not included in transect photos, i.e. Euphyllia fimbriata and Herpolitha. Altogether, 23 genera were identified from transect photographs. The remaining species are those with small polyps and indistinct growth form, which tend to encrust the substrate. To properly identify such species, detailed field observations of quadrats are needed.

The dominant species on the reef flat and the upper reef slope were similar. Porites was dominant in both areas, while Acropora sp., Montipora foliosa and Synarea undulata were the other common groups found. Dominant species of Acropora were different in both areas. A. hyacinthus and A. humilis were the common species on the reef flat, while other corymbose and table forms were abundant on the upper reef slope. Pectinia lactuca, the only remaining dominant species that differed from those already mentioned, was common on the lower slope. Although Zone a (the reef flat) was found, in this study, to contain the highest number of coral genera, the upper reef slope must also be considered as a diverse area. At this stage, it can be said that the number of genera to be found on the reef flat and the upper reef slope were probably similar.

TABLE 19

Proportion of live coral cover represented by individual species and genera

Percent surface cover by coral genera as a proportion of living coral cover in each zone	Reef flat (Zone a)	Upper reef slope (Zone b)	Lower reef slope (Zone c)
Acropora sp.	17.30	8.24	1.55
Diploastrea heliopora	-	1.08	-
Echinopora lamellosa	0.57	0.07	-
Favia sp.			
Favites sp.	1.81	1.37	-
Goniastrea sp.			
Fungia fungites	0.05	1.26	1.46
Gadinoceris	0.14	-	-
Goniopora	0.81	0.63	1.87
Heliopora coerrulea	0.09	-	-
Hydnophora sp.	0.29	0.59	-
Leptoria phrygia	0.09	-	-
Lobophyllia sp.	-	0.78	-
Merulina ampliata	-	0.89	-
Montipora foliosa	1.91	6.68	0.31
Pavona sp.	0.91	0.11	-
Pectinia lactuca	0.38	8.84	90.77
Platygyra lamellina	0.61	-	-
Plerogyra sinousa	0.09	0.45	3.11
Pocillopora sp.	0.38	0.15	-
Porites sp.	62.68	53.66	-
Symphyllia sp.	0.57	0.67	-
Synarea undulata	3.10	5.61	-
Other encrusting sp.	7.44	9.02	0.93
Total genera identified	20	19	6
Overall general identified in zones a + b + c = 23			

The lower reef slope was different from the reef flat and the upper reef slope in growth form, relief and species composition. Pectinia lactuca was the most common species on the lower reef slope, while Plerogyra, Goniopora and Fungia were also found. From general field observations, it can be concluded that an area of 10 square metres may be too small to represent the lower reef slope, in terms of the overall number of species present, even though most of the common forms were observed in the quadrats.

Coral growth form relief for each zone is shown in Table 20. On the reef flat, the relief of Porites is about 0.6 m. The relief of this zone may be limited by the sea level at low tide. The upper reef slope (Zone b) shows the highest coral relief (1.5 m), consisting mainly of Porites heads. The lower reef slope was comprised of low relief growth forms, such as Pectinia, that could not be measured.

TABLE 20

Maximum relief of growth form

Zone	Maximum relief of growth form (m)		
	Transect 1	Transect 2	Transect 3
Reef flat (Zone a)	0.6	0.6	0.6
Upper reef slope (Zone b)	1.5	1.5	0.9
Lower reef slope (Zone c)	-	-	-

5.2.6 Reef Diversity

As mentioned previously, a careful half-hour search for different coral species was made both over the main reef and over the west side reef by the same diver. After all had examined material from the initial collection, several participants made a further general collection over the main reef. The first half-hour collection from the main reef resulted in the discovery of 48 species, representing 23 genera. The collection over the west side reef yielded 86 species from 23 genera. The subsequent incidental collection over the main reef yielded a further 12 species, representing additional genera. Thus, a total of 60 species and 30 genera were found during the entire search.

After lists from all forms of systematic survey were cross-tabulated, 41 genera were recognised on the main reef. It should be pointed out that seven observers spent approximately 5 hours each on the main reef, during which time the additional 12 species were collected.

Perhaps the most noteworthy feature of the narrower reef on the western side of the bay, beyond the apparent higher species diversity, was the much higher proportion of Acropora species found there. The genus Acropora was represented by 29 different species on the west side reef. The main reef, by comparison, had only 12. As mentioned previously, one participant suggested that a relatively high diversity should be expected in any reef having a prominent representation of table Acropora, the occurrence of which could be taken as an indicator of general reef health and well-being.

