

**FACTORS AFFECTING THE DISTRIBUTION
OF BUTTERFLYFISH (Chaetodontidae)
ACROSS THE CORAL REEFS OF THE
TERNEFFE ATOLL, BELIZE**

BY

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ABSTRACT.

Butterflyfishes are conspicuous reef fish of the family Chaetodontidae occurring in abundance throughout the tropics (Burgess, 1978). Extensive research of the ecology and feeding behaviour of this family has taken place by marine ecologists since the intervention of SCUBA in the 1950s (Crossby & Reese, 1996). Coexistence amongst organisms in this diverse and competitive ecosystem is a dynamic subject. The aim of this study is to investigate two aspects of Chaetodon ecology to. This study concentrates on three species of butterflyfish across the reefs of the Terneffe Atoll at the four sites, Mauger Cay, Tarpon Creek, Calabash Cay and Cay Bokel, 33miles off the coast of Belize.

The "Lottery" hypothesis proposed by ecologists Sale (1977), and Chesson & Warner (1981) and the contrasting "Classical" hypothesis by Stephenson & Searles (1960), and Randall (1961) are both ideas about community co-existence. By using the variables of habitat preference and the association between species, substrate class and biological cover, this study aims to firstly test these theories to indicate the type association of community co-existence among reef fish. Secondly this study aims to investigate the positive correlation between the three species and abundance of coral, as proposed by Reese (1971, 1981) believing the family may be used as indicator organisms as to the health of the reefal environment.

The results are derived from data obtained by the non-governmental organisation (NGO), Coral Cay Conservation (CCC), collected by teams of volunteer survey divers. The association between habitat (as classified by Mumby & Harborne, 1998) and species is tested using χ^2 resulting in a preference for the "Dense massive and encrusting corals" habitat by all three species across all four sites. The statistical test r^2 is used to test for association between the three species at each sites and the nine benthos classes.

The results demonstrate habitat partitioning by all three species at Mauger Cay and Tarpon Creek, thus supporting the "Classical" hypothesis. The results for Calabash Cay and Cay Bokel show a random distribution of all three species, therefore supporting the "Lottery" hypothesis. All three species show an association with high coral cover, supporting the well-established theory that butterflyfish may apply as indicators organisms (Reese, 1977, 1981).

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" A coral reef explodes with life. Most evident are the fish- moving, darting, hovering: again and again sweeping by in waves. A panorama of species unlike any on earth" Humann, 1991.

1. INTRODUCTION.

1.1 ECOLOGICAL CHARACTERISTICS OF BUTTERFLYFISH (CHEATODONTIDAE).

Butterflyfishes of the family Cheatodontidae are conspicuous members of the ichthyofuna. One hundred and fourteen species of butterflyfishes, in ten genera, are recognised in the present work. The largest genus, *Chaetodon*, is subdivided into thirteen subgenera (Burgess, 1978). This family inhabit all tropical coral reefs world wide, thus attracting a great deal of attention from both the scientific community and the aquarium fish industry (Burgess, 1978 & Motta, 1989). Butterflyfishes are primarily reef fishes, and their distribution closely coincides with the limits of coral growth in regards to both their northern and southern extent as well as the depths to which they penetrate (Burgess, 1978). Observations on butterflyfish in their natural habitats and studies on the stomach contents of these fishes have indicated that butterflyfish eat small invertebrates, including coral polyps and planktonic copepods, and at least some browse on algae (Hiatt & Strasburg, 1960; Hobson, 1974). Harmelin-Vivien & Bouchon-Navaro (1983), studied the diets of 18 Chaetodontid fishes from the coral reefs of Moorea, French Polynesia, their results concluded that 16 of the species ingested coral polyps. When settling on coral reefs, fish larvae generally change from zooplanktivory to diverse forms of benthic feeding (Harmelin-Vivien, 1989). Whereas food has

not been reported to directly influence settlement, it is hypothesised by Harmelin-Vivien (1989), that food resource might play a role in the recruitment processes of butterflyfish, particular in the Indo-Pacific where the family rely heavily on coral as a food. Several studies have been made on the family to allow a better understanding of the community structure of coral feeding fishes (Haitt & Strasburg 1960; Talbot 1965; Hobson 1974; Reese 1975, 1977; Harmelin-Vivien 1979; Ralston 1981; Harmelin-Vivien & Bouchon-Navaro 1982).

Butterflyfish are deep-bodied, highly compressed fishes that are able to move between the branches or plates of certain corals with apparent ease. The coral reef is constructed, as to provide good protection for compressed fish such as butterflyfish. Butterflyfish occur almost entirely within the 21°C isotherms of the northern hemisphere summer (July) and southern hemisphere summer (January). Within these isotherms the majority of species are found in shallow waters, of less than 30 metres. The physical requisites (salinity, temperature, etc.) of both corals and butterflyfish are similar (Burgess, 1978). This study concentrates on the three following species; *Chaetodon capistratus* (Foureye butterflyfish) (Figure 1), *C. striatus* (Banded butterflyfish) (figure 2) and *C. ocellatus* (Spotfin butterflyfish) (figure 3).

1.2 ECOLOGY OF CORAL REEFS.

Coral reefs are diverse ecosystems and the hundreds, or sometimes thousands,

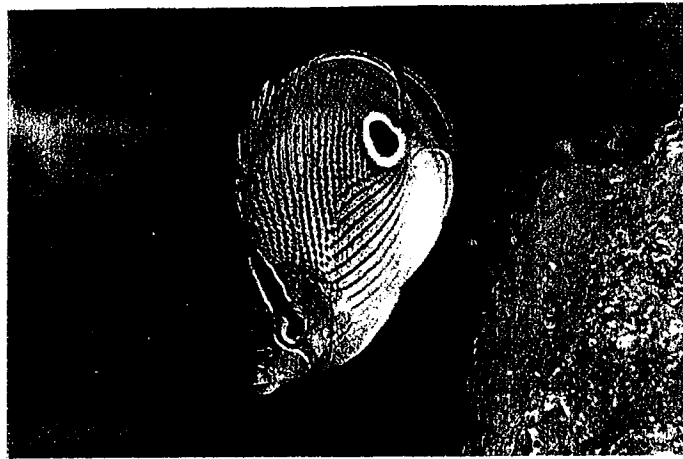


Figure 1. *Chaetodon capistratus* (Foureye Butterflyfish) taken from Humann, 1991



Figure 2. *Chaetodon striatus* (Banded Butterflyfish) taken from Humann, 1991



Figure 3. *Chaetodon ocellatus* (Spotfin Butterflyfish) taken from Humann, 1991

of fish species present make them richer than any other aquatic environment (Crosby & Reese, 1996). The importance of coral reef ecosystems may be seen in their numerous ecological, aesthetic, economic and cultural functions. Coral reefs protect coastlines from shoreline erosion, and serve as a living pantry for the subsistence harvest and consumption of many reef organisms (Crosby & Reese, 1996). For example Indonesia's 196.6 million people gain 50% of their protein from seafood (Harboun *et al.*, 1997). The cycle of reef accretion and erosion maintains beaches, and provides habitat for seagrass and mangroves, the breeding grounds for many reef organisms (Crosby & Reese, 1996). The study of reef fish ecology began a relatively short time ago. The development of Self Contained Underwater Breathing Apparatus (SCUBA) in the 1950s gave access to the reef environment and opened up possibilities for significant ecological studies.

1.3 THE ECOLOGICAL STRUCTURE OF CORAL REEF COMMUNITIES.

An early idea on the structure of ecological communities by Gause (1934) stated that closely related species are often in direct competition with each other. Although dated, ideas on ecological community structures have developed from this initial hypothesis. More recent ideas on ecological communities suggest that species inhabit separate, partitioned niches, thus

avoiding direct competition. The search for small-scale habitat partitioning has been conducted by Spiller (1984) by testing for inter- and intraspecific competition between two common orb-weaving spiders' *Meteperia grinnelli* and *Cyclosa turbinata*. Spiller (1984), concluded that due to the fact that the two species were never at the same stage in their life cycle together; co-existence was possible as the two species were never competing for the same sized prey. It has been suggested that, terrestrial organisms show a lower frequency of interspecific competition than marine organisms (Krebs, 1994). One explanation put forward by Krebs (1994) is that marine organisms in intertidal and subtidal zones often compete for space, while terrestrial organisms more often compete for food or nutrient resources, which tend to be more heterogeneous.

1.4 THE CLASSICAL HYPOTHESIS.

Two schools of thought concerning reef fish arose, from these early theories on competitive interactions within ecological communities. Stephenson & Searles (1960) and Randall (1961, 1965) suggested that the reef fish community was a system organised around competition and to overcome this, each species "partitions" itself into an individual niche. For example Greenfield & Greenfield (1982) demonstrate habitat partitioning, using, by way of example, two species of Blenny (small reef fish), exhibiting subtle habitat separation. *Acanthemblemaria spinosa* occurs only in holes left by invertebrates on vertical surfaces on dead coral, while *A. greenfieldi* is to be

found in the vacated holes of invertebrates on horizontal surfaces of dead coral. Fish diversity seemed to be maintained by fine-scale partitioning of the resources (in this case the dead coral) which reduce niche overlap and competition, allowing coexistence. This view of fish ecology complies with the classical competition theory (Greenfield & Greenfield, 1982).

1.5 THE LOTTERY HYPOTHESIS.

The second school of thought regarding community coexistence in reef fish, was put forward by Sale (1977, 1982) and Chesson and Warner (1981). Sale describes his theory as the Lottery Hypothesis. Data was drawn together to demonstrate that reef fish are by and large food and habitat generalists and suitable living space is the resource most likely to be in short supply for them. Sale (1977, 1982), argued that the coexistence of species was due to a "lottery" for living space in which the pelagic larvae are "tickets" and therefore will be site colonists. The lottery operates within habitats and at the level of the individual fish. Single vacant sites are unpredictably generated and are filled by individual colonists, to be held until these fish also disappear and are replaced in turn by new colonists of their own or other species.

Sale (1977), ideas on the Lottery Hypothesis came under criticism by Anderson *et al.* (1981), with the latter authors stating that the hypothesis lacks the proper mathematical modelling to back it up. The Lottery Hypothesis assumes space to be the limiting factor on a reef, based on the rapid

1.7 THE AIMS OF THIS STUDY.

The aims of this project is to investigate the preferred reefal habitats of the three species of *Chaetodon* across the Turneffe Atoll, Belize, Central America (Figures 4-7). This is to be achieved using data collected by volunteer SCUBA divers from the UK based Non Governmental Organisation (NGO), Coral Cay Conservation (CCC). The situation involving three ecologically similar species, inhabiting a taxonomically rich ecosystem is complicated, and competition is fierce (Sale, 1977). By investigating the distribution of Chaetodontids across the Turneffe Atoll, two hypothesis can be tested. Conclusions can be drawn, as to if the three closely related species follow the "classical" or the "lottery" hypotheses? The Classical hypothesis could be rejected if the three closely related species fail to follow a pattern of each occupying slightly different habitats and using different resources on the reef. It can be concluded that the lottery hypothesis may be rejected if the three species fail to show a more random distribution across the reefal environment.

Following on, this study aims to investigate if there is a positive correlation between butterflyfish and coral cover, thus proving the family make good indicator organisms on the health of the reefal environments of the Terneffe Atoll. In conclusion this study aims to investigate two aspects of butterflyfish ecology, for the three species inhabiting the coral reefs of the Turneffe Atoll .

2. THE STUDY AREA AND ITS HABITATS.

2.1 THE TERNEFFE ATOLL.

The evolution of a coral atoll begins when an underwater volcano emerges as an island above a tropical sea. When volcanic activity ceases, the island begins to erode in to a series of peaks and ridges, and fringing coral reef colonise the shoreline. Eventually when the mountainous interior of the island is reduced to a low hill and a large lagoon forms inside the reef the area becomes an atoll (Reese, 1984).

