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SPATIAL INEQUALITY: EVALUATING DIVERSITY OF HERMATYPIC CORALS IN SIMILAR REEF SETTINGS OF NORTH LANGKAWI

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Abstract – ***The aim of this study was to ascertain spatial inequality of diversity of hermatypic corals in north Langkawi, Peninsular Malaysia. Set in similar environmental settings, reef extent and reef conditions, coral taxonomy and species diversity were carried out on two fringing reefs, Teluk Datai and Teluk Dedap, located on opposite sides of the study area. The assumptions were firstly, the extent and morphology of the two reefs should be discriminatingly unequal, and secondly, both reefs should have high dissimilarity of diversity in terms of species compositions. Line Intercept Transect method was used to collect field data while Jaccard's Index was used to compute level of dissimilarity. Results showed there were 76 species of hard corals found in the much larger reefs in Teluk Datai comprising of 35 genera, 14 families and 4 sub-orders where dominant corals belonged to the families of Acroporidae, Faviidae and Poritidae. In Teluk Dedap, there were 37 hard coral species comprised of 4 sub-orders, 10 families, and 22 genera and dominant coral families belonged to Faviidae and Poritidae. Members of the Faviidae and Poritidae corals found in both reefs appeared to be the hardier ones with higher tolerance towards intermediate sediment load or more turbid waters. Jaccard's Index with a value of 73.04% of dissimilarity between the two fringing reefs showed that these reefs were quite diverse in its hermatypic coral compositions. The total coral area of Teluk Datai was 1,077,250 m^2 while in Teluk Dedap was 63,000m^2. The distributions of coral reefs do not necessarily reflect the limits of distribution of corals themselves. The number of coral species in Teluk Datai is twice of that found in Teluk Dedap. This study authenticated spatial inequality by proving both assumptions. It is not crucial to look at the extent of a reef but rather its richness or its diversity because in reef building process, it is the hardier species with the ability to tolerate and withstand physical and chemical environmental conditions that will eventually dominate.***

Keywords: hermatypic coral, spatial inequality, Jaccard's Index, coastal resources, turbid water

I. INTRODUCTION

Spatial inequality is understood to be a major geological issue which affects the world in terms of uneven distributions of amounts of resources available in a given area or qualities of services received. Besides global and local climate, earth features and latitude-longitude positioning, spatial inequality can be a result of culture, religion and race. The clustering of various groups of people within the given space of the different locations tends to share similar socioeconomic statuses. Resources, for example, are represented by natural commodities, assets, or wealth like drinking water and biodiversity. Services include medical and health benefaction and deliverance, infrastructure, industrial, educational institutions; while ecosystem services are provided by natural environment – the intangible elements life depends on.

Contrary to medical and educational services and the likes, inequalities in natural resources such as the provisions of coral reef ecosystem services cannot be easily amended by making distribution more equitable or even between communities and populations. The services provided by coral reefs transcends between various categories and dimensions.

Coral reefs are recognized as occurring in a number of major morphological, or structural, types. Fringing or shore reefs are the most common and widespread of the reef structural types. They occur in the nearshore environment and are best-developed along rocky coasts of uplifted continental coastlines and islands as well as along shores of exposed limestone islands where there is a firm substrate. Their inshore distribution renders them susceptible to coastal activities, more so than other reef structural types. Fringing reefs are nearly always found below the low-tide level, but extensive intertidal exposure forming broad tidal flats is known to occur in areas where there are moderate to large tides. Fringing reefs are often simply veneers of reef organisms that cover some type of hard, non-reef material.

The actual reef consists of a large and rigid structural mass of calcium carbonate formed by the cemented skeletal remains resulting from the successive growth and development of hermatypic corals, i.e., the reef-building corals. Hermatypic corals are found growing actively on the reef crest and face where the reef is growing seaward and upward or toward the sea surface. Although corals are colonies of small animals, each living unit of the hermatypic corals contains algal populations within its own tissues which are capable of photosynthesis, thus providing an energy source for both the coral and the algae. The corals themselves are relatively slow-growing colonies of animals with growth rates ranging between one-tenth and ten centimeters per year in length. The large and diverse animal

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populations associated on the reef and by the organic materials (including plankton) that are continually brought to the reef by marine currents.

