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COMMUNITY STRUCTURE OF REEF-BUILDING CORALS IN THE FLORIDA KEYS: CARYSFORT REEF, KEY LARGO AND LONG KEY REEF, DRY TORTUGAS

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The reefs of the Florida Keys are widely known and have drawn the attention of scientists since the early 1800s. The landmass of the Keys are the fossil remains of Pleistocene reefs (Hoffmeister and Multer, 1964). Their species composition can be seen in nearly every canal cut and rock quarry (Hodges, 1977). Receiving less attention however, are the reefs that make up the present living chain of reefs from Fowey Rocks south to the Dry Tortugas. These reefs are distributed in and along the outer edge of the shallow lagoon on the seaward side of the Keys. There are hundreds of individual reefs in the Keys, however there are less than 25 that could be considered to be more than patch reefs. The largest, most well-developed outer reefs presently are, in north-south order: Carysfort, Molasses, Looe Key, the Sambos, Long Key, and Loggerhead Reefs. Looe Key, Carysfort, Molasses and Long Key Reefs are similar in that they have rich coral communities which exhibit species zonational patterns similar to other Caribbean reefs (e.g. Goreau, 1959), and a topographic relief that appears to be the result of active coral growth on top of older reefs or eolian dune systems (Shinn 1963, 1977, 1980). Rates of reef accretion are greatest in the region of Key Largo and the Dry Tortugas (Shinn 1977). Although they exist at the northern and southernmost ends of the Florida Keys, Carysfort Reef, Key Largo and Long Key Reef in the Dry Tortugas are the most similar of the large reefs. Each is exposed to prevailing seas and has approximately the same depth range and species composition.

This communication is the result of two parallel studies on the distribution of reef-building corals on Carysfort Reef, Key Largo and Long Key Reef, Dry Tortugas. The aim of the projects was to characterize the species composition of reef-building corals from the northern and southernmost localities of the Keys, establish base line data for future studies, and, through comparison, attempt to identify the impact of man on the reefs in the Key Largo area of the northern Florida Keys. Participants in the project include K. Lukas, J. Thompson, D. Girardin, K. Gordon, J. Halas, C. Richardson. Other contributors included J. W. Japp and J. Wheaton-Smith from the Department of National Resources, State of Florida, and G. Davis of the National Park Service. All assisted in phases of the field work and all are due grateful thanks. This research was supported by the Smithsonian Institution and Harbor Branch Foundation with logistical support in the Dry Tortugas provided by The National Park Service.

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METHODS

There are many stages of reef development and community complexity in both the Key Largo and Tortugas areas. The sites were chosen for their exposure to the prevailing seas and the general lushness of reef community as observed in aerial photographs and preliminary SCUBA excursions to each reef. As the long range goal of the project was to provide baseline data for both areas, the most information on the organization of the reef communities could be gathered in short time periods at the richest areas. Furthermore, should changes occur in the species composition of either reef, it might be most readily detectable in the areas of highest coral coverage and species diversity, as there is some suggestion that the most complex regions of ecosystems may be the most susceptible to environmental perturbation (Margalef, 1963). Carysfort Reef was surveyed in the spring of 1975 and Long Key in July 1975.

The abundance and species composition of the coral community was estimated using line transects (Loya, 1972). This technique estimates projected surface-area coverage. It is biased in that flat colonies will project more surface area than round colonies which are spherical in skeleton morphology but not in tissue coverage (Porter, 1972). The upper surfaces of most colonies however, are covered with tissue, while their sides are often not. The error introduced by not using the chain method is probably 2-3 percent. However, the reduction in underwater working time afforded by the line transect allowed us to undertake a project of this magnitude in the relatively short period of time we had available. If one colony overlapped another, each colony was measured and recorded sequentially. This was not common in most parts of the reef with the main exception being the regions of profuse *Acropora cervicornis* growth on Carysfort Reef and the sides of the surge channels on Long Key Reef.