The Turneffe Atoll lies 33 miles off the coast of Belize (figure 6). Situated south of the Yucatan Peninsula, Belize has 22,963 km² of land, including 689 km² of off shore cays, of which the Turneffe Atoll is the largest covering 330 km² (figure 6). Belize is fringed by a submerged coastal shelf edged by a well developed barrier reef, 250km in length (figure 6), the second largest in the world (Guilcher, 1988). The Tereffe Atoll is oriented NNE-SSE and is roughly lens-shaped. large sand cays are situated around the inner perimeter (figure 7). Temperature and salinity in the inner lagoon are subject to wide fluctuation, but surface temperatures in June-July averages 29°C (Guilcher, 1988). The cays are a mix of high and low lands: the high lands, mostly fronting the reef to the east, are generally covered with littoral forest, palmetto or coconut; the lowlands with high and low

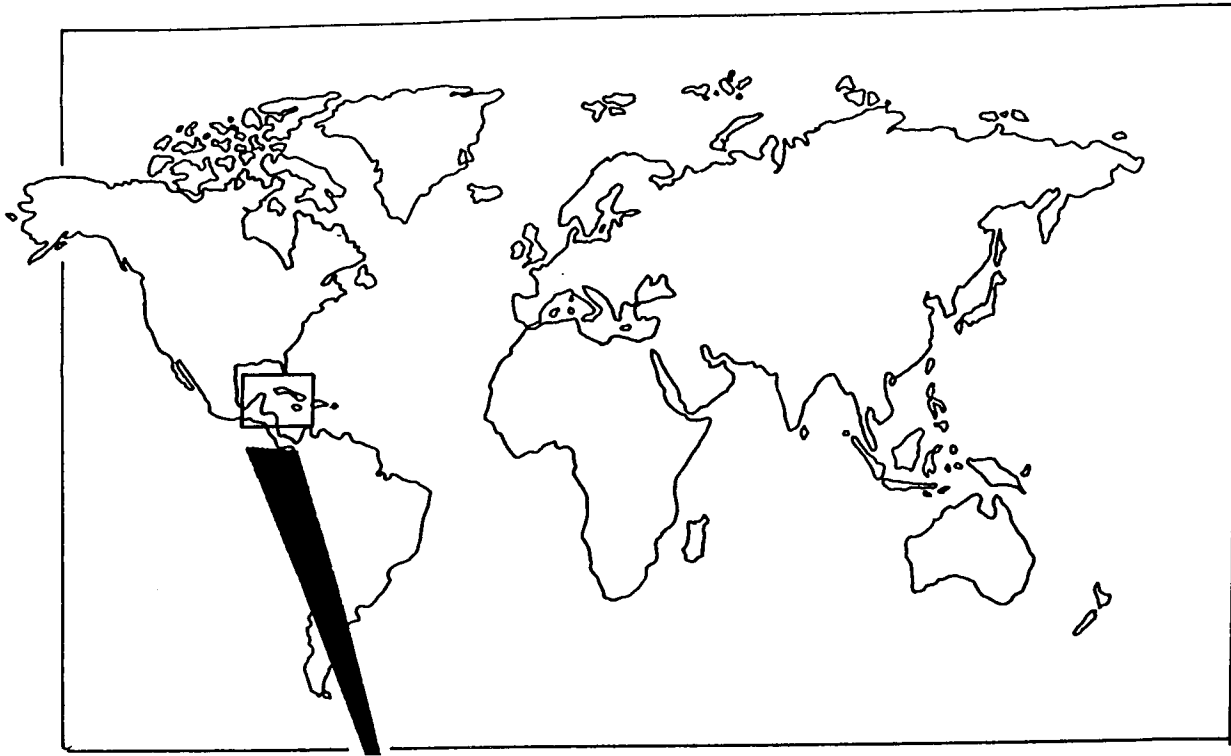


Figure 4. Belize in relation to the rest of the world (own illustration).



Figure 5. Belize in relation to the rest of the Caribbean (own illustration).

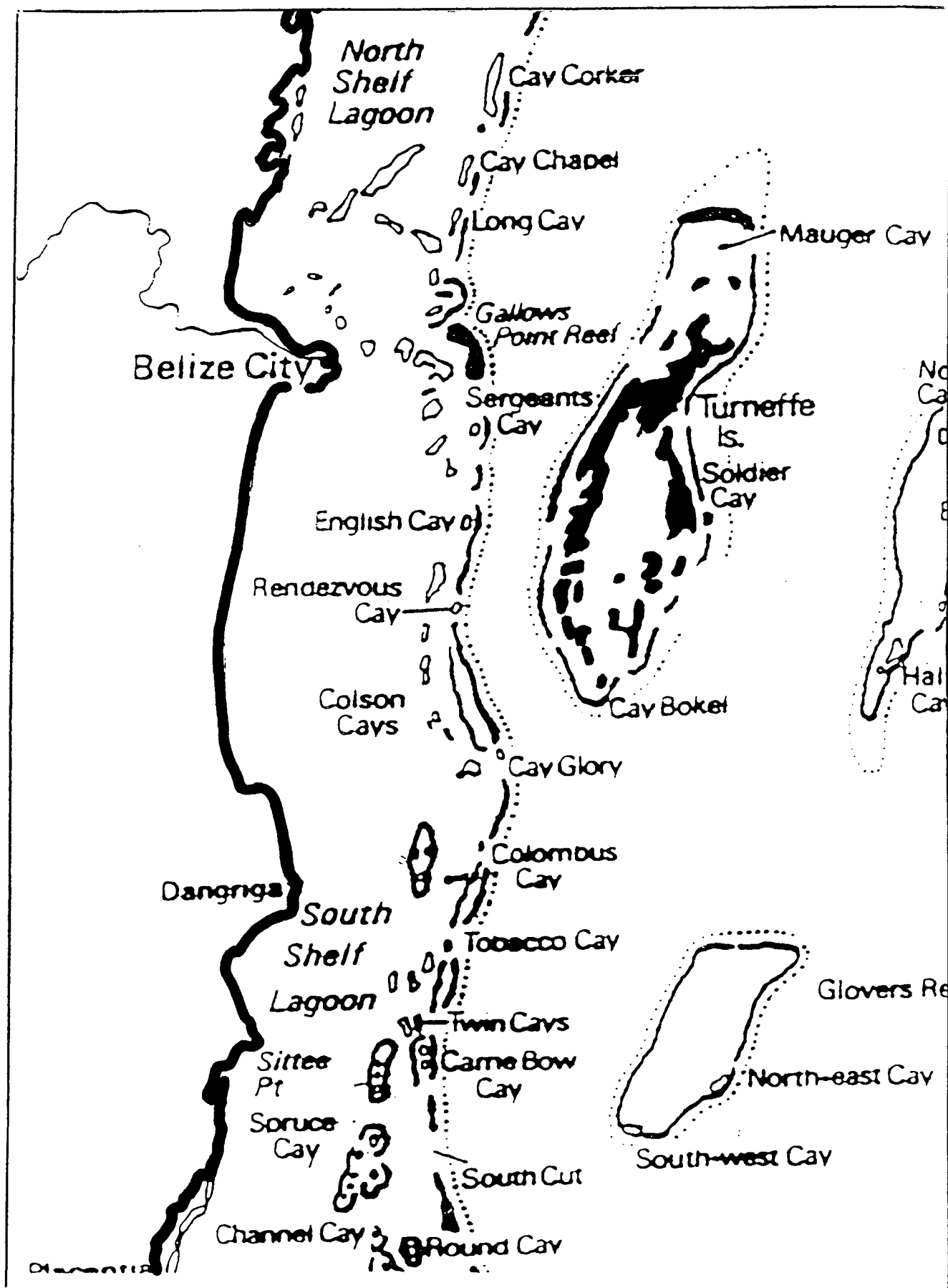


Figure 6. Terneffe Atoll and the Belizian Barrier Reef taken from Guilcher, 1988.

Turneffe Atoll

Revised base map

Preliminary classification / DGPS control

- Mangrove
- Sand
- Back reef
- Cleared land
- Differential GPS control point
(see attached list of coordinates)

Mauger Cay

Figure. 7 Terneffe Atoll, taken from CCC, 1995.

Tarpon Creek

Calabash Cay

Cay Bokel



Scale 1:60,000



The complex pattern of cays, spits, channels, lagoons and reef are excellent breeding ground for turtles and the largest colony of American crocodiles in the Caribbean (CCC, 1995). The site is important for multiple bird species, the atoll has been used by fishermen since Mayan times and today is dotted with fishermen's camps, mostly from Belize City (CCC, 1995).

2.2 STUDY SITES AND HABITAT CLASSIFICATIONS.

There are 15 different study sites on the Turneffe Atoll, listed below in table 1.

Cay Bokel	Long Ridge	Crawl Cay
Tarpon Creek	Snake Point	Dog Flea
Calabash Cay	Half Moon Cay	Dead Man's Cay
Grand Bouge	Cay Bokel	Long Ridge
Terneffe Flats	Northern Bouge	Mauger Cay

Table 1. showing the 15 study sites of Terneffe Atoll

For this study, only data from the four study sites in bold print have been used. Mauger Cay is the most northerly study on the Atoll, with Cay Bokel the most southerly, and Calabash Cay and Tarpon Creek to the east west of the Atoll respectively (figure, 7), therefore giving an even spread of results

from across the Atoll.

2.3 THE HABITAT CLASSIFICATION OF THE REEFAL ENVIRONMENTS OF THE TERNEFFE ATOLL.

Generally speaking, the term "habitat" has a variety of meanings which differ according to a person's scientific discipline or personal preference. For example, an ecologist might equate habitat types with physical conditions such as gradients of wave exposure or inundation, whereas a geologist may wish to place greater emphasis on geomorphology (Mumby & Harborne, 1998). Mumby & Harborne, (1998), have developed a habitat classification scheme for the reefs of Belize. The scheme may be defined as a description of benthic geomorphology and the associated composition of species (or life forms) and substrata. The reefs of the Terneffe Atoll supports 11 different habitat types.

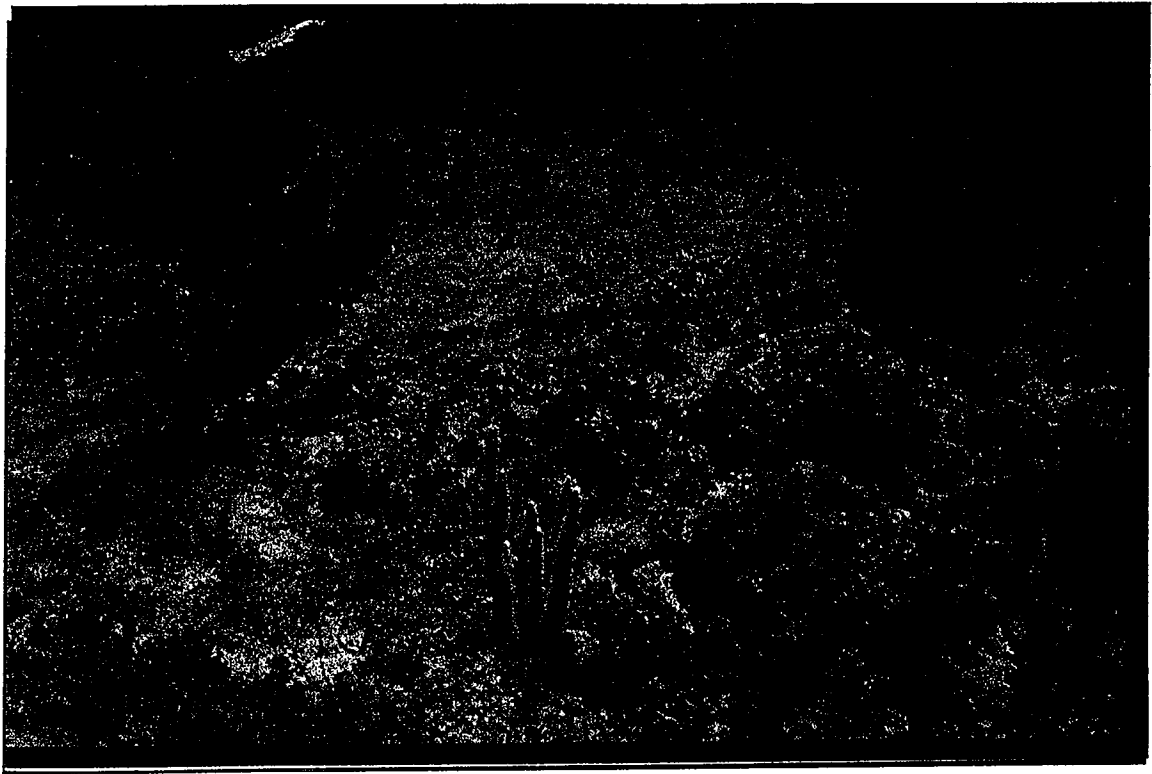


Figure 8. showing the gorgonians (soft corals) *Gorgonia ventalina* (Common sea fan) and *Plexaurella* sp. (Sea rods) on a sand and bedrock substrate, covered by *Lobophora variagata* and *Sargassum* sp (algae).

Habitat 1. Fleshy Brown Algae and Sparse Gorgonians.

This benthic class is dominated by a high abundance of fleshy brown algae, particularly from the genera *Lobophora*, *Pandina*, *Turbinaria*, and *Sargassum*. The gorgonians *Pseudoplexaura* spp., *Pseudopterogorgia* spp. and *Gorgonia ventalina* are present at fairly low densities ($< 3\text{m}^2$). The dominant underlying and exposed substrata are hard comprising of either dead coral, rubble of bedrock. Algal cover rarely exceeds 70% (Mumby & Harborne, 1998).

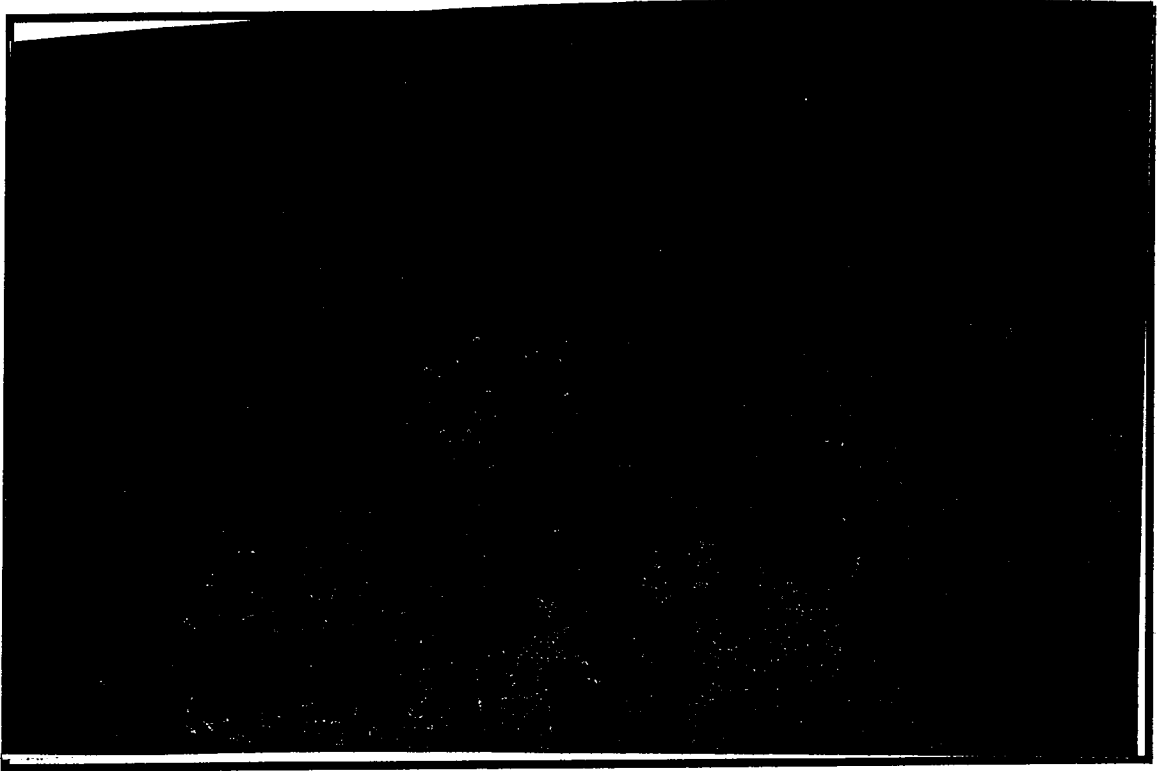


Figure 9. showing dense colonies of gorgonians (soft corals) of the species *Gorgonia ventalina* (Common sea fan), *Plexaurella* sp. and *Pseudoplexaura* sp. (Sea rod) on a rubble substrate.