The following is a list of genera found on the main reef during swimming searches:

First search	Second search
Acropora	Galaxea
Favia	Psammocora
Favites	Scapophyllia
Porites	Leptastrea
Mycedium	Pseudosiderastrea
Pavona	Goniopora
Cyphastrea	Euphyllia
Symphyllia	
Montipora	
Millepora	
Hydnophora	7 genera
Pocillopora	
Synaraea	
Pectinia	
Pachyseris	
Merulina	
Echinophyllia	
Goniastrea	
Leptoria	
Fungia	
Acanthastrea	
Platygyra	
Echinopora	
23 genera	7 genera
	Total: 30 genera

Genera identified from the half-hour search of the side reef on the western edge of the bay included:

Acropora
Porites
Fungia
Millepora
Synaraea
Galaxea
Goniastrea
Montipora
Lobophyllia
Favites
Leptastrea
Pavona
Merulina
Platygyra
Pachyseris
Herpolitha
Pectinia
Hydnophora
Pocillopora
Diploastrea
Oxypora
Cyphastrea
Echinopora

23 genera

Genera directly identified in the field during surveys of the main reef included:

(1) Point-Quarter Survey

Acropora
Stylocoeniella
Montipora
Fungia
Herpolitha
Porites
Favia
Favites
Goniastrea
Leptoria
Diploastrea
Echinopora
Merulina
Lobophyllia
Symphyllia
Pectinia
Euphyllia

(2) Intercept Line Transect Survey

Acropora
Porites
Pocillopora
Millepora
Favia
Favites
Montipora
Hydnophora
Symphyllia
Pachyseris
Pavona
Platygyra
Psammocora
Lobophyllia
Fungia
Pectinia
Merulina

(1) Point-Quarter Survey (Cont'd.)

Plerogyra
Sinularia
Millepora
Pocillopora
Hydnophora
Leptastrea
Cyphastrea

24 genera

(2) Intercept Line Transect Survey (Cont'd.)

Cyphastrea
Goniastrea
Echinopora
Plerogyra
Diploastrea
Herpolitha
Genus 1
Genus 2

25 genera

(3) Plotless line transect (point intercept) area (a)

Montipora
Platygyra
Acropora
Porites
Pavona
Pocillopora
Hydnophora
Millepora
Favites
Merulina
Favia

11 genera

(4) Plotless line transect (point intercept) area (b)

Porites
Acropora
Hydnophora
Favia
Pocillopora
Goniopora
Cyphastrea
Merulina
Lobophyllia
Pavona
Pectinia
Montipora

12 genera

(5) Photographic transect

Acropora
Diploastrea
Echinopora
Favia
Favites
Fungia
Gadinoceris
Goniastrea
Goniopora
Heliopora
Leptoria
Lobophyllia
Merulina
Montipora
Pavona
Pectinia

(5) Photographic transect
(Cont'd.)

Platygyra
Pocillopora
Porites
Symphyllia
Synaraea

21 genera

5.3 Summary

In comparison with results obtained from the formal procedures, it appears that the mean values of the preliminary estimates of live coral cover did not differ in any great degree from the overall measured range. The possible exception to this is that the sparsely covered areas appeared, if anything, to be slightly over-estimated (see Table 21).

In estimating dominance and zonation, it appeared that the principal genus was readily identified in the preliminary survey for Zones a, b, and c, i.e. those regions in which larger corals occurred. The secondary dominant was also well identified in Zones a and b in the preliminary assessment, but less well in the deeper regions when compared to results obtained by direct measurement (Table 22).

The visual estimations of genus numbers in all zones made during the preliminary survey averaged 25. This figure approximated the number of genera found throughout the whole reef (Table 23) by individual methods, such as the species search, the intercept line transect method and the point-quarter method (top two zones only). It appears, therefore, that about 25 of the 41 genera reported on the reef (63%) were observed with relative ease by using any one method. The remainder required additional effort for discovery.

Assessment of reef conditions after the preliminary visual survey proved to be the most contentious of all facets of survey procedures covered during the field work. In part, this may be explained by the participants' differing backgrounds. More than this, however, individuals expressed strong convictions concerning the quality of the main reef and expended considerable energy advocating their particular viewpoints during group discussions.

Another important factor was that the majority of the participants thought the main reef was fair to excellent (five thought it good, one fair, one excellent, and one poor). Thus, the estimated quality was toward the upper end of the scale (mean point value = 59, i.e. good). The discussion, therefore, tended to focus on the definition of differing grades of good or acceptable.