Coral reefs are unique among marine associations or communities in that they are built up entirely by biological activity. They are one of the most productive ecosystems in the world in terms of support and maintenance of a large animal biomass (quantity of living matter). Although the coral reef appears to be a discrete and self-contained ecological system, its productivity is wholly maintained by the characteristics of the surrounding environment. In this regard, the basis for the high productivity of the coral reef ecosystem is a result of the production of the reef itself, together with its surrounding and supporting environment [1]. It is this level of productivity which is the basis for sustaining the reef's characteristically high diversity and species-rich ecosystem in the marine environment today.

The reefs found within the Malaysian waters are mainly of the fringing type [2, 3]. Most Malaysian reefs which have been gazetted as marine parks are found in the South China Sea and the Sulu Sea i.e. between the east coast of Peninsular Malaysia and East Malaysia. There are only two prominent reef areas on the west coast of Peninsular Malaysia. One of them, the Pulau Payar archipelago, has been gazetted as a marine park while the other, Pulau Langkawi archipelago, has become one of the main tourist attractions of the northern region. The beauty of pristine natural coastal and marine resources of coral reefs had drawn not just the mass influx of tourists but development and construction of infrastructure to cater for the demands of tourism, ecotourism and even alternative tourism. Anthropogenic activities particularly related to tourism have had its toll on the natural environment and biodiversity-ecosystem services losses were unaccounted for [3]. This in mind along with the need to tab our natural and invaluable coral resources we inherit which is possibly spatially unequal formed the basis of this study. The objective was to ascertain spatial inequality existed with the two fringing reefs having similar environmental settings. In order to authenticate this, two assumptions were made:

(i) the extent and morphology of the two reefs should be discriminatingly unequal, and
(ii) the two reefs should have high dissimilarity of diversity in terms of species compositions.

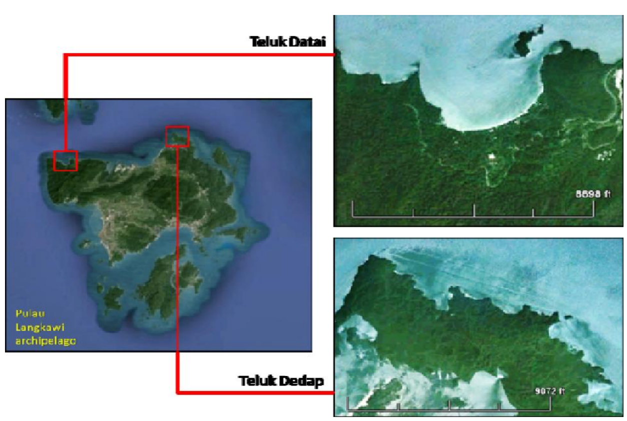

Fig. 1. The study area of North Langkawi: Teluk Datai and Teluk Dedap.

The two fringing reefs in this study were Teluk Datai on the northwest and Teluk Dedap at the northeast of Pulau Langkawi (Fig. 1). Both areas have similar environmental settings and were naturally undisturbed but had later subjected to coastal development.

II. MATERIALS AND METHOD

(1) To substantiate the first assumption on the extent of reefs, coral distribution areas need to be mapped and the reef conditions need to be assessed. The Line Transect Intercept (LIT) survey method by Loya (1978) and Marsh *et al.* (1984) were used [4, 5]. To verify the morphological features of the reefs, cross-sectional reef profiles were drawn.