Habitat 2. Bedrock / Rubble and Dense Gorgonians.

This benthic class is dominated by bare bedrock or rubble and visually dominated by dense soft corals, particularly *Pseudopterogorgia* spp. And *Gorgonia ventalina*. Few hard corals exist (Mumby & Harborne, 1998).

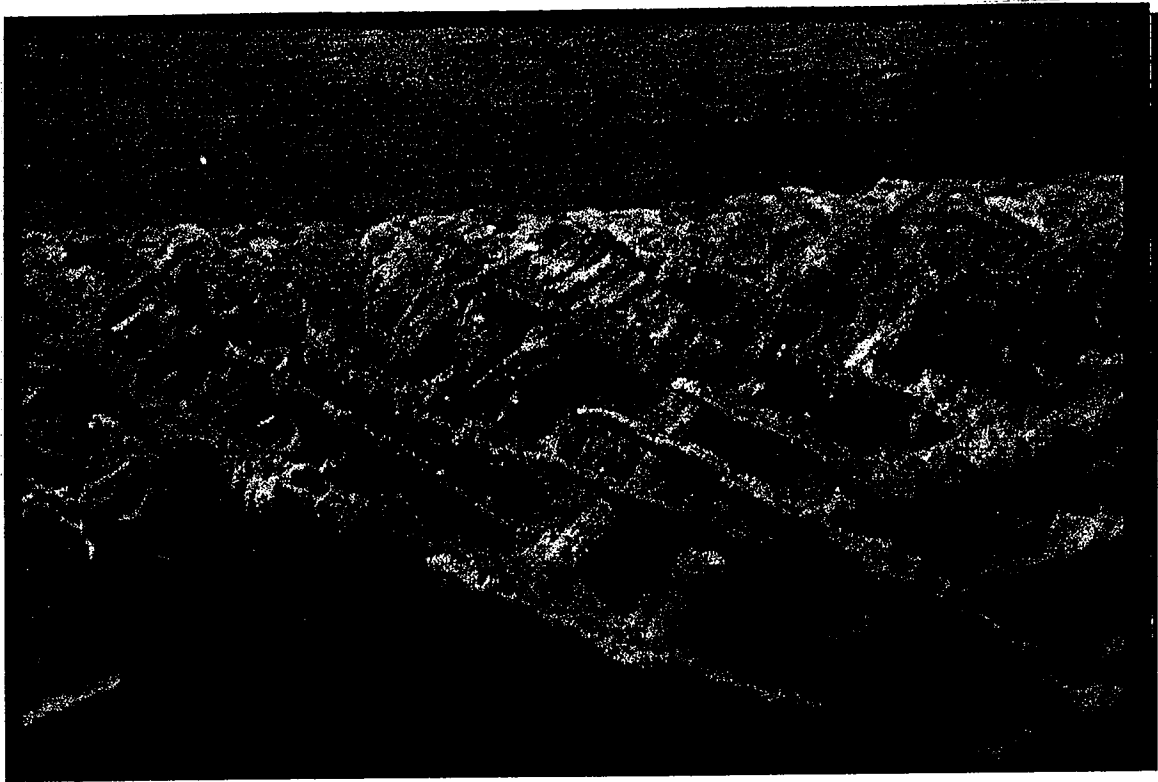


Figure 10. Dense colony of *Acropora palmata* (Elkhorn hard coral).

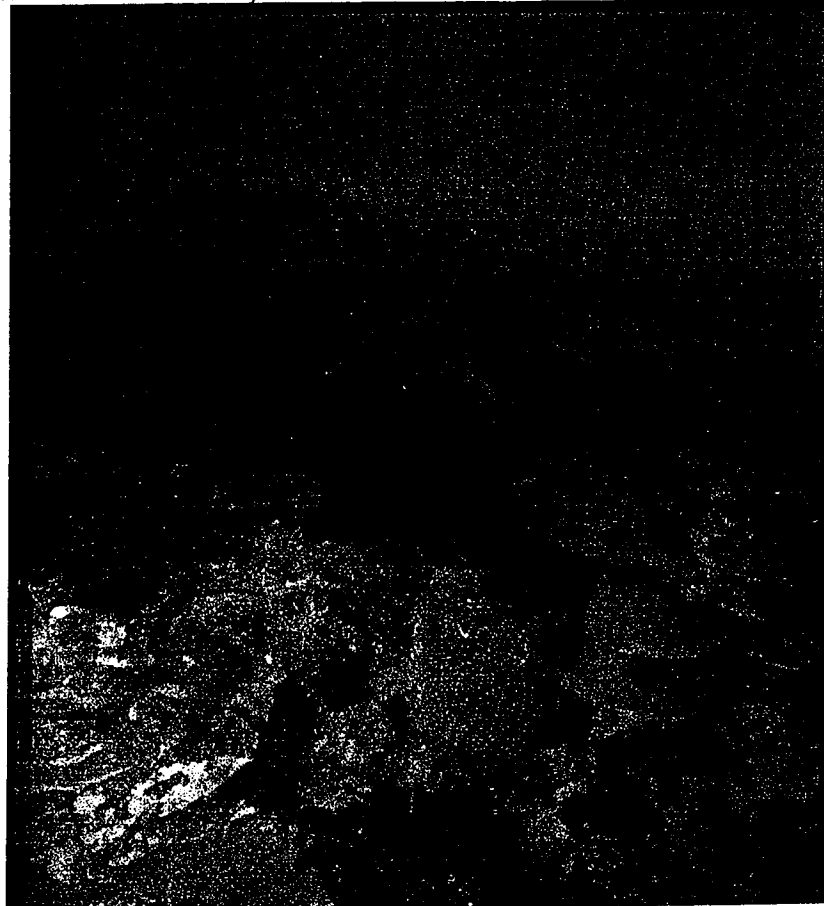
Habitat 3. Branching Corals.

This benthic class is visually dominated by patches of either *Acropora palmata* or *Acropora cervicornis* (hard corals) and occasionally by both species. The encrusting sponge life form is the most common. The substratum is dominated by rock and dead coral. Stands of *A. cervicornis* are usually found in deeper, usually less turbulent water than *A. palmata* and are associated with small massive corals such as *polities asteroides* and *Montastraea* spp. (hard corals) and greater cover of brown fleshy algae and upright sponges (Munby & Harborne, 1998).

Figure 11. Dense colonies of *Montastraea annularis* (Star hard coral), *M. faveolata* (Mountainous star hard coral) in various different growth forms. Back ground dominated by colonies of gorgonians (soft corals).

Habitat 4. Dense Massive and Encrusting Corals.

This habitat class consists of a diverse community of species. The commonest coral species include *Montastraea annularis*, *M. cavernosa*, *Siderastrea siderea*, *Dichocoenia stokesii*, *Agaricia agaricites*, *Porities* spp. (hard corals), are abundant, hard corals may make up greater than 5% of the coverage. Soft corals are also common, particularly *Pseudoplexura* spp. the substratum is dominated by bedrock and sand (Mumby & Harborne, 1998).



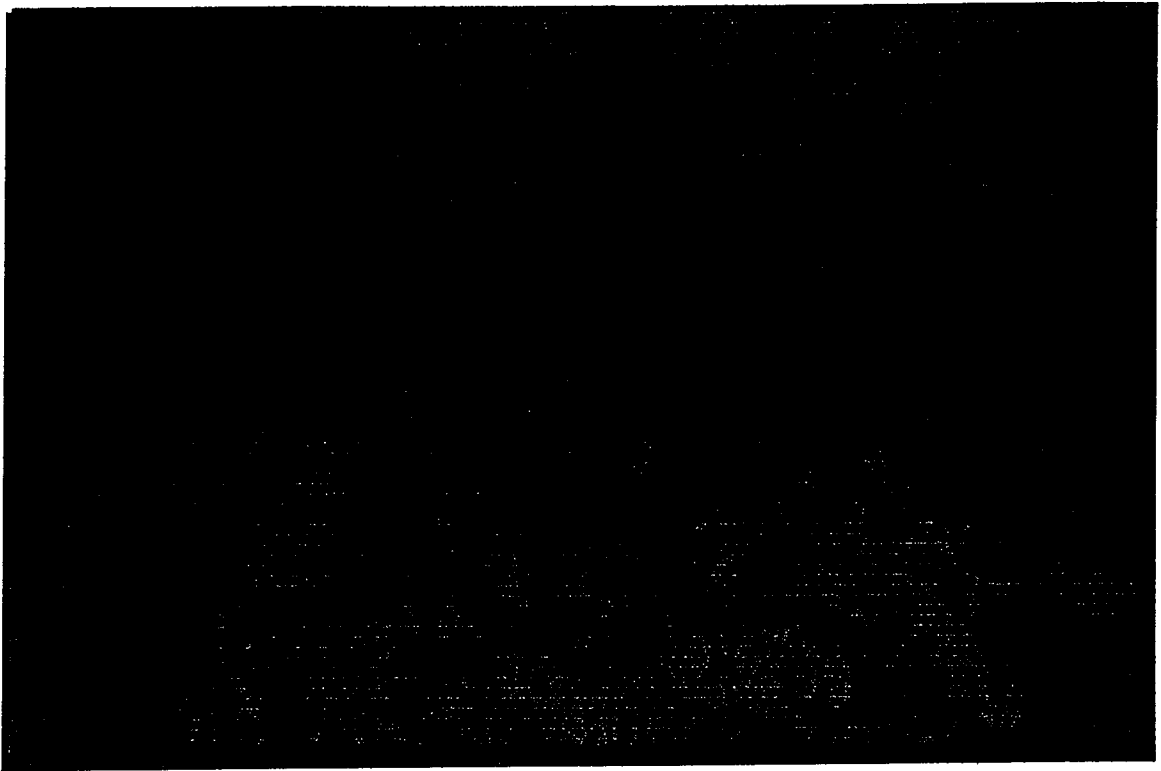


Figure 12. Sparse colonies of the gorgonians *Pterogorgia* sp (Sea whip) on sand.

Habitat 5. Bedrock / Rubble and Sparse Gorgonians

This benthic class is dominated by bedrock which can exceed 80% cover. Gorgonians (soft corals) are common at low to medium densities ($<3\text{m}^2$), particularly *Pseudoplexaura* spp., *Pseudopterogorgia* spp. and *Gorgonia ventalina*. Hard coral and algal cover is low (Mumby & Harborne, 1998). The class is distinguished from the Sparse massive and encrusting corals class (hab. 10) by virtue of having much less than 1% hard coral cover (i.e. in practice, hard corals cannot be seen).

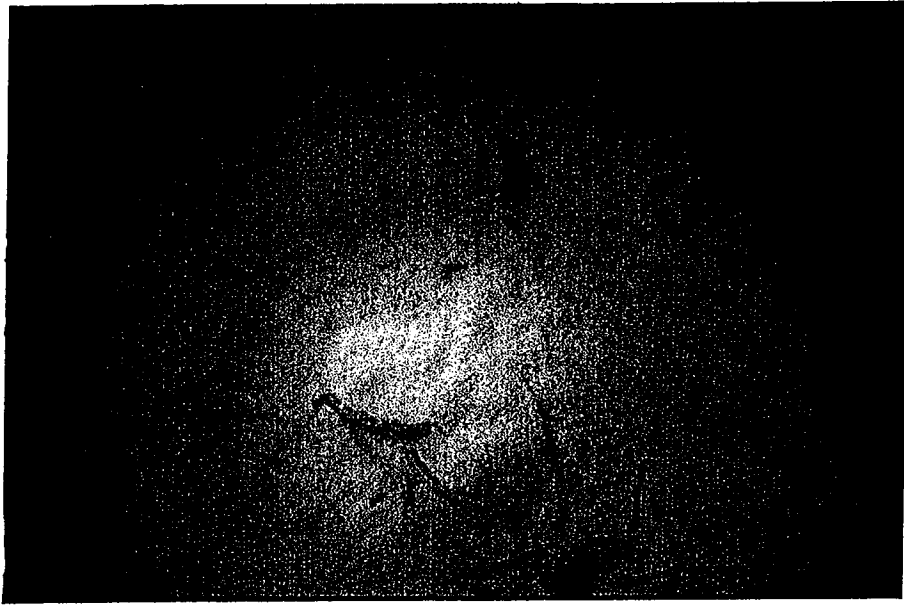


Figure 13. Sand and very sparse *Syringodium filiforme* (Manatee grass).

habitat 6. Sand and Sparse Algae.

This benthic class is dominated by sand (over 90% cover). There is Some sparse algae, particularly green turf.