No comparative measurements were made to quantify reef growth form and relief and no systematic field work was done to assess associated fish populations. One observer did maintain, however, a species count during the preliminary survey, reporting 23 species from the main reef and 43 from the west side reef. Likewise, no attempt was made to quantitatively assess reef damage or to measure algal cover.

The overall field assessment exercise was perhaps most useful in bringing to the fore implicit assumptions held by individual investigators and in laying the groundwork for a wider appreciation of the strengths and weaknesses of different survey techniques.

After a preliminary group analysis of the field work, participants agreed that, insofar as possible, those using transect methods would also use the point-quarter method in reef surveys. Those using the point-quarter method would, likewise, endeavour to apply a transect method as well.

It is hoped that consistent use of two methods over a period of approximately two years will provide a sufficient data base to allow the possibility of adopting a common survey technique or recipe for application of a subset of those presently used to be assessed.

TABLE 21a

Comparison among estimations of live coral cover as a percentage of surface area (main reef)

Method	Zone			
	a	b	c	d
Preliminary visual Estimation	56.7	75.0	55.8	33.3
Point-Quarter	20.2	84.0	28.6	-
Plotless line transect (Point-intercept)	53.0	64.7	-	-
Photographic transect	41.1	74.3	32.2	-
Transect/quadrat	41.1	47.9	72.9	25.0
	Total Transect (Zones a b c d)			
	1	2	3	
Transect/quadrat	53.1	38.4	45.5	

TABLE 21b

Comparisons among estimations of dead coral cover as a percentage of surface area (main reef)

Method	Zone			
	a	b	c	d
Preliminary visual estimation	-	-	-	-
Point-quarter	-	-	-	-
Intercept line transect	17.4	17.9	10.9	3.2
Plotless line transect (Point-intercept)	21.0	23.3	-	-
Photographic transect	26.6	14.0	21.4	-
Transect-quadrat	25.0	37.5	14.5	-

TABLE 22

Comparison among estimations of species dominance
(main reef)

Method	Zone a	Zone b	Zone c	Zone d
Preliminary Visual Estimation (numbers refer to persons citing each genus as a dominant)	Porites (9) Acropora (1)	Porites (6) Acropora (5) Lobophyllia (1)	Pectinia (4) Lobophyllia (2) Plerogyra (1) Acropora (1)	Pectinia (1) Fungia (3) Lobophyllia (1) Plerogyra (1) Goniopora (1)
Point-Quarter (numbers represent percentage surface cover of living coral)	Porites (86.6) Montipora (8.3) Goniastrea (6.3) Acropora (4.2) Pocillopora (4.2 Favites (4.2) Hydnophora (4.2)	Porites (54.5) Acropora (13.0) Fungia (11.0) Montipora (10.3) Pectinia (9.5)	Pectinia (92.0) Hydnophora (5.8)	
Plotless line transect (point-intercept) (numbers represent percentage surface cover of living coral)	Porites (46.4) Acropora (17.8) Montipora (12.5) Others (23.3)	Porites (48.1) Acropora (29.1) Montipora (2.5) Others (2.5)		
Intercept line transect (numbers represent percentage surface cover of living coral)	Porites (44.2) Acropora (21.0) Goniastrea (8.5) Favia (4.6)	Porites (44.9) Acropora (12.2) Montipora (11.8) Hydnophora (5.8)	Porites (25.9) Symphyllia (20.0) Pectinia (19.3) Acropora (4.7)	Pectinia (44.0) Symphyllia (11.5) Favia (8.3) Porites (8.4)

(to be cont'd.)

TABLE 22
(Cont'd.)

Method	Zone			
	a	b	c	d
Photographic transect (numbers represent percentage cover of living coral)	*Porites* (62.7) *Acropora* (17.3) *Synaraea* (3.1) *Montipora* (1.9)	*Porites* (53.7) *Pectinia* (8.8) *Acropora* (8.2) *Montipora* (6.7) *Synaraea* (5.6) *Fungia* (1.3) *Diploastrea* (1.1)	*Pectinia* (90.8) *Plerogyra* (3.1) *Goniopora* (1.9) *Acropora* (1.6) *Fungia* (1.5)	

TABLE 23

Comparisons among estimations of diversity
(main reef)

Method	Zone a	Zone b	Zone c	Zone d
Preliminary visual estimation (# genera)		25 (mean)		
Point-Quarter (H' species diversity)	2.48	3.55	0.99	
# genera	12	17	8	
# species	13	18	8	
Plotless line transect, point intercept (# genera)	11	12		
Intercept line transect # genera	17	17	17	12
# species	16	16	16	12
Photographic transect (# genera)	20	19	6	