Mapping of coral distribution

Line Transect Intercept (LIT) survey method [4, 5] were carried out during low water spring tides. This seemed to be an appropriate time for such surveys as the reefs were exposed allowing the observer easy access to mapping. SCUBA diving and snorkeling techniques are involved only during higher seawater level. LIT survey method was used to assess the sessile benthic community of coral reefs. The community is then characterized using lifeform categories which will provide a morphological description of the reef community. The LIT method estimates the cover of an object or group of objects within a specified area by calculating the fraction of the length of the line that is intercepted by the object. This measure of cover, usually expressed as a percentage, is considered to be an unbiased estimate of the proportion of the total area covered by that object with the assumptions that the size of the object is small relative to the length of the line, and that the length of the line is small relative to the area of interest [4]. Eight reef features were used in this study which were (i) sand, (ii) sand/pebble/rock, (iii) rock, (iv) live coral (≤50%), (v) live coral (≥50%), (vi) coral debris, (vii) mud, and (viii) mangrove. Presence of mangrove was deemed necessary as part of reef feature in this study as in this region mangrove and reefs co-existed in close proximity.

The LIT has been used for objectives ranging from large-scale spatial problems [6, 7] to morphological comparisons of coral communities, and studies assessing the impact of natural and anthropogenic disturbances [8, 1, 9]. These categories are recorded on data sheets by divers swimming along lines of plastic fibre tape which are placed roughly parallel to the reef crest at varying depths of 3m to 10m at each site. Transect lengths vary depending on location of the reef edge.

Since the study areas are highly influenced by the rise and fall of the tides, direct ground mapping would require a relatively longer time as sampling frequency needs to be increased. This is basically due to the short time span of reef exposure during low water spring tide and the fortnightly occurrence of spring tides. An alternative method was used in this study where transect lines were laid out and vertical photographs were taken at every 2-m interval. These photos were then marked and recorded in working sheets/maps which will later be laid out for reef mapping process. This method not only allows a more detailed visual interpretation but allows the interpreter to identify specific features and locations of these features. This alternative method also provided more safety as the condition of fast rising tide during spring tidal condition may prove to be quite risky judging from the location of the fringing reefs which faces the Andaman Sea.

The area of each reef feature was estimated from the scaled map with the aid from data collected from the LIT method during survey, Malaysian Topology Map (series L7030 Sheet 3069, 1985) and Admiralty Chart (series N7030 Sheet 3069, 1989).

Morphological features of reefs

Cross-sectional reef morphologies were drawn for both reefs to illustrate the differences in physical characteristics. Location of reef profile transects are given in Fig. 2.

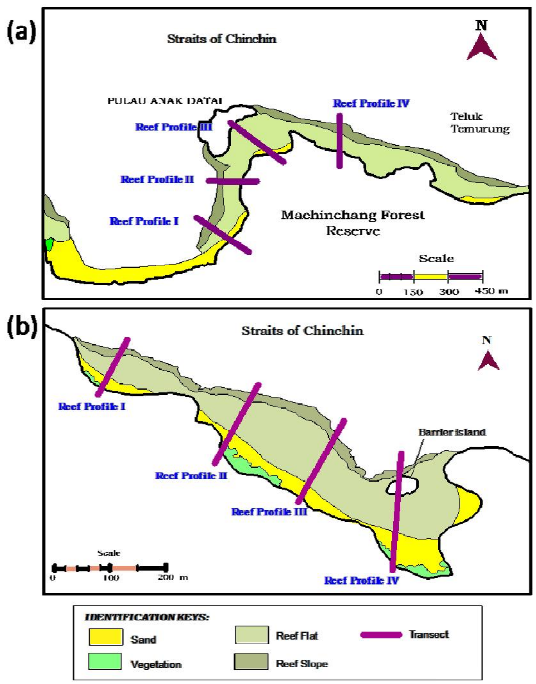

Fig. 2. Transect locations for cross-sectional reef morphology of (a) Teluk Datai (b) Teluk Dedap

(1) To demonstrate the second assumption on dissimilarity of diversity and species compositions, coral taxonomy studies were conducted and Jaccard's Index was later used to calculate the percentage of dissimilarity of species composition between the two reefs.

Coral Taxonony

Samples of representative corals collected during field surveys were brought back to the laboratory for the cleaning process prior to identification or its taxonomic study. The corals were bleached and dried to rid the living organisms thus exposing only the skeletons that were made of calcareous materials. This needs great care in order to minimize damage to the skeletal structures which forms the principal classification features in coral taxonomy studies.