Figure 14. dense colony of *Agaricia grahamae* (Sheet hard coral) with patches of *Lobophora* sp (Algae).

Habitat 7. Sheet Corals.

This benthic class is characterised by colonies of *Agaricia lamarcki*, *A. grahamae*, *a. undata* or *A. purpurea*. Although coral cover may not be dominant, the coral community is diverse including *Montastraea annularis*, *M. cavernosa*, *Meandrina meadrites*. Soft corals are abundant and usually include colonies of *Isiligorgia schrammi*. Algae tend to dominate the benthos, particularly the brown fleshy alga, *Lobophora variegata*, *Dictyota* spp., and *Halimeda* species. The sponge community is abundant and diverse. The substratum is dominated by bedrock and dead coral (Mumby & Harborne, 1998). The sheet coral is particularly common in deep water and is usually

associated with escarpments.

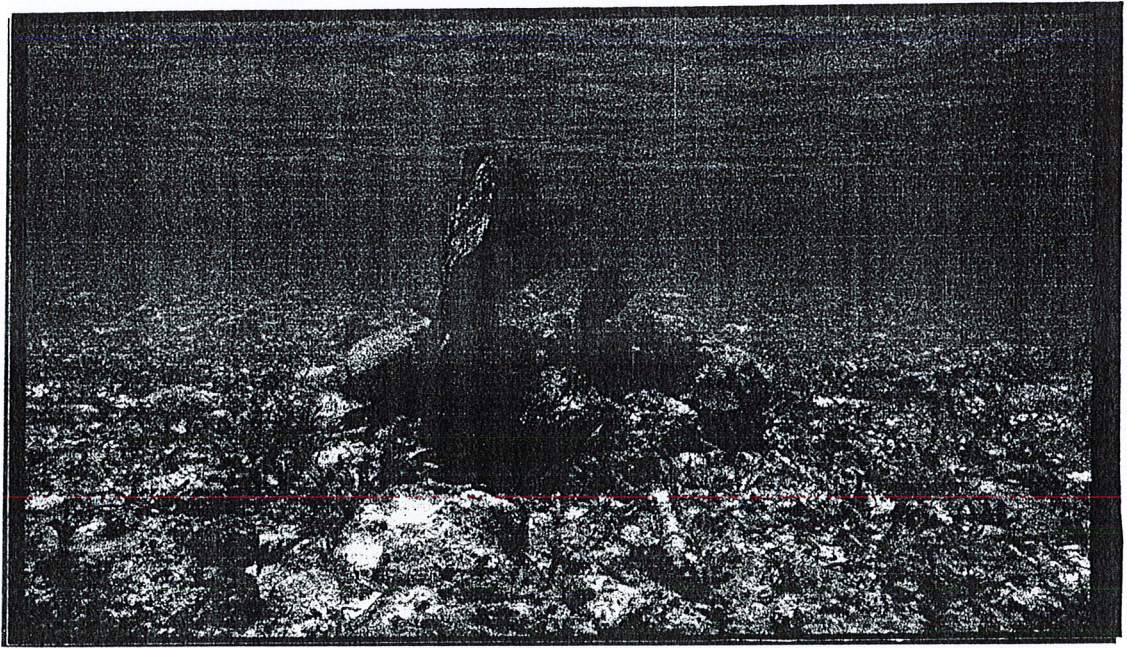


Figure 15. *Thalassia testudinum* (Turtle grass) and small gorgonians, *Gorgonia ventalina* (Common Sea fans) amongst a collection of small hard coral species.

Habitat 8. Seagrass with Distinct Coral Patches

Where aggregations of soft corals and / or hard corals are found interspersed with seagrass, the benthic class is referred to as "seagrass with distinct coral patches". While corals may attain 3% cover, the visually dominant feature is still seagrass.

The commonest hard coral species are *Porities astreoides*, *Montastraea*

annularis, *M. cavernosa*, *Siderastrea siderea*, *Dichocoenia stokesii* and *Millepora alcicornis*. Soft corals may be dominated by *Pseudoplexaura* spp (Mumby & Harborne, 1998).

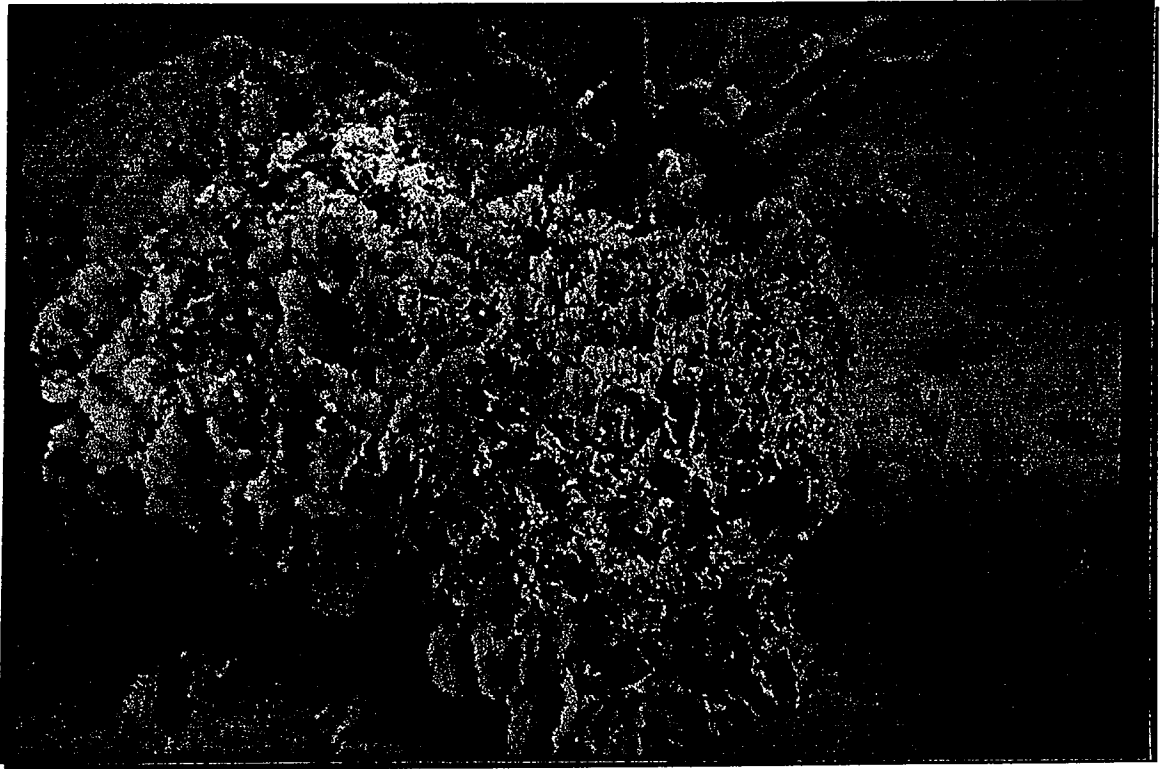


Figure 16. large patches of *Agaricia tenuifolia* (Ribbon hard coral) and a stand of *Acropora palmata* (Elkhorn hard coral) on a sandy substrate.

Habitat 9. Ribbon and Fire Coral with Green Calcified Algae

This benthic class is dominated by *Agaricia tenuifolia* and algae from the genus *Halimeda*. Brown fleshy and red / brown branching algae are usually present. In shallow water some colonies of *Acropora palmata*, *Porites porites*,

and *Millepora* spp. may be common (Mumby & Harborne, 1998). This class is often associated with the spurs of low relief spur and grooves zones.

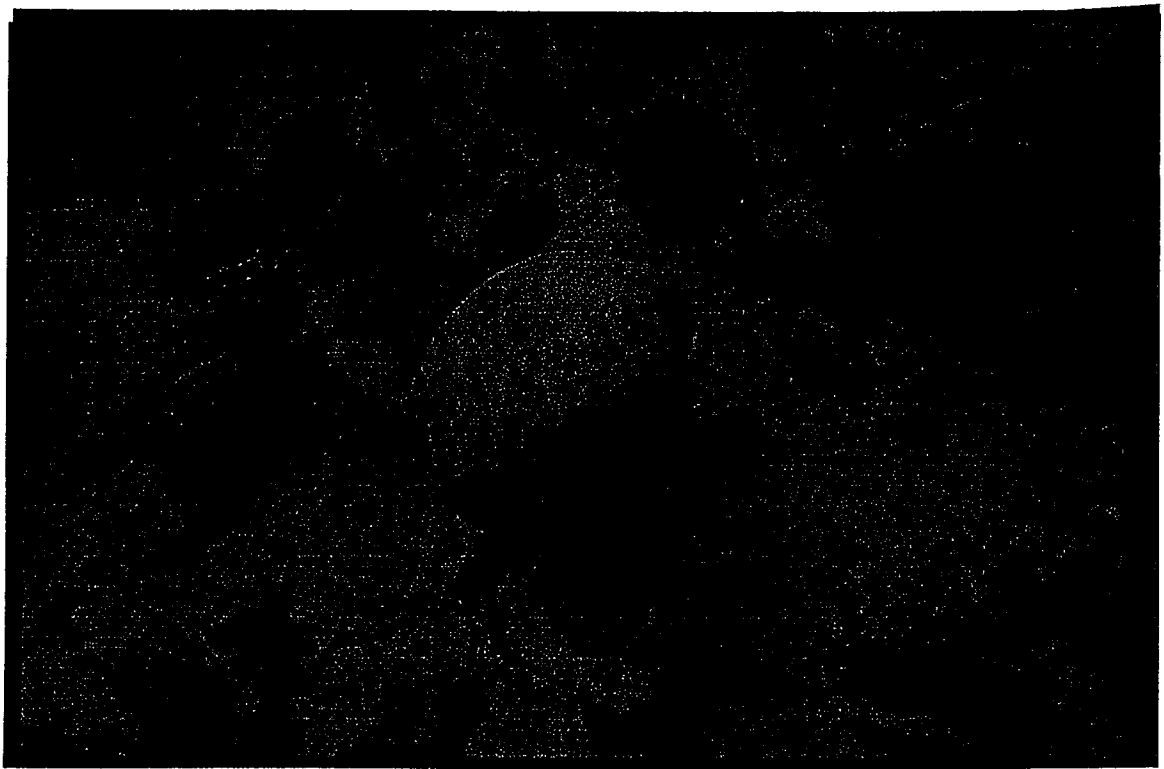


Figure 17. individual *Diplora strigosa* (Brain hard coral) with *Gorgonia ventalina* (Sea fans) on a sandy substrate.

Habitat 10. Sparse Massive and Encrusting Corals.

The main diagnostic feature of the this class is the visual absence of hard corals (less than 1% cover). Soft corals are common, particularly *Pseudoplexura* spp. the substratum is dominated by bedrock and sand (Mumby & Harborne, 1998).

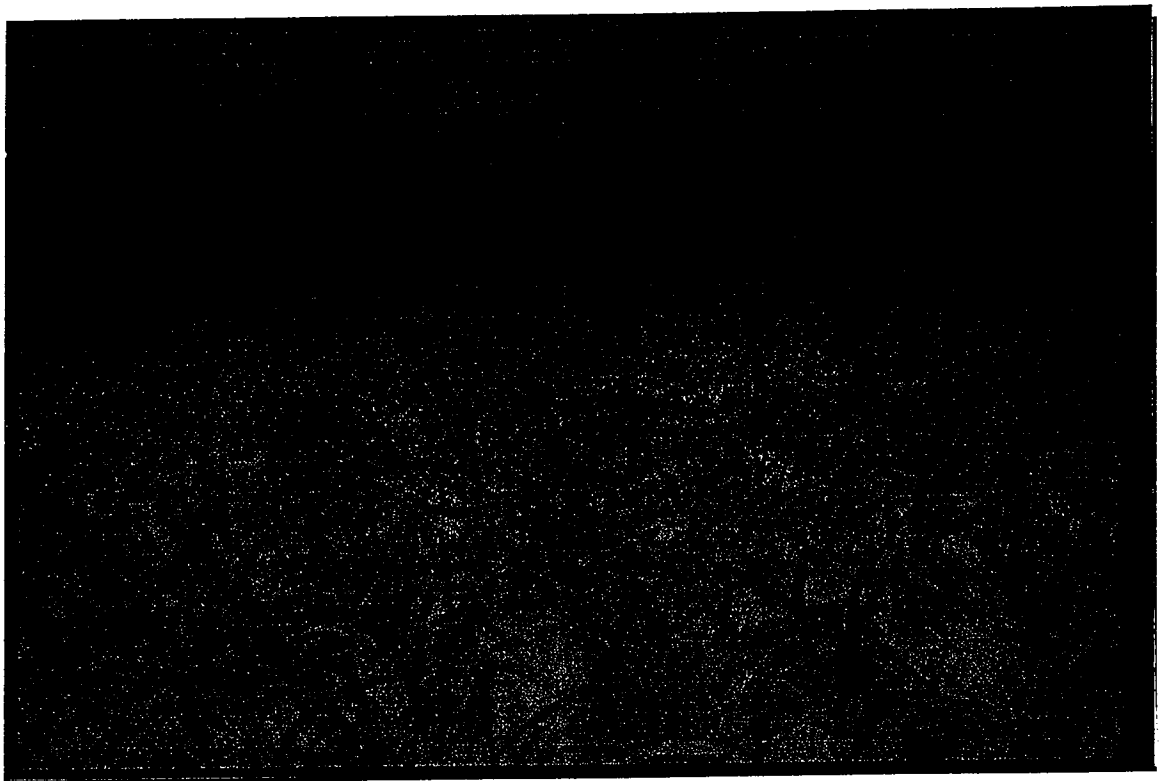


Figure 18. medium dense *Thalassia testudinum* (Turtle grass) on a substrate of sand.