Total reef (# genera, all transects)	a b c & d
Preliminary visual estimation	31
Species search	30
Intercept line transect	25
Point-Quarter (Zones a b & c only)	24
Total # genera recorded in detailed examinations	38 +2 unknown
Photographic transect (Zone a,b and c)	23

6. RECOMMENDATIONS AND CLOSURE

6.1 Recommendations

The workshop passed the following recommendations:

(1) Trade in Corals

The Unesco/UNEP Workshop on Coral Reef Survey Management, and Assessment Methods in Asia and the Pacific,

recognising the importance of coral reefs in contributing to marine production,

being aware of the dependence of many coastal inhabitants of developing countries on coral reef fisheries, and

realising the need for concerted and cooperative action amongst the countries of Asia and the Pacific, does hereby recommend that:

- steps be taken to control or prohibit the large-scale commercial exploitation of corals on a national basis, and
- legislation be enacted to prevent the importation and trans-shipment of illegally-exported corals.

(2) Harmonisation of coral reef study methodology

The Unesco/UNEP Workshop on Coral Reef Survey Management, and Assessment Methods in Asia and the Pacific, recommends that researchers be encouraged to use one method, such as the point-quarter method, as a back-up to present practices. Those using the point-quarter method would adopt another method as back-up.

(3) Development of coral reef studies

The Unesco/UNEP Workshop on Coral Reef Survey Management, and Assessment Methods further recommends that a Unesco/UNEP working group on coral reef studies, methodology or similar organisational device be formed (to include the participants in the present workshop) to facilitate international work on coral reef problems and that a first meeting be held in early 1984 at a place to be decided upon by mutual agreement.

6.2 CLOSURE

During the closing ceremony, the Director of the Phuket Marine Biological Centre, Mr. Urupun Boonprakob, delivered an address in which he highlighted Thailand's interest in the study and management of coral reefs. He thanked the participants for coming to Thailand. On behalf of Unesco and UNEP, Mr. R. Aertgeerts thanked the Department of Fisheries and the local organiser, Dr. Hansa Chansang, for the excellent arrangements for this workshop.

ACKNOWLEDGEMENTS

The success of this workshop was due, in large part, to the tremendous effort made by the staff of the Phuket Marine Biological Centre (PMBC), Phuket, Thailand. Particular thanks are due to Dr. Hansa Chansang, who both organised the logistics of the field investigation and arranged for the conference facilities. Thanks are also due to PMBC staff members, who laid out transect lines, serviced diving equipment and took care of the many details associated with the activity. As a final point, the facilities provided by PMBC enabled extended scuba diving by the majority of participants, thereby permitting the acquisition of an adequate array of field data.

ANNEX I

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ANNEX II

ADDRESSES DELIVERED AT WORKSHOP OPENING

Welcoming Address

by

Khun Vanich Vareekul

Deputy Director-General of the
Department of Fisheries,
Ministry of Agriculture

Good morning, Dr. Harger and Mr. Aertgeerts, Unesco representatives;
Dr. Elder, UNEP representative;
distinguished participants from South East Asia and the Pacific;
ladies and gentlemen.

It is my pleasure to be here at the Unesco/UNEP Workshop on Coral Reef Survey Management, and Assessment Methods in Asia and the Pacific. As the Deputy Director-General of the Department of Fisheries, I feel it is our honour to have the opportunity of organising this workshop here in Phuket.

All of us in this room know very well the significance of coral reefs to man and the problems arising from human utilisation and destruction of the resources in this part of the world. In Thailand, we are aware that our reef resources are rather limited, compared with those of our neighbouring countries. The government has tried to do its best to conserve coral reefs. We have laws prohibiting the collection and exportation of corals. More action is going to be taken to protect other associated fauna. Admittedly, we need to know more about our reefs so that effective management and resource utilisation planning can be carried out.

The attention and assistance of Unesco and UNEP in bringing about more knowledge of our coral reefs, their problems and, hopefully, resolutions are most welcome. This meeting is one of the important steps that will lead us to our objective of knowing both our resources and the best ways of utilising them. I am confident that this workshop will be a fruitful one.

In addition, I hope that the expertise of all those participating here will help our staff at the Phuket Marine Biological Centre to gain more knowledge and experience of our reefs in the Andaman Sea.

I do apologise for any mistake or inconvenience that may arise during this workshop, since this is the first time that our staff has organised such an international meeting.

Finally, I wish you a successful meeting and a pleasant stay, both in Phuket and Phi Phi Island.