The taxonomic keys used here are based on the concept of dichotomous key, a type of key used widely in the identification of plants and animals. Single or multiple characters are given in contrasting pairs (occasionally in groups) and a choice must be made between the alternatives thus eliminating each genus in turn. Some of the features used in coral identification include morphology of the corallum, corallites, septal arrangement, appearance of the columella, arrangement of the costae, etc. These features were used together with *in situ* identification of corals wherever possible as field observations and detail skeletal features form the basis of coral identification.

Species diversity

In biogeography, Jaccard's Index (Jaccard's coefficient) is one of the simplest numerical methods used for comparing the species diversity between two different samples or communities.

$$\text{Jaccard's Index} = \frac{C}{(N_1 + N_2 - C)} \times 100$$

where,

C = number of species shared between a pair of regions

N_1, N_2 = number of species in each of the two regions.

Jaccard's Index calculation above will provide percentage of faunal similarity. In order to obtain levels of dissimilarity, the calculated value will be subtracted from 100% for diversity between the two coral communities found at Teluk Datai and Teluk Dedap.

III.RESULTS AND DISCUSSION

Distribution of corals in Teluk Datai

Reef features mapped for Teluk Datai is shown in Fig. 3. The breadth of the reef was estimated to extend from 50 m to 300 m from shoreline. The corals dominated approximately 409,500 m^2 (Table 1). About 247,500 m^2 was covered by ≥50% live corals, while the remaining 162,000 m^2 was covered by ≤50% live corals. The sandy beach covered the second largest area *i.e.* estimated as 210,000 m^2. Sand, pebbles, and rocks covered an area of approximately 181,250 m^2. The rocky shores covered an area of about 135,500 m^2. Dead corals *i.e.* the coral debris covered an area of 108,000 m^2. This is considered large.

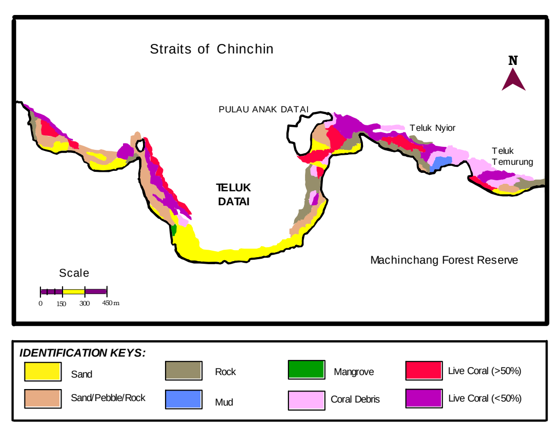

Fig. 3. Distribution of reef features of Teluk Datai, Pulau Langkawi.

A patch of mud flat was detected near Teluk Nyior covering an area of approximately 22,500 m^2 in 1989. An area of 26,250 m^2 of mud flat was observed in 1994. This increase of 3,750 m^2 was probably the result of increasing sedimentation rate around Teluk Nyior.

A small mangrove area was also found at Teluk Datai and it covered about 7,500 m^2 in 1989. In 1994, the area was estimated as 6,750 m^2. Again this change may be disregarded because of errors that might have occurred during the reef feature boundary delineation.

For a reef existing within turbid waters, this fringing reef was considered quite extensive with gradual slopes in most areas. These were depicted in Fig. 4 of Teluk Datai cross-sectional reef morphologies.

Table 1. Area coverage of reef features at Teluk Datai, Pulau Langkawi

Reef Feature	Area (sq. m)
Sand	210,000
Sand/Pebble/R ock	181,250
Rock	135,500
Live Coral (≤50%)	162,000
Live Coral (≥50%)	247,500
Coral Debris	108,000
Mud	26,250
Mangrove	6,750
TOTAL	1,077,250

Distribution of corals in Teluk Dedap

The breadth of the reef was measured to extend from 0 m to 120 m from shoreline. Estimated area coverage of the mapped reef features at Teluk Dedap is shown in Table 2.