The length of transects used to measure coral abundance was determined by running two 50 meter long transects on the fore-reef terrace of Carysfort Reef at a depth of 17 meters. The species that the line crossed were recorded for each successive meter and a species area curve derived. The data (Fig. 1) show that the species area curve reaches its asymptote in the first twenty meters. A measurement transect length of twenty-five meters was chosen as optimal and used throughout the two study areas. (For more details see Loya, 1972).

On both reefs, measurement transects were positioned along a reference line set from the surface. A single long line was stretched from the deepest point of the reef to the shallow reef flat. Measurement transect lines (25m in length) were placed perpendicular to this line creating a grid of transects that paralleled the reef flat and the prevailing swell. The interval between measurement transects varied from 3 to 20 meters depending on the coral coverage and reef geomorphology. In areas of extremely steep slope the lines were spaced at three meter intervals, ten meters in regions of high coral coverage, and twenty meters apart in zones of very low coverage.

Carysfort Reef

Carysfort Reef (Fig. 2.) consists of two parallel platforms tangential to the prevailing seas. The inner platform is densely covered with living reef corals, while the outer platform supports a much reduced population of hermatypes. Seaward of the outer platform, fathometer recordings show small knolls between 25-35m. At forty meters there is a sill 3-4m high which is colonized by reef-building coral communities consisting mostly of Agricia spp. and Montastrea spp. (Dustan, Girardin, and Halas, unpublished observations). The angle of the slope increases seaward of this deep sill and the bottom drops off into the Straits of Florida.

The study site is situated on the inner terrace of Carysfort Reef, approximately 75 meters south of the Carysfort lighthouse. The transect line runs on a compass bearing of 100 degrees magnetic from behind the reef flat to the edge of the first terrace at 20 meters. The inner terrace is approximately 250 meters wide and exhibits zonational patterns in the distribution of the reef-building corals that resemble the zonational patterns described for Jamaica (Goreau, 1959) and the Bahamas (Storr, 1964). Zones occur in a series of successive bands parallel to the reef flat and thus perpendicular to the direction of the prevailing seas. The zonational patterns are not as well defined as in Jamaica and there is considerable patchiness in the distribution of species. The study area contains six zones based on changes in species composition and morphology (Fig. 3., Table 1). From behind the reef towards the Straits of Florida these are:

1. Back reef
2. Reef flat
3. Acropora palmata zone
4. Gorgonian zone
5. Fore-reef terrace
6. Fore-reef escarpment

The terminology used here is modified from Goreau (1959) and Kinzie (1973). This ecological zonation scheme is similar to that proposed for Key Largo Dry Rocks (Shinn 1963) and Grecian Rocks (Shinn 1980).

Carysfort Reef Zonation

The inshore limit of Carysfort Reef, the back reef, is characterized by low coral coverage on a coarse sand bottom. Small outcrops of Montastrea annularis and Acropora cervicornis are colonized by encrusting Porites astreoides and Agaricia agaricites. The sand bottom interdigitates with the lee side of the reef flat. In some places there is an abrupt change between the two areas and in others the transition is more gradual. These ecotone areas are inhabited by large M. annularis colonies and groves of A. cervicornis. Along the irregular backside edge of the reef flat there are large colonies of Acropora palmata. Some colonies are overturned suggesting occasional heavy storm damage.

The reef flat is approximately 50 meters wide and tabletop flat. It is covered with *Acropora palmata* and red crustose coralline algae, and is similar, but more expansive, than the reef flats of the inner reefs Grecian and Key Largo Dry Rocks (Shinn 1963, 1980) ,and those described for St. Croix by Adey (1975). The frame is constructed of densely packed dead *Acropora palmata* colonies in growth position which are encrusted with red crustose coralline algae. Other reef building species, mainly *Porites astreoides*, *Agaricia agaricites*, and *Acropora cervicornis* inhabit hollows that place them below the mean height of the reef flat. The structure of the reef flat appears dense but is riddled with narrow tunnels beneath the branches of the dead *Acropora palmata* framework. The seaward edge of the reef flat grades into irregular groves of *Acropora palmata* that suggest the beginnings of a spur and groove structure. In places the colonies are dense and overlap extensively, often overgrowing one another (Photo A). This region is the region of greatest wave activity on the reef. Close to the reef flat the tips of the *Acropora palmata* branches are level with the reef table and gradually deepen seaward. Further seaward, coral coverage decreases and the *Acropora palmata* colonies become oriented into long spurs that jut into the open sea (Shinn, 1963). Irregular sand channels run between the spurs with relief between the channel floors and top of the spurs approaching 2-3 meters in places. Coral rubble, mostly *Acropora palmata*, is strewn along the channels between the spurs.