Habitat 11. Seagrass

This benthic class is dominated by seagrass from the genera *Syringodium* and *Thalassia*. Standing crop biomass is 11-80 g.m² and cover is 30-70%.

Some corals may be present, particularly, *Siderastrea radians*, *Manicina areolata* and *Porites* spp. Some gorgonians from the genera *Pseudopterogorgia* and *Pterogorgia* may be present. Algae from the genera *Laurencia*, *Halimeda*, *Penicillus*, *Avarinillea*, *Udotea* and *Cymopolia* are likely to be present. The substratum is dominated by sand / mud (Mubby & Harborne, 1998).

impression of the benthos type within each habitat. This investigation should show patterns as to the distribution of each of the three species across a reefal environment, conclusions can be drawn as to how the three species interact with each other and there immediate environments.

Since 1986, CCC has utilised a workforce of over 900 specially trained volunteer divers to collect detailed topographic, bathymetric and biological data for the establishment of management plans for selected areas of the Belize barrier reef (Mumby, *et al.*, 1995). After three years of surveying, CCC has built up a complete data base, comprising of data on the whole of the Turneffe Atoll's reef system. Sets of data can be extracted from the main database for analytical purposes.

3.1 DATA COLLECTION METHODS

Volunteer research programmes are applied to a wide variety of scientific disciplines. Self funding volunteer labour can be a valuable resource to a host country operating under financial, manpower and training constraints (Mumby *et al.*, 1995). CCC, has adopted this concept to assist the Coastal Zone Management Unit of Belize. CCC trains volunteer divers to conduct detailed surveys of marine resources in preparation for sound management initiatives.

3.2 CCC VOLUNTEER TRAINING PROGRAM.

Volunteer divers undergo an intensive 8-day training program in marine life identification and survey techniques. The program has been developed and refined since 1986, and it incorporates lectures, practical exercises, one to one tuition and frequent testing. The course syllabus includes the identification of all species of macroalgal, seagrass, coral and other marine invertebrates; training in marine survey techniques (assessment of biological cover, abundance and topographic features); aspects of the relevant biological issues (species interactions, taxonomy, physiology) and consideration of current coastal zone management issues and practices (Mumby, *et al* 1995).

3.4 SYNOPSIS OF THE BASELINE SURVEY TECHNIQUE.

Survey data is used primarily to describe the nature of habitats evident in arial photography or satellite imagery in order to allow the preparation of baseline habitat maps. The techniques itself uses teams of four volunteers who survey along a plot less belt-transact approximately 3m wide. Individual reef transacts are orientated perpendicular to the reef crest in order to describe the vertical zonation (figure 19). each transact is assigned a unique code that allow the data to be carefully indexed and entered into a database.

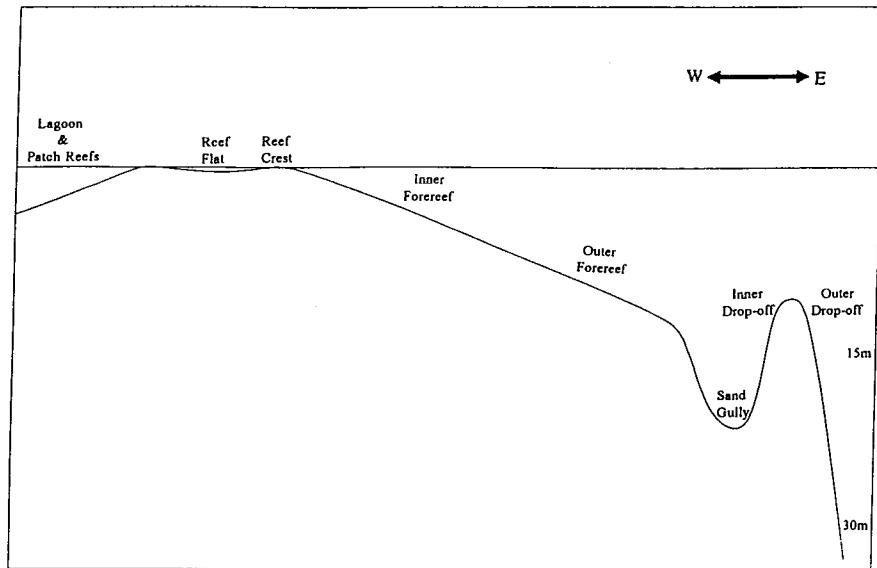


Figure 19. stylised profile of a reef, showing vertical zonations, taken from Mumby *et al.*, 1995.

For safety reasons, (to avoid decompression) a CCC transect starts at a maximum depth of 30m . The transect then finishes as close to the reef crest as possible, thus spanning all the major reef zones as shown in figure 19. These reef zones are defined by characteristic geological and morphological features.

A survey team is comprised of four SCUBA divers, split into two "buddy" pairs, each of which has a specific task during the survey. The information gathered by each diver can be listed as follows .Diver 1in the first Pair collects the physical information, including depths every 10m and substratum types and any human or natural impacts. Diver 1 also navigates the team on a given bearing and takes photographs of the habitat if necessary. Diver 2 records the fish species present along the line of the transect. Diver 3 in the second

pair records the hard coral and soft coral (gorgonian) species, and sponge forms. Diver 4 records Algae and invertebrates (both identified to a range of taxonomic levels depending on ease of differentiation).

During a survey, divers 2, 3 and 4 not only compile a list of the species or growth forms present, using an underwater note book or slate, but also assign each an ordinal abundance rating using the scale shown in table 2.

RATING	MEANING
0	ABSENT
1	RARE
2	OCCATIONAL
3	FREQUENT
4	ABUNDANT
5	DOMINANT

Table 2. abundance rating given to species, substrate and biological cover.

Substratum types (for example sand and rubble) and major biotic groups (for instance hard corals and algae) are assessed on a this ordinal scale in order to categorise the nature of the substratum and biological cover. The substratum categories are the responsibility of diver 1, whilst divers 2, 3 and 4 are responsible for the biological coverage data.

In order to measure the distance covered during the survey the divers use a 10m rope. Diver 1 holds one end of the rope and diver 3 holds the other. At the start of the survey the second pair remain stationary whilst the first pair

swim along the line of the transect, on a given compass bearing, surveying continuously until the rope becomes taught. the first pair then stop and wait for the second pair to swim along the same 10m section of reef, again surveying continuously. The process is then repeated along the length of the sub-transact. the rope is usually positively buoyant but many are also fitted with small pieces of polystyrene to avoid damage to the benthos.

Finally, diver 1 is also responsible for signalling to the rest of the team when a new habitat is encountered. This ensures that all the divers are aware that they should start compiling a separate species list and associated abundance's particular to the habitat.

Surface marker buoys are used in order to allow position fixing of the start and end points of each sub-transect and to allow the sub-transects to follow on from one another. The position of this buoy can then be measured using a Global Positioning System (GPS) on the dive boat and the next sub-transect can then begin at the point where the buoy was tied. Spatially referencing each transect is vital to allow the data to be incorporated into a Geographical Information System (GIS) for analysis and map production. The ultimate fate of the data used in this project is used in the production of a digitised habitat maps. Which can be used in the creation of marine protected areas, by pin pointing ecologically important hot spots (Mumby *et al.* , 1995).

3.5 DATA EXTRACTION

The base line survey results for the 4 studies were extracted from the CCC database, resulting in 657 records containing sightings of either one, two or all three of the species of Cheatodontid in question. Each record had a habitat number assigned to it, and scores for biological cover and substrate (benthos), allowing the investigation to follow two roots; habitat preference, and benthos preference of the three species across the four sites. Appendix 2 show a spread sheet containing the aforementioned data.

3.6 DATA ANALYSIS.

3.6.1 CHI SQUARED ANALYSIS; ASSOCIATION OF SPECIES AND HABITAT.

To test statistically for association between the three species and the eleven habitats across the for sites, as described by Mumby & Harborne, 1998, the results have been tested using chi square (X^2). This test can be used when one wishes to test for an association between two or more sets of measurements. Appendix 3 shows the calculations involved to arrive at X^2 in the form of a contingency table. To arrive at X^2 the observed figure (O) i.e. the number of records for a species in a habitat must be subtracted from the expected value (E) then the result must be squared and divided by the expected value (E). The next process is to total the figure obtained for the above calculation for that particular species in that habitat for the other three

studies, this number is the X^2 , thus:

$$X^2 = \sum \frac{(O-E)^2}{E}$$

Calculate the degrees of freedom using the rule (number of columns minus one)

Multiplied by (number of rows minus one) in the contingency table. Compare the calculated value of X^2 with the critical value for degrees of freedom and the appropriate significance level, as given in appendix 3. If your test statistic is larger than the critical value, reject the null hypothesis and alternative hypothesis.

3.6.2 LINEAR REGRESSION ANALYSIS; RELATIONSHIP BETWEEN SPECIES AND BENTHOS.

For each survey the divers give each benthos type (biological cover and substrate) a score of 0-5, this gives an accurate representation of exactly what is there, as even the same habitat types vary slightly, therefore no two transects for the same habitat are the same.

To try and develop a more accurate representation of benthos influencing the occurrence of each species, the percentage of each species (x axis) in each habitat was plotted against the mean score for the five biological cover types (y axis) . The same was done for the four substrate types. When examining

the relationship between two variables, in this case species abundance against benthos type, by the method of correlation, it can be appropriate to examine the relationship by means of linear regression analysis. Linear regression analysis defines the form of the relationship between the two variables, and then to determine how closely the data fit this relationship. With the use of the graph function on the Microsoft Excel spread sheet software package, a best fit line is plotted through the scattered points.

For the biological cover data each species in each study was plotted against the five different benthos classes, this was repeated for the substrate classes of which the linear regression was calculated. From the linear regression it is possible to calculate the r^2 value, this shows the correlation between x and y, i.e. the strength of the two variables (species occurrence, against benthos). The r^2 can be interpreted as the proportion of the variance of Y explained by the fit. r^2 goes from a minimum of 0 to a maximum of 1.0. The bigger the r^2 , the more likely it is that x and y are really related, the correlation can be seen as one particular example of a general group of statistics called measures of association, statistics that indicate how strongly two variables are related.

4. RESULTS.

4.1 ASSOCIATION BETWEEN SPECIES AND HABITAT.

The graph (Figure.20), below shows the total number of surveys where Cheatodontids wher recored (all three species)

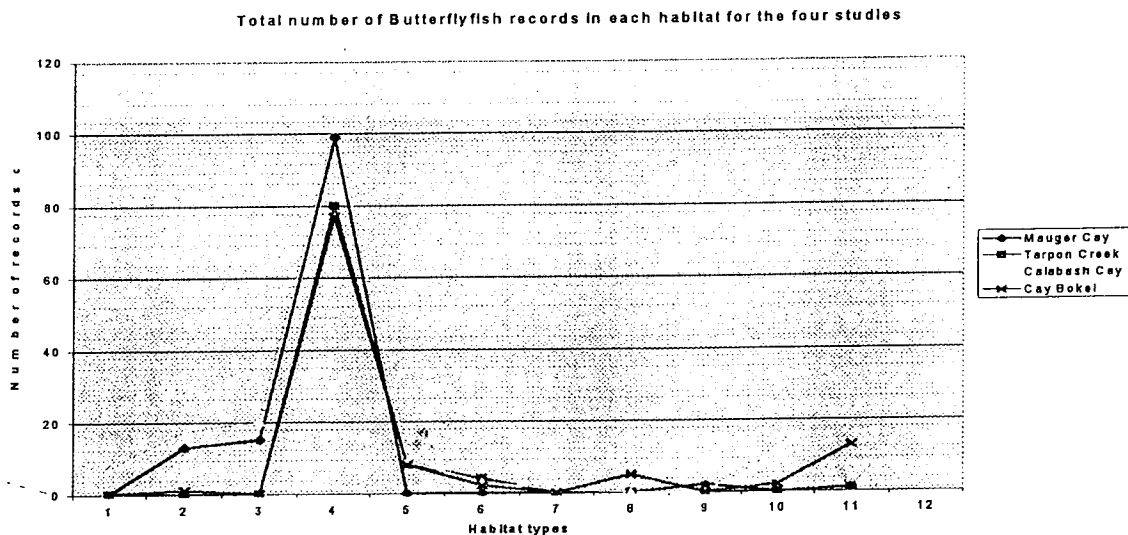


FIGURE 20

This graph shows quite conclusively that “Dense massive and encrusting corals” (habitat 4) contained the highest number of records of Cheatodontids for all four sites. Across the four sites, each of the 11 habitats appear with records of at least one species present, except habitat 7 (Appendix 2).

The association of species and habitat was taken a step further by plotting three graphs, showing the total number of records of fish in each habitat for each of the three species across the four studies (figures 21-23). As expected by the results

Total number of records for *Cheatodon stilius* for each habitat across the four sites

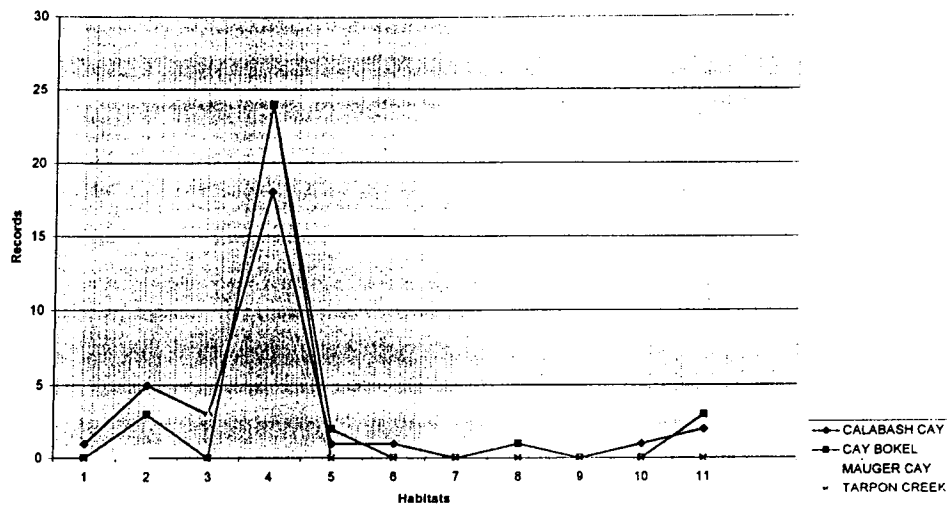


FIGURE 21.