Live coral zone was observed to be at the lower reef flat and the reef edge. It is considered to be the richest zone in terms of live coral growth and scleractinian species diversity. Live corals covered an estimated area of 7,700 m^2 (12.2%) of 63,000 m^2 total reef at Teluk Dedap. Of this live coral cover, 7.9% (5,000 m^2) are dominated by $\leq$50% live corals and the remaining 4.28% (2,700 m^2) by $\geq$50% live corals. Comparatively, coral debris was quite extensive and the area of coverage was 18,000 m^2 (28.5%). The coral debris zone is sometimes termed "coral rubble zone" because as the name implies, broken corals normally cover this zone. However, this does not necessarily imply that the zone is a dead one. The two main features seen from the reef are the long sand strips along the beaches and the mudflats of Teluk Dedap. These alone constituted 35,550 m^2 (56.5%) of the estimated total reef area. Mudflats are easily considered the "dead" zone of the reef and appear to be gradually expanding itself onto the reef claiming the coral rubble zone. The only typical reef feature not found within Teluk Dedap fringing reef in Tanjung Rhu is the mangroves.

From Fig. 5 the three main reef features of Teluk Dedap are very clearly signified by the landward corridors formed by each feature along the length of the reef. The sandy beach formed the shoreline followed by mudflats and irregular strips of coral debris preceded live coral coverage at the lower reef flats and the reef slopes. Basically the reef of Teluk Dedap is flat, narrow and shallow. These were based on the profiles drawn (Fig. 6) and the depth of which the reef is exposed during low water springs. The entire reef was observed to be exposed at water levels below 0.4m and fully submerged at water levels above 1.7m. Depths of the reef were found to be approximately 0.6 m - 1.7 m at reef flats and 1.6m - 2.8m at the slopes during spring tides. The reef slope in this area is very narrow and the live corals are mainly massive or submassive boulders distributed quite sporadically.

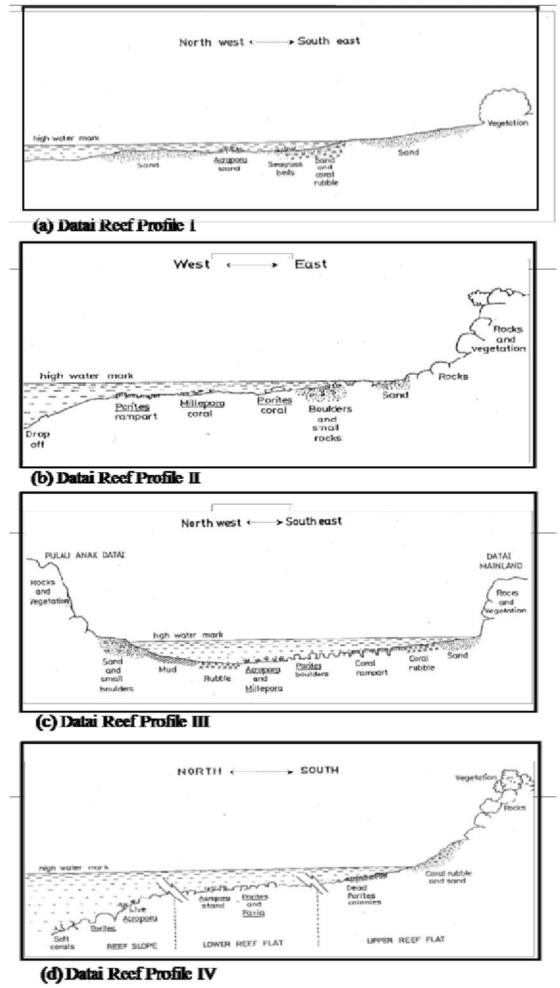

Fig. 4. Cross-sectional area of Reef Profiles, showing reef morphology of Teluk Datai

Table 2. Area coverage of reef features at Teluk Dedap, Pulau Langkawi.