Interspersed with the *Acropora palmata* community are patches of the hydrozoan *Millepora complanata* in association with *Porites astreoides*, *Favia fragum*, the *Gorgonia ventilina*, and carpets of the zooanthid *Palythoa spp.* The blades of the Millepora colonies are oriented predominantly tangential to the prevailing seas with blades occasionally offset at right angles. This species association is analogous to the sea fan zone described by Storr (1964) for the Bahamas and occurs mostly on the tops of the *Acropora palmata* spurs and reef rock to a depth of approximately four meters. *Millepora complanata* is very abundant on the tops of the outcrops, comprising over 80% of the total coral coverage or over 45% of the reef substrate. This area is similar to the Millepora-Montastrea zone on Dry Rocks (Shinn, 1963) but more spread out and not as well organized.

Seaward of the *Acropora palmata* zone there is a trough that is approximately 25 meters wide. The bottom consists mostly of hard reef rock covered with gorgonians and reef corals. Coral coverage in this trough drops to an estimated 20%. The morphology of the corals and rock coverage are similar to the shallow barren zone described by Kinzie (1973) for the reefs of Discovery Bay, Jamaica and appears analogous to Shinn's Rubble zone of the inner reefs (Shinn, 1963, 1980). Seaward of the trough is a broken line of reef rock forming an irregular ridge which has a relief of 2-3 meters. This ridge parallels the reef crest and is dissected by numerous small channels and breaks. In a few places, the ridge takes on the appearance of the shallower spur and groove system of the *Acropora palmata* zone. The top and seaward side of the ridge supports a large sea fan community

(Storr, 1964). Millepora complanata covers 48% of the reef substrate at the transect site. Other species include an occasional large colony of Montastrea cavernosa, M. annularis, and Colpophyllia natans. This ridge system terminates abruptly on the seaward side in an area of sparse coral coverage and the gorgonian zone begins.

Unlike the region just described, the gorgonian zone has a sparse cover of small hemispherical colonies of Porites astreoides, and Dichocoenia stokesii and supports a rich and diverse community of gorgonians and algae (Photo B). The sea-fan-Millepora complanata species complex is virtually absent. The substrate is hard reef rock of very low relief which allows settlement of gorgonians (Kinzie, 1973) which include members of Pterogorgia, Pseudoptergorgia and Eunicia. There are no surge channels or buttress features.

Occasionally situated on this flat, gently sloping plane are large colonies of Montastrea annularis. In the transect area one such colony approached 7 meters in diameter and 3 meters in height. This colony sheltered a fish cleaning station and was the center of focus of the local fish population (Photo C). At a depth of nine meters the gorgonian zone terminates sharply with the sudden occurrence of Acropora cervicornis colonies. Coral coverage changes from less than 10% to over 25% in less than 3 meters horizontal distance (Photo D). The presence of these Acropora cervicornis marks the beginning of the fore-reef terrace population, an area of high species diversity and coverage. Just seaward of the gorgonian zone the community is dominated by Acropora cervicornis, Montastrea annularis, and Colpophyllia natans. Further seaward, the dominant species change to Stephanocoenia michelinii, Montastrea annularis, and Mycetophyllia ferox. This species assemblage in turn is replaced by a Siderastrea siderea dominated community on the fore-reef escarpment. Submarine light levels on the fore-reef terrace are relatively low due to turbidity (visibility is usually less than 17-18m).

