A REVIEW OF CORAL REEF SURVEY AND MANAGEMENT METHODS IN SINGAPORE

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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 off-shore islands. Figure 1 shows the locations of these reefs including those affected either directly by land reclamation or indirectly by industry.

Research efforts

Studies on coral reefs as well as on 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 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 spp.* (Moll, 1977), taxonomy of the nudibranchs (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 Territip (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.

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 (1979) and Teo (1981) which were completely field oriented involved the use of various ecological survey methods.

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 1000 hrs and 1600 hrs (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 snorkelling 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 the 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 the 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 on 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 snorkelling equipment and an underwater watch, random counts of fishes present in each zone within 30 minutes during the rising tide were made.

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Studies by Chan (1979) and Teo (1981) made use of similar methods to plot the reef profiles along transects. These were obtained by stretching a string marked at one metre intervals taut 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 snorkelling gear only was used. He recorded the organisms within 1 metre on either side of the transect line for the reef flat and edge, and 2 metres on 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 area covered by the different species of corals were calculated in the following way:-

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

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

Vertical (or transverse) 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 4 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 indicies used in these studies are shown in Appendix 1.

Management

There is no authority in Singapore 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 eg. 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 being 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 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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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)

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

(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.

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

The maximum value of the Shannon-Weaver Diversity Index is calculated using $H^1max = \ln S$ 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_i = number of individuals of species i.

N = total number of individuals in sample

= 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.

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

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

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 evenness (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 i.

log = base 10, base e or base 2.

S = number of species

Pielou's Evenness Index can also be computed where

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

where $H^1 max = \log S$.

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)

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

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

a = number of species in both communities.

(ii) Sorenson's index (1948)

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

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.