Reef Feature	Area (sq. m)
Sand	18,800
Sand/Pebble/Rock	1,000
Rock	750
Live Coral (≤50%)	5,000
Live Coral (≥50%)	2,700
Coral Debris	18,000
Mud	16,750
Mangrove	-
TOTAL	63,000

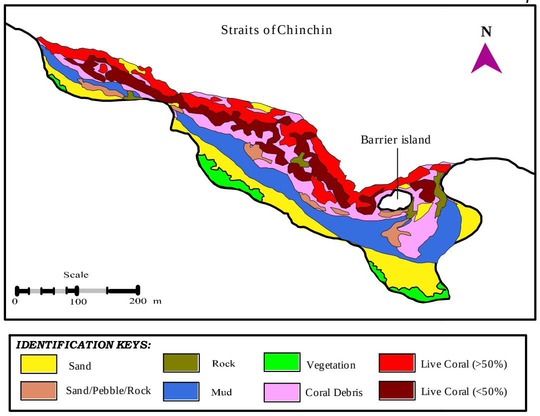

Fig. 5 Distribution of reef features of Teluk Dedap, Pulau Langkawi.

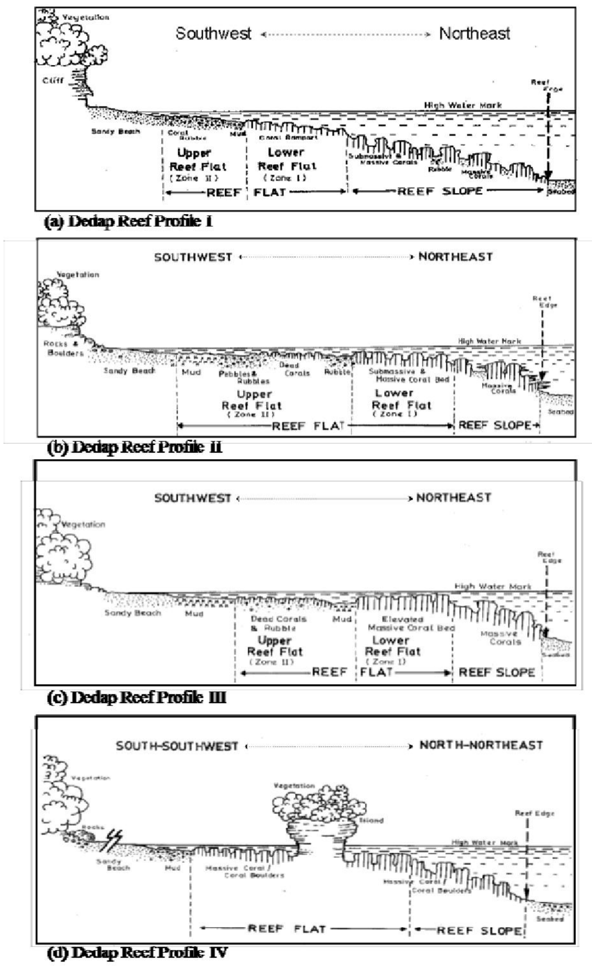

Fig. 6. Cross-sectional area of Reef Profiles, showing reef morphology of Teluk Dedap

Species Diversity of Teluk Datai Fringing Reefs

Both hard and soft corals were found in the coral reefs of the control area, Teluk Datai. The reef edge and slope are the most developed with higher species diversity compared to the reef flat which has fewer coral species. Diversity increases as one approaches the reef rim and slope. Most of the corals found here were the hard coral types while the soft corals were found mainly on the sea bed.

There are 76 species of corals found in Teluk Datai fringing reefs comprising of 35 genera. There are a total of 14 hard coral families within this fringing reef belonging to 4 sub-orders (Fig.7). Majority of the corals belong to Acroporidae, Faviidae and Poritidae families. These groups of corals are known to be tolerant to intermediate sediment load in the water column.