Opening Remarks

by

Dr. J.R.E. Harger

Unesco Representative

Mr. Khun Vanich Vareekul, Deputy Director-General of Fisheries;
participants;
Mr. Elder, Representative of UNEP;
ladies and gentlemen.

I am pleased to welcome you all here today on behalf of the Director-General of Unesco, Mr. M'Bow, and to say how glad I am that so many of you were able to make it to this workshop, despite your busy schedules.

This workshop, which Unesco is running together with UNEP, represents another step forward in the implementation of COMAR.

The COMAR project aims to contribute to establishing a scientific basis for understanding the characteristics and functioning of the coastal system. COMAR was established at the Unesco 21st General Conference in 1980. By means of appropriate training and information development, together with research activities, the capacity of countries to manage their coastal zones will be increased through the implementation of this project.

This process has focused the attention of Unesco's Division of Marine Sciences on the coral reef ecosystems and the need for elucidating the fundamental role played by this diverse coastal community in maintaining a productive output, capable of being of use to the human community.

In July 1980, Unesco convened a "Seminar on Marine and Coastal Processes in the Pacific: Ecological Aspects of Coastal Zone Management", where some of the problems that concern us today were examined by an international group of scientists. Unesco, then, in May 1981, convened a "Workshop on Research and Training Priorities for Coral Reef Management", in association with the Fourth International Coral Reef Symposium in Manila.

Both the aforementioned activities developed recommendations for work at the international level. The present workshop is a follow-up to some of those suggestions. It is an attempt to develop a systematic and common basis for surveying and assessing the status of coral reefs throughout the region of South East Asia and, perhaps, into the Pacific as well.

This is an important task, because it is vitally necessary that scientists working on a day-to-day basis be in constant communication with one another directly through the medium of their work itself. If we are able to agree on a common format for reporting the results of ongoing investigations into the disposition and distribution of coral reefs throughout this region, we will be in a position to develop a widespread understanding of the ecosystem as a whole. Thus, we will be able to readily gauge its overall health.

In this age of rapidly expanding human population, the requirement of accurately assessing and fostering food production is becoming increasingly important. It is with this in mind that we must seek to understand the basis for coral reef function and productivity.

Unesco will continue to develop work concerning coral reef analysis, with a workshop in coral taxonomy to be held at the Phuket Marine Biological Centre in 1983 or early 1984.

I wish you every success in your endeavour.

Opening Remarks

by

Dr. D. Elder

UNEP Representative

Director-General of Fisheries, Khun Wanit, on behalf of UNEP, as one of the co-sponsors of this meeting on coral reef studies methodology, I would like to express our gratitude for the opportunity to be here in Phuket to take part in this activity. We also feel privileged that you have taken time from your very busy schedule of activities to be here with us for this meeting.

We would like to thank the director of the Centre, as well as his staff for taking the time to participate in the workshop.

My colleague from Unesco, Dr. Harger, has already expressed several points concerning the importance of this meeting and how it came about from a technical point of view. Since his remarks reflect our views also, I would like to mention briefly, from a slightly different point of view, what we consider a very significant aspect of this meeting and what it represents.

Over the last few years, under the auspices of UNEP's Regional Seas Programme, an action plan for the Protection and Development of the Marine Environment for the East Asian Region has been formulated, refined and adopted. In the past year, two inter-governmental meetings were held which resulted in decisions about the implementation of the action plan and the institutional and financial arrangements for doing so.

Initially, it was agreed that six projects should be implemented, each one becoming the responsibility of a national institution of the EAS region. In addition, the governments established a trust fund for financing these projects during the initial two years of the programme. At a political level, they established mechanisms for coordinating their implementation. UNEP was asked to serve as the secretariat for the action plan during the 1982-1983 biennium. One of the projects concerned the assessment of coral reef resources and damage to these resources from activities such as coastal development, dynamite fishing and other such practices. One of our colleagues, Dr. Ed Gomez of the Philippines, will be the main person responsible for coordinating the implementation of this project.

My purpose in mentioning these things is not merely to point out boring organisational aspects, but to indicate that one very significant thing about this meeting is that it is the first substantial and tangible activity to take place under the auspices of one of the projects of the recently adopted EAS action plan. In a sense, this meeting really marks the beginning of the implementation phase of the action plan.

Before finishing, it would be inappropriate not to mention at least an acknowledgement and expression of thanks to Dr. Hansa Chansang for her hard work in arranging the excellent facilities for this meeting. It is obvious from the quality of excellence of organisation thus far that the meeting will be a success. We thank her and her colleagues for all they have done and will do during the coming week. For our part, we look forward to a fruitful time of work together. Thank you.