Total number of records of *C. ocellatus* for each habitat across the four studies.

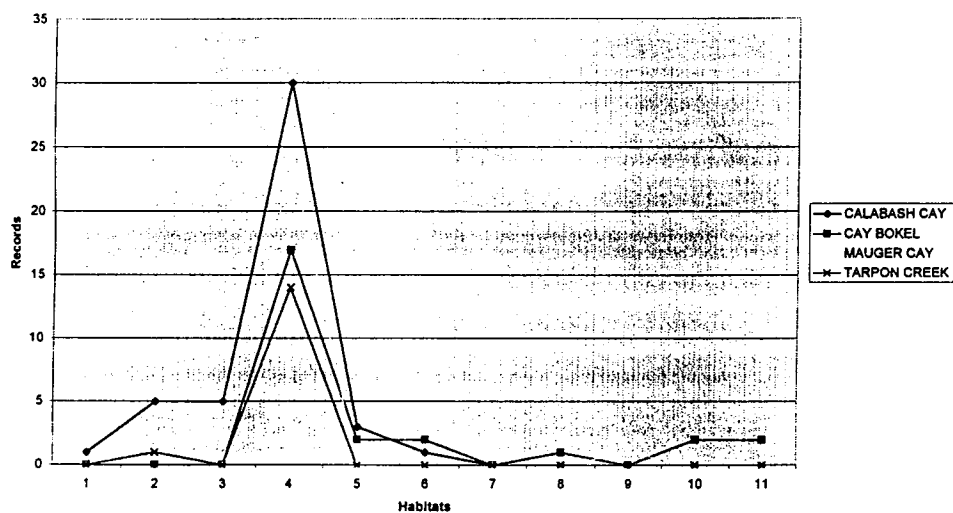


FIGURE 22

Total number of records of *C. capistratus* for each habitat across the four studies

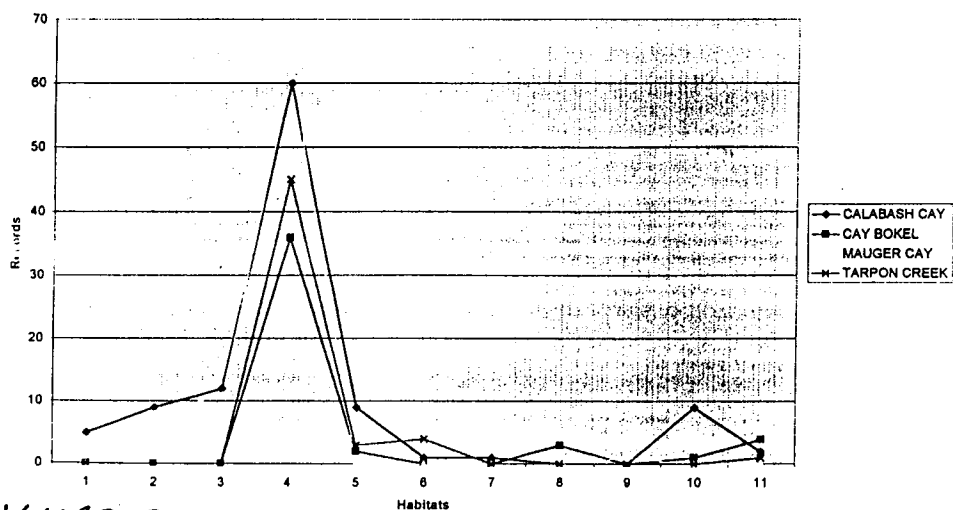


FIGURE 23

produced in figure20 “Dense massive and encrusting corals” is quite clearly the favoured habitat, with none of the three species showing much deviation in terms of habitat preference across the four studies. It is possible to test the association of the total number of records of each of the three species in each habitat across the four studies statistically by applying the X^2 test for association.

The X^2 for values for the association between each species and each habitat, across the four sites is given in figure24. This test statistic figure needs to be compared with the critical value given below figure 24, for the appropriate degrees of freedom and significance level.

HABITAT	<i>C. ocellatus</i>	<i>C. capistratus</i>	<i>C. striatus</i>
1	1.997	5.535	2.472
2	4.061	8.511	7.387
3	0.689	10.845	5.621
4	8.112	12.173	11.65
5	3.635	8.109	2.629
6	3.388	8.967	2.473
7	0	0	0
8	3.032	10.656	4.709
9	0.972	1.391	0
10	6.079	5.535	2.47
11	6.08	8.456	11.337

Figure 24. X^2 Values for the association between each species and habitat.

Significance level= **40.256** (30 degrees of freedom, 10% significance level).

By inspecting the ~~four~~ graphs (figures20-24) it appears that there is an association between each species and habitat four. The results propose that

there is no association between habitat type and species. Each value is less than the critical value of 40.256 (30 degrees of freedom, 10% significant level) therefore the null hypothesis cannot be rejected, and it must be accepted that there is no statistical association between species and any of the habitats.

4.2 ASSOCIATION BETWEEN SPECIES AND BENTHOS.

In order to test for an association between the three species in question and five different biological coverage and the four different substrate types a linear regression analysis can be undertaken. This test results in the association between the two variables be expressed as an r^2 value. Generally r^2 values of greater than 0.7 are considered to represent a strong association (Erickson & Nosanchuk, 1992). Figure 25 shows the r^2 values for each of the three species at each study for the biological cover types. Figure 26 shows the r^2 values for the substrate class types, with the shaded cell showing a strong correlation.

STUDY	SPECIES	H/C COV.	S/C COV.	SPG. COV.	ALG. COV.	INVT. COV.
MAUGER	<i>C. ocellatus</i>	0.5134	0.171	0.326	0.0686	0.751
	<i>C. capistratus</i>	0.8267	0.8267	0.73	0.6024	0.0052
	<i>C. striatus</i>	0.9767	0.7853	0.7883	0.1894	0.2019
TARPON	<i>C. ocellatus</i>	0.2803	0.4306	0.0836	0.7576	0.9474
	<i>C. capistratus</i>	0.2803	0.4306	0.2031	0.7023	0.365
	<i>C. striatus</i>	0.2112	0.478	0.127	0.8307	0.1946
CALABASH	<i>C. ocellatus</i>	0.0235	0.024	0.1391	0.0793	0.3812
	<i>C. capistratus</i>	0.343	0.2459	0.6991	0.0025	0.0733
	<i>C. striatus</i>	0.4001	0.5972	0.6241	0.1042	0.0204
CAY BOKEL	<i>C. ocellatus</i>	0.0758	0.0908	0.0387	0.0285	0.0158
	<i>C. capistratus</i>	0.2178	0.0678	0.3849	0.0239	0.0521
	<i>C. striatus</i>	0.0047	0.0464	0.0003	0.4454	0.0009

Figure 25. r^2 values for each study showing the strength of the correlation

between species and biological cover class.

H/C COV.= Hard coral coverage

ALG. COV = Algae coverage.

S/C COV.= Soft coral coverage

INVT. COV= invertebrates

SPG. COV.= Sponge coverage

STUDY	SPECIES	DEAD CORAL.	RUBBLE	SAND	BEDROCK
MAUGER	<i>C. ocellatus</i>	0.0057	0.7368	0.6714	0.0565
	<i>C. capistratus</i>	0.6666	0.9655	0.5883	0.54
	<i>C. striatus</i>	0.3812	0.9879	0.8696	0.1742
TARPON	<i>C. ocellatus</i>	0.8182	0.7082	0.0401	0.8109
	<i>C. capistratus</i>	0.8162	0.7082	0.3212	0.855
	<i>C. striatus</i>	0.642	0.669	0.8201	0.721
CALABASH	<i>C. ocellatus</i>	0.0077	0.0132	0.259	0.0002
	<i>C. capistratus</i>	0.0718	0.0119	0.4684	0.0139
	<i>C. striatus</i>	0.1755	0.0542	0.5942	0.036
CAY BOKEL	<i>C. ocellatus</i>	0.1221	0.1123	0.0877	0.0066
	<i>C. capistratus</i>	0.0722	0.4627	0.2836	0.3022
	<i>C. striatus</i>	0.0001	0.5109	0.1232	0.0997

Figure 26. r^2 value for each study showing the strength of the correlation between species and substrate class.

4.3 SIGNIFICANT TRENDS WITHIN THE RESULTS.

The calculated X^2 value for all three species in each habitat is significantly smaller than the critical X^2 value of 40.256 possibly due to the low number of records. For example there are only one or two records for each species in most sites, across a very wide total of 11 habitats.

The results of the linear regression analysis to test for association between species and benthos preference show some quite conclusive results. High r^2 values, of 0.7-0.9 for hard and soft coral coverage, and sponge coverage at Mauger Cay show a strong association between *C. capistratus* and *C. striatus*. In contrast *C. ocellatus*, at Mauger Cay has an r^2 squared value of 0.751 for invertebrate coverage. The results also show a strong association between all three species at Tarpon Creek and algal coverage, and *C. ocellatus*, again shows a very strong association (0.9474) with the invertebrate coverage at Tarpon Creek, similar to Mauger Cay.

In contrast to Mauger Cay and Tarpon Creek, in the north and west of the Turneffe Atoll, respectively, Calabash Cay in the east and Cay Bokel in the South show no strong association between any of the five biological coverage types and of the three species. Interestingly, there is no clear strong association between any of the three species at Calabash Cay and Cay Bokel and the four substrate types. Mauger Cay supports a strong association between the substrate class, rubble for all three species, and *C. striatus* shows an association with sand. *C. ocellatus* and *C. Capistratus* at Tarpon Creek show an association between dead coral and rubble. All three species at Tarpon Creek can be associated with bedrock.

5. DISCUSSION.

5.1 APPLYING THE HYPOTHESES MAINTAINING REEF COMMUNITY STRUCTURES TO THE RESULTS.

As mentioned in the introduction, the aim of this study is to investigate two aspects of Chaetodontid ecology. The first being; can the results demonstrate that the three species follow the classical hypothesis or the lottery hypothesis community structure? Stephenson & Searles (1960) and Randall (1961, 1965) suggest that reef fish communities are an equilibrium: a system organised around competition, and fish diversity is maintained by fine-scale habitat partitioning, therefore suggesting that each species develops its own individual habitat. This was described as the classical hypotheses. The alternative hypothesis, Sale (1977, 1982) and Chesson & Warner (1981) suggest that coexistence of species of fish across a reef is a "lottery" for living space, where individual fish randomly colonise vacant sites. The second aspect is to investigate if the importance of Chaetodontids as "indicator organisms" as emphasised by Reese (1975, 1981). Reese (1975, 1981) believes there to be a positive correlation between butterflyfish and dense, healthy stands of coral.

5.2 APPLYING THE CLASSICAL HYPOTHESES TO THE RESULTS

If one was to be able to reject the classical hypothesis, it would be expected that the results fail to prove that each species takes advantage of slightly

different resources across the reefal environment. Statistically there is little association between each of the three species and the eleven habitats (figure 24), but one just needs to study figure 20 to see there are far more records for habitat 4, for all three species, in all four studies than any other. For example Mauger Cay has a total of 97 records for all three species, Tarpon Creek 80, Calabash Cay 102 and Cay Bokel 77. So in terms of habitat partitioning of each species as suggested by Stephenson & Searles (1960) and Randall (1961, 1965), very little is taking place on the scale of individual habitats.

This is not to say that partitioning between the species is not taking place on a smaller scale within the habitat. By inspecting the results for association between species and biological cover (figure 25), *C. capistratus* and *C. striatus* at Mauger Cay show a strong correlation between hard coral, soft coral and sponges. Partitioning can be demonstrated by the fact that *C. ocellatus* at the same site shows an association with invertebrates. Results which support the classical hypothesis can be seen in the results for Tarpon Creek, with all three species exhibiting a correlation with Algae coverage and again *C. ocellatus* shows an association with invertebrates. Examples of partitioning, for the substrate classes (figure 26) can also be seen at Mauger Cay and Tarpon Creek, with all three species showing a correlation with rubble and *C. striatus* with sand at Mauger Cay. At Tarpon Creek all three show an association with bedrock and *C. ocellatus* and *C. capistratus* with dead coral and rubble. Interestingly no species at Calabash Cay or Cay Bokel

display r^2 values high enough, to show any correlation with any of the benthos classes.

5.3 APPLYING THE LOTTERY HYPOTHESIS TO THE RESULTS.

The lottery hypothesis can be rejected if the results fail to show a random distribution of species across the reefal environment. If the three species were to show that space really is the limiting factor, and factors such as biological cover and substrate class having a lesser effect on the recruitment process, as suggested by Sale (1977), this idea could apply. In contrast to Mauger Cay and Tarpon Creek where each species show a direct correlation with at least one biological coverage and substrate class, Calabash Cay and Cay Bokel display r^2 values of less than 0.7 indicating a poor correlation between all three species and benthos (figure 25-26). It is therefore possible that Sale's (1977) idea on the lottery hypothesis could apply for the three species at Calabash Cay and Cay Bokel.