Submassive and branching corals were commonly found at the reef flats and these were dominated by the *Porites*, and *Acropora* species. Massive boulders of *Porites*, *Favia*, *Favites* and *Platygyra* species were found towards the reef edge where diversity is commonly higher. Encrusting and foliose corals were also found around these solid massive corals. Free-living corals of *Fungia* however, formed the solitary ones that were normally scattered throughout the reef. Few tabulated forms of *Acropora* corals were found mainly along the reef slope.

As in the case of a typical tropical fringing reef, other types of reef organisms were also found at Teluk Datai. These include the vivid coloured sponges, ascidians, molluscs, submarine vegetation (*Sargassum* sp.) and echinoderms (holothurians and echinoids).

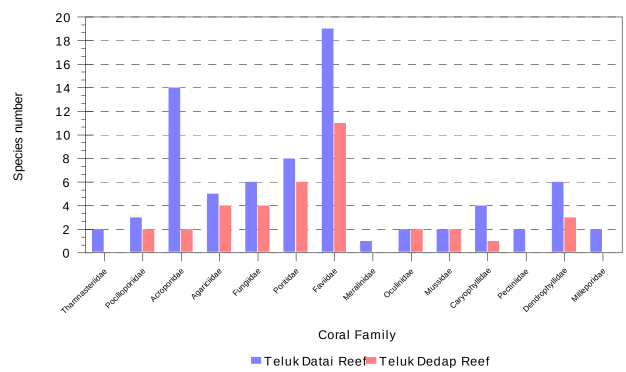

Fig. 7. Hermatypic coral species compositions of Teluk Datai and Teluk Dedap fringing reefs.

Species Diversity of Teluk Dedap Fringing Reefs

There were a total of 37 hard coral species within the Teluk Dedap . These species comprised of 4 sub-orders, 10 families, and 22 genera. The dominant family in this reef is the Faviidae, with the most number of species and live coral cover (Fig. 7; Fig. 5). Dominant species appeared to be from the genus *Goniastrea*, *Favia*, *Favites* and *Platygyra*. The next dominant family is Poritidae with its dominant species being the *Porites* that firmed the structural basis for the entire reef.

Other species appear to be randomly distributed throughout the reef. *Fungia* were normally found living in congregation in tidal pools during low water. Other genera seemed to occur in patches on the reef mainly the *Acropora*, *Montipora*, *Goniastrea* and *Galaxea* colonies. *Galaxea fascicularis* is dominant on the reef edge, forming large submassive colonies.

Various other organisms were found on this reef and these include anthozoans, sponges, alcyonaceans, molluscs, and echinoderms. Most sponges found were the encrusting type with vivid hues of purples and reds. The common echinoderms found were mainly holothurians and echinoids. Submarine vegetation were also found here which include turf algaes and most common of all is the *Sargassum* sp.

A comparison of species diversity using Jaccard's Index

Table 3 also compares the hard coral species richness found in both Teluk Datai and Teluk Dedap fringing reefs of north Pulau Langkawi. There were 24 coral species commonly shared between the fringing reefs of Teluk Datai and Teluk Dedap. Using the Jaccard's Index, faunal diversity or resemblance was calculated as follows:

If :

C	=	24	(number of shared species)
N_1	=	76	(number of species in Teluk Datai)
N_2	=	37	(number of species in Teluk Dedap)

Jaccard's Index = 24/(76 + 37 – 24)] * 100
= 26.96%

Level of dissimilarity will then be:
100% - 26.96% = 73.04%

Result of the Jaccard's Index showed that there were 73.04% of coral dissimilarity between the fringing reefs of Teluk Datai and Teluk Dedap. In other words the similarity level between the two reefs was only 26.96%. This would also mean that corals found (*i.e.* coral samples collected in the same year for both sampling locations) within these two regions are quite diverse. Studies by Abdullah and Yasin (2010) [3] showed that Teluk Datai fringing reef was 17 times larger than the Teluk Dedap reef. The larger reef area would provide larger space for coral larval settlement.

Dominant hard coral families in Teluk Dedap reef belong to Faviidae and Poritidae. In Teluk Datai dominant hard coral families belong to Acroporidae, Faviidae and Poritidae. As mentioned earlier these groups of hard corals, Faviidae and Poriitidae, are the hardier ones that seemed to be able to tolerate intermediate sediment load hence more turbid waters. These groups of corals tend to form distinguishable submassive and massive coral boulders towards the reef edge.

Corals of the Hydrozoan class were found in Teluk Datai reef but absent in Teluk Dedap. However, only 2 species of this group were found in Teluk Datai. The number of coral species in Teluk Datai is twice of that found in Teluk Dedap. It is not valid to state that species richness is related to the extent of a reef because it is known that coral reefs are not uniform in their composition. In some areas they built from several hundred species such as that found in the Great Barrier Reef, and in others from 40 (Hawaii) or less (eastern Pacific) [10].

Studies by Wood (1984) [10] stated that the richness of different reef areas, the position of faunal centers, the distribution of coral genera and species and the similarities between different reef areas are not attributable to any single factor. Instead, they result from the combination of past and present geological and environmental events.

Distribution of corals is governed by a multitude of factors and is not a predictable subject. From the collected data, it was obvious that the vast Teluk Datai area appeared to inherit more favorable environment for larval settlement. Larval settlement involves a certain amount of choice of substrate and location. Environmental factors such as water depth, type of substrate and forces of swell and current also play important part both in successful establishment and subsequent growth. The final pattern of distribution of coral colonies and the way in which they and the reef grow produce a variety of habitats and microhabitats. These habitats each encourage growth of certain species or forms of coral and a particular type of associated or visiting fauna. The zone generally subjected to the most variable conditions is the reef crest or reef flat. Corals may be exposed to air and direct sunlight during low tides, to changes in salinity and to strong wave action. Species diversity is often limited because of these environmental constraints. Much the same applies to the back reef zone, which lies to the leeward and usually landward side of the reef crest. Here, corals have to withstand exposure to sun and air. In addition, there is relatively little water movement and sediments tend to accumulate. This is clearly seen from the mudflats fringing the sandy beach at the back reef zone of Teluk Dedap. The fore reef lies to the seaward side of the reef crest, and the shallower regions are typically the most actively growing and diverse within the reef habitat as a whole. This in itself explains the distribution of live corals on the lower reef flats of the study area. The reef condition in Teluk Datai however, appeared to be healthier than that found in Teluk Dedap mainly because:

i. percentage of total live coral coverage is larger in Teluk Datai,
ii. percentage of ≥ 50% live coral coverage is much larger in Teluk Datai,
iii. coral debris (coral rubble zone) is larger in Teluk Dedap indicating possible increasing coral deaths and destruction,
iv. mudflats or the dead zone is larger in Teluk Dedap,
v. Teluk Datai reef is more extensive, an indication of larger space provision for coral larval settlement for reef building process.

IV. CONCLUSIONS

Based on the list of coral species found and the distribution surveyed at both Teluk Dedap and Teluk Datai reefs, it would be logical to say that Teluk Datai is richer in terms of diversity. However, if the aspect of reef area coverage was to be considered in relation to species richness, it would be valid to state that Teluk Dedap is richer in diversity. This is because the size of estimated reef area in Teluk Datai is several folds larger than that found in Teluk Dedap but the difference is only two-fold in terms of species diversity at generic and species level.

The distribution of coral reefs does not necessarily reflect the limits of distribution of corals themselves. Hermatypic corals often grow successfully without actually forming reefs. Neither are coral reefs uniform in their composition. This is clearly seen from the two reefs mapped in the north of Pulau Langkawi itself, the Teluk Datai and Teluk Dedap fringing reefs. Therefore it is not crucial to look at the extent of a reef but rather its richness. In reef building process, it is the hardier species with the ability to tolerate and withstand the physical and chemical environmental conditions that will eventually dominate. In this study lies the evidence that spatial inequality existed even within a small geographical area having similar environmental settings. Both assumptions were proven in the results obtained. For the case of the reefs in this study, the bathymetric characteristics and its surrounding physical features played critical roles in determining distribution of natural resources and perhaps localized ecosystem services, hence resulting in spatial inequality.

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