Summary of association between species and benthos:-

Mauger Cay	<i>C. ocellatus</i> ;- invertebrates, Rubble.
	<i>C. capistratus</i> ;- hard coral, soft coral, sponges, rubble.
	<i>C. striatus</i> ;- hard coral, soft coral, sponges, rubble, sand.
Tarpon creek	<i>C. ocellatus</i> ;- algae, invertebrates, dead coral, rubble, bedrock.

C. capistratus;- algae, dead coral, rubble, bedrock.

C. striatus;- algae, bedrock.

Calabash Cay	<i>C. ocellatus</i> ; none
	<i>C. capistratus</i> ; none
	<i>C. striatus</i> ; none
Cay Bokel	<i>C. ocellatus</i> ; none
	<i>C. capistratus</i> ; none
	<i>C. striatus</i> ; none

5.4 EVIDENCE TO SHOW THAT BUTTERFLYFISH CAN APPLY AS INDICATOR ORGANISMS.

Reese (1975) claims that the effect of coral diversity and richness was that generally where there is more coral there are more Chaetodontids. Indicating that coral rich areas of unimpacted reefs support higher populations of such fish, than areas of low coral density and impacted areas. Therefore being ideal indicators of damaged or areas of low coral density.

There are probably no areas of the reefs fringing the Turneffe Atoll that suffer from any significant anthropomorphic physical damage (Guilcher, 1988). There are only a few very isolated cases of coral damage across the Atoll, probably due to anchor, or hurricane damage (personal observation). The whole reefal environment of the area is generally in a healthy condition. The concept of using Chaetodontids as indicators of ecological conditions is now

well-established (Soule & Kleppel, 1988. & Jones & Kaly, 1996). One would expect to find an abundance of butterflyfish in coral rich habitats as apposed to habitats with low coral coverage (i.e habitat 11, seagrass).

Of the eleven habitat types, habitat 4 supports the densest and most diverse coral cover, with hard coral coverage >5% , typical species of hard coral associated with habitat 4 include *Montastraea annularis* , *M. cavernosa*, *Porites* spp *Dichocoenia stokesii* and *Millepora alcicornis*. Particularly common soft corals include *Pseudoplexura* spp and *Pseudopterogorgia* spp (Mumby and Harborne, 1998). This relationship between all three species and coral cover as indicated in figure 24, can be considered to correlate with the idea that there is a direct relationship with coral coverage and abundance of butterflyfish.

5.5 RELATIONSHIP BETWEEN THE RESULTS AND PUBLISHED WORK.

Chaetodontids are among the best studied of coral reef fishes, feeding ecology and some aspects of behaviour have been firmly established (Roberts & Ormund, 1992). The positive correlation between *C. capistratus* at Mauger Cay soft coral cover, can be supported by work done by Lasker (1985) in a study of *C. capistratus*, and browsing preferences of this species on Caribbean gorgonians (soft corals). Laster (1985) suggests a preference for *Pseudoplexura* spp, a species proved to be popular by this projects results, due to the abundance of both *C. capistratus* and *Pseudoplexura* spp

in habitat 4. Birkeland & Neudecker (1981) studied the foraging behaviour of *C. capistratus* and noticed the abundance of the species, which feeds mainly on gorgonians was positively correlated with total coral cover and with genetic diversity of corals. This statement could hold true as *C. cpistratus* also shows a strong association with hard corals at Mauger Cay.

Findley & Findley (1989) in there study of butterflyfish communities in Belize, state that *C. capistratus* as well as feeding on hard and soft corals, are active generalists, including polychaetes, crustaceans (invertebrates) and eggs in there diet. This statement dose differ from this projects results, as there is little direct association between *C. capistatus* and invertebrates in any of the four sites. But stands of hard, soft corals and sponges, of which this species can be associated with make idea habitats for invertebrates (Tricas, 1989 & personal observations).

Findley & Findley (1989) claim that *C. capistratus* feeds in a foraging manner, therefore the results for *C. capistratus* at Mauger Cay could have been individuals recorded foraging among hard corals, soft corals and sponges for its invertebrate pray. Individuals and colonies of invertebrates are sometimes hard to spot by the survey divers in such environments and are not often recorded properly

Findley & Findley (1989) seem to think that *C. striatus* and *C. ocellatus* are more generalist feeders among invertebrates, the projects results show a

strong association between *C. ocellatus* and occurrence of invertebrates at Mauger Cay and Tarpon Creek, therefore correlating with the results of Findley & Findley (1989). Research undertaken by Lonely & Hildeband (1941) has establish that *C. capistratus* displays a preference for rocky substrates, this statement correlates with the results for *C. capistatus* at Mauger Cay, showing an association with rubble dominated substrates. For Tarpon Creek the same species can be expected to be seen in association with rubble and bedrock again following the substrate preference stated by Longley & Hildeband (1941). report that *C. striatus* has a preferred benthos of coral rubble, as adopted by the species at Mauger Cay.

Generally, the results of associations between species and benthos at Mauger Cay and Tarpon Creek can be supported by previous research (Findley & Findley, 1989., Longley & Hildeband, 1941., Laster, 1985., Birkeland & Neuddecker, 1981). A critical assessment of data derived from CCC volunteers by Mumby et al., (1995) was undertaken to assess the accuracy and constancy of data recorded by volunteers. The work by Mumby et al (1995) concluded that substrate composition and biological cover were recorded with an accuracy of 70-90% in reef sites. So it can be concluded that the data used in this project is of high accuracy, due to Mumby et al (1995)'s investigation, This in tern is supported by the fact that the results of butterflyfish habitat preferences can be supported by previous work on the subject.

When considering if butterflyfish can be used as indicator organisms, as to the health of a reef by showing an association with colonies of coral as, proposed by (Reese 1981, 1975), one can associate the results of this project, i.e. the high abundance of butterflyfish in habitat 4, with an array of literature supporting the result. Harmelin-Viveien & Bouchon-Navaro (1983) observed that when coral communities are damaged in any way, butterflyfish are populations are the first family in the community to suffer. White (1988) states coral rich environments across the reef ^{supports} more individuals and species per unit area, than areas of less coral abundant areas. Both Randell (1967) and Wicklers (1963), noted that chaetodontids feed on coral polyps in aquaria, thus supporting the idea of reliance of coral in more natural environments.

6. CONCLUSION.

Interpretation of this piece of work results suggest that the lottery hypothesis could apply for the butterflyfish communities of Calabash Cay and Cay Bokel due to the appearance of a random distribution ^{of species} amongst the available resources (i.e. benthos). The distribution amongst the same species for Mauger Cay and Taspon Creek show distinct patterns therefore suggesting the application of the classical theory. It seems interesting that the results of this study can apply to two very contrasting ideas on reef fish community structures, in what can be described as a relatively confined area. If the results of this study are to be believed, it could be said that both the lottery and classical community structures of reef fish can be applied to the butterflyfish community of the Terneffe Atoll, depending on the site in question. It could prove interesting to carry out this investigation across the remaining eleven sites across the Atoll.

The results show quite conclusively an association between butterflyfish and coral, as segregated by the scientific community. In terms of habitat preference there is heterogeneity across the four sites on the Atoll, but some variation in association between species and benthos remains. All three species at Calabash Cay and Cay Bokel exhibit an association with habitat 4, but no association with hard or soft corals, which have proved to be more abundant by Mumby & Harborne, (1998) in this habitat than any other. One idea which could explain this trend could be variation in reef profiles amongst

the sites (figure 19). The reef profiles of Mauger Cay can be approximately three times the length of anywhere else on the Atoll (personal observations). Longer reef profiles could be considered more diverse in terms of coral species. Mauger Cay also supports coral formations in the inner forereef area (figure 19) decried as "spurs and grooves" (long strips of hard coral species, divided by grooves dominated by sand). The variation in substrate over a relatively small area could encourage habitat partitioning.

7. REFERENCES.

- Anderson, GRV. Ehrlich, AH. Ehrlich, PR. Roughgarden, JD. Russell, BC. & Talbot, FH. (1981) The community structure of coral reef fishes. *The American Naturalist*. 117, 476-495.
- Birkeland, C. & Neudecker, S. (1981) Foraging Behaviour of Two Caribbean Chaetontids *Chaetodon capistratus* and *C. Aculeatus*. *Copeia*. 1, 169-178.
- Bouchon-Navaro, Y. (1981) Quantitative distribution of the Chaetodontidae on a reef of Moorea Island (French Polynesia). *Journal of Experimental Marine Biology and Ecology*. 55, 145-157.
- Bouchon-Navaro, Y. (1986) Partitioning of food and space resources by Chaetodontid fishes on coral reefs. *Journal of Experimental Marine Biology and Ecology*. 103, 21-40.
- Bouchon-Navaro, Y. & Bouchon, C. (1985) Impact of coral degradation on a chaetodontid fish assemblage (Moorea, French Polynesia). *Proceedings of the Fifth International Coral Reef Congress, Tahiti*. 5, 427-433.
- Bouchon-Navaro, Y. & Bouchon, C. (1989) Correlation's between Chaetodontid fishes and coral communities of the Gulf of Aqaba (red Sea) *Environmental Biology of Fishes*. 25, 47-60
- Burgess, WE (1978) *Butterflyfish of the World*. TFH Publications, Neptune City, NJ.
- Chesson, PL. & Warner, RR (1981) Environmental variability promotes coexistence in lottery competitive systems. *The American Naturalist*. 117, 923-943.
- Coral Cay Conservation (1995) *Marine Research Program at the Terneffe Atoll, Belize*. Final report to the Darwin Initiative for the survival of species. (unpublished).
- Crosby, MP. & Reese, ES (1996) *A Manual for Monitoring Coral Reefs With Indicator Species: Butterflyfishes as indicator of Change on Indo Pacific Reefs*. Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, Silver Spring, MD.
- Erickson, BH. & Nosanchuk, TA. (1992) *Understanding Data* (2nd ed.) Open University Press. Buckingham, UK.

Findley, JS. & Findley, MT. (1985) A search for patterns in butterflyfish communities. *The American naturalist*. 126, 800-816.

Guilcher, CG. (1988) *Belize*. Belize City Press.

Greenfield, DW & Greenfield, TA. (1982) Habitat and resources partitioning between two species of *Acanthemblemaria*, with comments on the chaos hypothesis. *The Atlantic Barrier reef Ecosystem at Carrie Bow Cay, Belize*. Smithsonian Institution Press. Washington.

Harboun, A, Church, J. Raines, P. Ridley, J. Rettie, L. & Walker, R. (1997) *The Banggi Islands Conservation Project (Central Sulawesi, Indonesia)*. Report prepared on behalf of Yaysan Pengembangan Sumber Daya Laut. (Unpublished Report) Coral Cay Conservation, London.

Harmelin-Vivien, ML. & Bouchon-Navaro, Y. (1983) Feeding diets and significance of coral feeding among Chaetodontid fishes in Moorea (French Polynesia). *Coral Reefs*. 2, 119-127.

Harmelin-Vivien, ML. (1989) Implications for feeding specialisation on the recruitment processes and community structures of butterflyfish. *Environmental Biology of Fishes*. 25, 101-110.

Haitt, RW & Strasburg, DW (1960) Ecological relationships of the fish fauna on the coral reefs of the Marshall Islands. *Ecol. Monogr.* 30. 65-127.

Hobson, ES, (1974) Feeding relationships of Teleostean fishes on coral reefs in Kona, Hawaii. *US Natl. Mar. Fish. Serv. Fish. Bull.*, 72 (4) 95-131.

Jones, GP. & Kally, VL. (1996) Criteria for selecting marine organisms in biomonitoring studies, p 29-48, in Schmitt, RJ. & Osenberg, CS. Eds *Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats*. Academic Press, New York.

Lasker, HR. (1985) Prey preference and browsing pressure of the butterflyfish *Chaetodon capistratus* on Caribbean gorgonians. *Mar. Ecol. Prog. Ser.*, Vol. 21, 213-220.

Krebs, CJ. (1994) *Ecology*, 4th ed. Harper collins, New York.

Leis, JM. (1989) Larval biology of butterflyfishes (Pisces, Chaetodontidae): what we really know? *Environmental Fish Biology*. 25, 97-100.

Longley, WH. & Hildebrand, SF. (1941) Catalogue of fishes of Tortugas. *Pap. Tortugas Lab.*, 34. 1-374.

Motta, PJ. (1989) Strengths and weaknesses in butterflyfish research: concluding remarks. *Environmental Biology of Fishes* 25, 243-245.

Mumby, PJ. Harborne, AR. Raines, PS & Ridley, JM. (1995) A critical assessment of data derived from Coral Cay Conservation volunteers. *Bulletin of Marine Science* 56, 737-751.

Randall, JE. (1961) Overgrazing of algae by herbivorous marine fishes. *Ecology*. 42, 812-817.

Randall, JE. (1965) Grazing effects on sea grasses by herbivorous reef fishes in the West Indies. *Ecology*. 46, 255-260

Reese, ES. (1977) Coevolution of corals and coral feeding fishes of the family Chaetodontidae. *Proceedings, Third International Coral Reef Symposium, Rosenstiel School of Marine and Atmospheric Science, University Of Miami, USA*. 268-274.

Reese, ES. (1975) A comparative field of the social behaviour and related ecology of reef fishes of the family Chaetodontidae. *Z. Tierpsychol.*, 37, 37-61.

Reese, ES. (1981) Predation on corals by fish of the family Chaetodontidae: Implications for conservation and management of coral reef ecosystems. *Bulletin of Marine Science*. 31, 594-604.

Roberts, CM. Ormond, RFG & Shepherd, ARD. (1988) The usefulness of butterflyfishes as environmental indicators on coral reefs. *Proceedings of the 6th International Coral Reef Symposium, Australia*. 2, 331-336.

Roberts, CM & Ormond, RFG. (1992) Butterflyfish social behaviour, with special reference to the incidence of territoriality: a review. *Environmental Biology of Fishes*. 34, 79-93.

Sale, PF. (1977) maintenance of high diversity in coral reef fish communities. *The American Naturalist*. 111, 337-359.

Sale, PF. (1980) Assemblages of fish on patch reefs; predictable or unpredictable? *Environmental Biology of fishes*. 5, 243-249.

Sale, PF. (1982) Stock recruitment, relationships and regional coexistence in a lottery competitive system: A simulation study. *The American Naturalist*. 120, 139-159.

Soule, DF & Kleppel, GS. (1988) *Marine Organisms as Indicators*. Springer-Verlag New York.

Spiller, DA. (1984) Seasonal reversal of competitive advantages between two spider species. *Oecologia*. 64, 322-331.

Stanley, DB. (1989) Biogeography of the Chaetodontidae: analysis among closely related species. *Environmental Biology of Fishes* 25, 9-31.

Stephenson, TA. & Searles, RB. (1960) Experimental studies on the ecology of intertidal environments at Heron Island. *Australian Journal of Marine and Freshwater Research*. 11, 241-267.

Tricas, TC. (1989) Prey selection by coral feeding butterflyfishes: strategies to maximise the profit. *Environmental Fish Biology*. 25, 171-185.

Appendix 1.

example of a CCC biological survey form.

BIOLOGICAL RECORDING FORM - CARIBBEAN

Habitat No: _____ of: _____ Date: _____ / _____ / _____

Study: _____ Transect No. _____ Zone Code: _____

Database Code: _____

Percentage Cover: _____ % Start time: _____ End time: _____

First: _____ Last: _____ No. dives/snorkels in Belize: _____

Recorder's name: _____ Phys: _____ Fish: _____ Coral: _____ Algae: _____

Depth limits: Min _____ m Max _____ m

Underwater visibility _____ m

Cox _____

ZONE	HABITAT CLASS	SUBSTRATUM	BIOLOGICAL COVER
Barrier Reef	Sand	Live corals	Live hard corals
	Coral	Dead corals	Soft corals
	Sandy Drop Off	Bedrock	Sponges
	Matrix Drop Off	Sand	Invertebrates
	Gorgonian Plain	Mud	Algae
	Reef Crest	Rubble	Seagrass
	Hard Coral Reef	Mangrove	Mangrove
	Spurs / Grooves		
	Sand & Coral Matrix		
	Seagrass Bed		
	Seagrass Patches		
	Patch Reef		
	Sandy Algal Canopy		
	Mud Bed		
Lagoon			
	Sediment		
	Seagrass		
	Patch Reef		
	Mangrove		
	Other		

HABITAT DESCRIPTION

1. Substratum types within the Habitat: _____

2. Main animal groups in Habitat: _____

3. Main Plant groups in Habitat: _____

4. Other comments: _____

SPECIES LIST

Score 0-5 Abundance:

None = 0
Rare = 1
Occasional = 2
Frequent = 3
Abundant = 4
Dominant = 5

MARINE ALGAE

GREEN

Filamentous - loose tufts:
Polyphysa polyphysoides
Enteromorpha flexuosa
Cladophora prolifera

Sheet - like:
Ulva sp.

Cup - like:
Udotea cyathiformis

Disc - like:
Acetabularia sp.

Lacy:
Anadyomene sp.

Marble - like:
Ventricaria ventricosa
Halimnionchus osterhoutii
Valonia dictyosphaeria

Brush - like:
Caulerpa cupressoides
Caulerpa paspaloides
Caulerpa prolifera
Caulerpa sp.
Rhizophthalmus phoenix
Penicillus capitatus
Penicillus dumetosus
Penicillus pyramidalis
Neomeris annulata

Blade - like:
Avrainvillea
Cladocarpus luteofuscus
Udotea flabellum
Udotea wilsonii
Udotea occidentalis

Calcified:
Halimeda incrassata
Halimeda opuntia
Halimeda monile
Halimeda goreaui
Halimeda copiosa
Halimeda tuna
Halimeda discoidea

RED

Sheet - like:
Halimnionchus floresia
Kallymenia limmingshii

Course branched: (eg. Gracilaria sp.)

Fine branched:
Liagora sp.

Calcified:
Amphiroa sp.
Encrusting
Reef cement

Filamentous:

Turf:
Wrangelia argus

BROWN

Pyramid - like:
Turbinaria sp.

Fine branched:
Dictyota sp.

Blade - like:
Stylopodium zonale
Lobophora variegata
Padina sp.

Leaf - like:
Sargassum sp.
Sargassum hystrix

BLUE - GREEN

MARINE PLANTS

Red mangrove
White mangrove
Black mangrove

Seagrass:
Turtle (blade - like)
Manatee (cylindrical)
Halophila decipiens (leaf - like)

SCLERACTINIA: Hard Corals

Elkhorn
Staghorn
Fused staghorn
Club finger
Finger
Green cactus

ANTIPATHARIA: Black Corals

Antipathes sp.
Wire

OCTOCORALLIA: Soft Corals

Common sea fan
Deepwater fan
Branching: rod
plume
Red sea whip
(deep water)
Flat sea whip
(shallow water)
Corky sea finger

Appendix 2.

spread sheet of raw habitat and substrate data, number of each species in each habitat, and mean values for benthos class.

HAB TYPE	MAUGER tot	SUBDEAD	SUBR	SUBSAND	BEDROCK	COVHC	COVSC	COVSPON	COVALG	COVINV	210	211	212
1													
2	13	1.1	0.1	3.3	0.4	2.1	2.8	0.8	2.6	1	15.4	61.5	23
3	15	3	0.1	1.7	1	2.9	2.6	1.1	2.9	0.9	13.3	73.3	13.3
4	99	1.2	0.1	2.1	0.5	2.8	2.9	1.5	2.5	1	25.7	59.4	13.1
5													
6													
7													
8													
9	2	1		1	0	3	2	1	2	0	50	50	0
10													
11	1	0	0	5	0	0	0	0	2	1	0	0	100

HAB TYPE	TARPON tot	SUBDEAD	SUBR	SUBSAND	BEDROCK	COVHC	COVSC	COVSPON	COVALG	COVINV	210	211	212
1													
2													
3													
4	83	0.7	2.9	0.2	2.8	2.7	2	2.2	0.9	13	16.8	54.2	28.9
5	3	0.3	3.8	0	1.8	2.8	1.8	0.8	0.7	3	0	100	0
6	4	0	5	0	1	1.2	0.8	1	0.5	0	0	100	0
7													
8													
9													
10													
11	1	0	4.5	0	1.5	1.5	0.5	3	0.5	0	0	100	0

HAB TYPE	CALABASH tot	SUBDEAD	SUBR	SUBSAND	BEDROCK	COVHC	COVSC	COVSPON	COVALG	COVINV	210	211	212
1	7	0.5	0.5	1.5	3.1	1.3	1.3	1.2	2.8	0.5	14.2	71.4	14.2
2	17	0.9	1.1	2.9	0.2	2.1	2.6	1	2.1	1	34.6	52.9	17.6
3	20	1.6	1.6	2.2	0.6	2.7	2.4	0.9	2.8	0.4	20	65	15
4	92	0.7	0.9	2.6	0.5	2.6	2.2	1.6	2.4	0.7	20.4	59.2	20.4
5	13	0.1	0.4	3.8	0.1	1.3	1.7	1	1.5	0.3	22.2	66.6	11.1
6	3	0.1	0.3	4.8	0	0.8	1.2	0.5	1	0.8	33.3	33.3	33.3
7	1	0.5	0	2	0	2.5	2.5	3	0.5	0.5	0	100	0

8													
9													
10	10	0.9	1.8	2.9	0.1	2.5	2.2	1.4	2.3	0.6	0	83.3	16.6
11	4	0	0	4.8	0	0.8	0.5	0.2	0.5	0.2	0	50	50

HAB TYPE	CAY BOKEL	SUBDEAD	SUBR	SUBSAND	BEDROCK	COVHC	COVSC	COVSPON	COVALG	COVINV	210	211	212
1											210	211	212
2	1	1	0	3	0	2	3	1	4	1	0	0	100
3				0	0	0	0	0	0	0.4	0	0	0
4	77	0.9	0.5	3.2	0.1	2.8	3.2	2.5	3.1	0.7	12	49.4	28.6
5	6	0.5	0.5	4.5	0	2	1.5	1.5	2	1.5	0	50	50
6	2	4.8	0.1	4.9	0	0.5	0.5	0.8	2.5	0.1	0	50	50
7													
8	5	1	0.8	3.8	0	3	2.8	1.8	1.3	0	36	40	24
9													
10	2	0.5	0	3.5	0	1.5	1.5	1.5	2.5	0	0	0	100
11	9	0.1	0	4.6	0	0.7	1.3	0.7	2	0.8	38.4	23.1	38.5

SUB DEAD= DEAD CORAL (MEAN SCORE)

SUBRUB= RUBBLE

SUBSABD= SAND

BEDROC= BEDROCK

COVHC= HARD CORAL COVER

COVSC=SOFT CORAL COVER

COVALG= ALGAE

COVINV= INVERTABRATES

210= CHAETODON CAPISTRATUS

211= CHEATODON STRIATUS

212= CHEATODO OCELLATUS

%

%

%

Appendix 3.

Contingency table to enable the calculation of Chi squared value.

Appendix 4.

Table for Chi squared test for association, Critical values at significance levels, Chalmer & Parker 1989.

Table III(5). The χ^2 test for association

Critical values of χ^2 at various significance levels. Reject the null hypothesis if your value of χ^2 is bigger than the tabulated value at the chosen significance level, for the calculated number of degrees of freedom.

degrees of freedom	significance level:										
	99%	98%	95%	90%	80%	70%	50%	30%	20%	10%	5% 2% 1%
1	0.000157	0.000628	0.00393	0.0158	0.0642	0.148	0.455	1.074	1.642	2.706	3.841 5.412 6.635
2	0.0201	0.0404	0.103	0.211	0.446	0.713	1.386	2.408	3.219	4.605	5.991 7.824 9.210
3	0.115	0.185	0.352	0.584	1.005	1.424	2.366	3.665	4.642	6.251	7.815 9.837 11.341
4	0.297	0.429	0.711	1.064	1.649	2.195	3.357	4.878	5.989	7.779	9.488 11.668 13.277
5	0.554	0.752	1.145	1.610	2.343	3.000	4.351	6.064	7.289	9.236	11.070 13.388 15.086
6	0.872	1.134	1.635	2.204	3.070	3.828	5.348	7.231	8.558	10.645	12.592 15.033 16.812
7	1.239	1.564	2.167	2.833	3.822	4.671	6.346	8.383	9.803	12.017	14.067 16.622 18.475
8	1.646	2.032	2.733	3.490	4.594	5.527	7.344	9.524	11.030	13.362	15.507 18.168 20.090
9	2.088	2.532	3.325	4.168	5.380	6.393	8.343	10.656	12.242	14.684	16.919 19.679 21.666
10	2.558	3.059	3.940	4.865	6.179	7.267	9.342	11.781	13.442	15.987	18.307 21.161 23.209
11	3.053	3.609	4.575	5.578	6.989	8.148	10.341	12.899	14.631	17.275	19.675 22.618 24.725
12	3.571	4.178	5.226	6.304	7.807	9.034	11.340	14.011	15.812	18.549	21.026 24.054 26.217
13	4.107	4.765	5.892	7.042	8.634	9.926	12.340	15.119	16.985	19.812	22.362 25.472 27.688
14	4.660	5.368	6.571	7.790	9.467	10.821	13.339	16.222	18.151	21.064	23.685 26.873 29.141
15	5.229	5.985	7.261	8.547	10.307	11.721	14.339	17.322	19.311	22.307	24.996 28.259 30.578
16	5.812	6.614	7.962	9.312	11.152	12.624	15.338	18.418	20.465	23.542	26.296 29.633 32.000
17	6.408	7.255	8.672	10.085	12.002	13.531	16.338	19.511	21.615	24.769	27.587 30.995 33.409
18	7.015	7.906	9.390	10.865	12.857	14.440	17.338	20.601	22.760	25.989	28.869 32.346 34.805
19	7.633	8.567	10.117	11.651	13.716	15.352	18.338	21.689	23.900	27.204	30.144 33.687 36.191
20	8.260	9.237	10.851	12.443	14.578	16.266	19.337	22.775	25.038	28.412	31.410 35.020 37.566
21	8.897	9.915	11.594	13.240	15.445	17.182	20.337	23.858	26.171	29.615	32.671 36.343 38.932
22	9.542	10.600	12.338	14.041	16.314	18.101	21.337	24.939	27.301	30.813	33.924 37.659 40.289
23	10.196	11.293	13.091	14.848	17.187	19.021	22.337	26.018	28.429	32.007	35.172 38.968 41.638
24	10.856	11.992	13.848	15.659	18.062	19.943	23.337	27.096	29.553	33.196	36.415 40.270 42.980
25	11.524	12.697	14.611	16.473	18.940	20.867	24.337	28.172	30.675	34.382	37.652 41.566 44.314
26	12.198	13.409	15.379	17.292	19.820	21.792	25.336	29.246	31.795	35.563	38.885 42.856 45.642
27	12.879	14.125	16.151	18.114	20.703	22.719	26.336	30.319	32.912	36.741	40.113 44.140 46.963
28	13.565	14.847	16.928	18.939	21.588	23.647	27.336	31.391	34.027	37.916	41.337 45.419 48.278
29	14.256	15.574	17.708	19.768	22.475	24.577	28.336	32.461	35.139	39.087	42.557 46.693 49.588
30	14.953	16.306	18.493	20.599	23.364	25.508	29.336	33.530	36.250	40.256	43.773 47.962 50.892