The morphology of the fore-reef slope is irregular with corals, gorgonians, and sponges occupying reef rock knolls separated by small patches of fine sediment. Most of the hermatypic corals grow upwards off the sediment covered bottom and then increase in surface area. This creates tall, slightly expanding cylindrical coral mounds between 0.5 and 1 meter above the soft, fine sediment covered bottom. In some instances the pillars are formed by a single coral colony and in others a few colonies, making the mound similar to a multiscoop ice cream cone. The sides of these coral build-ups are colonized by small corals, encrusting gorgonians, sponges, and bryozoa in addition to a rich and diverse algal community. Biological erosion appears to be intense and many of these pillars topple easily when jarred. These mounds vary in size and often coalesce when the edges of living coral colonies meet. This coalescence gives the reef the appearance of being much more solid than it really is and adds tremendously to the geometric complexity of the internal framework structure. Toward the escarpment the pillars are more isolated, rise higher off the bottom, and the reef framework even less solid.

The escarpment marks the end of the fore-reef terrace. In places it is a vertical drop of slightly over five meters and in others a steep slope. Coral capped reef rocks overhang the steeper edges. Collapsed overhangs and slump block features are common (Photo E and F). In some areas large talus piles of reef rock cover the soft bottom at the base of the escarpment, and in other places the reef gradually grades into a soft, fine sediment substrate. On a large scale the escarpment appears to be irregularly buttressed. The buttresses seem to be constructed by reef-building corals growing on old slump blocks and reef debris. These buttress features are approximately 30 meters apart. Seaward of the escarpment is a soft fine sediment covered bottom that stretches flat some 100 meters to the beginning of the outer terrace.

The outer terrace supports a sparse coral population similar in species composition and morphology to the gorgonian zone. This assemblage is characteristic of the outer slopes of Molasses, French, and Elbow reefs in Key Largo. Large colonies of <u>Montastrea annularis</u> are scattered sporadically over the bottom and, as in the gorgonian zone, support diverse fish populations and frequently, cleaner fish stations. There are small sand channels running seaward and most species of coral are usually small.

Long Key Reef

Long Key Reef lies at the southeastern edge of the Dry Tortugas platform. The study site lies southeast from Fort Jefferson ,facing southeast, the direction of the prevailing swell, and away from the direction of most winter storms. The prevailing current pattern over the Tortugas platform is from northwest to southeast such that the water passing over the reef drains from across the entire reef platform (Davis, 1982). This green to blue-green water is laden with organic debris and fine sediment. Estimated horizontal visibility was almost always less than 10 meters during our field session earning the nickname "shadowland" for the reef. The reef supports a large diverse fish population (Jones and Thompson, 1975), along with associated reef algae and gorgonians. Long Key was chosen as the study site as it is the only reef in the Dry Tortugas that displays zonational patterns and geomorphology similar to Carysfort Reef, our primary work site in the northern Keys.

The morphology of Long Key Reef may be seen in Fig. 4, a fathometer tracing which was run over the transect site on a compass heading of 120 degrees magnetic. The reef is backed by a shallow lagoon which leads into a reef flat composed of coral rubble. The seaward edge of the reef flat slopes very gently to a depth of approximately 10 meters where the slope increases. Seaward of the reef are a few scattered gorgonian and coral encrusted rocks. The reef measures just slightly under four hundred meters from the flat to the base of the reef at 18-20m. Long Key Reef (Fig. 5, Table 2.) may be divided into five distinct parallel zones which lie parallel to the reef flat and tangent to the prevailing seas:

1. Lagoon
2. Reef flat
3. Patch reef zone
4. Gorgonian zone
5. Spur and groove

The lagoon was not surveyed with transects. It consists of small patches of Acropora cervicornis, and Porites porites. There is one small grove of Acropora palmata situated in a channel. This is the only living stand of this species in the area to our knowledge, although the species was much more abundant in the 1800's. In 1976 a cold water thermal shock killed two-thirds of the small stand (Davis, 1982)

The reef flat is composed of loose coral rubble, mostly Acropora cervicornis, Porites spp. and a few Acropora palmata fragments. At high tide it is submerged and is frequently exposed at low tide. The flat appears to be the result of the accumulation of debris tossed up by storms and not the end product of in-situ of coral growth. The gently sloping shallows in front of the flat are sparsely covered with Porites porites, Porites astreoides, Siderastrea radians and support a dense, fleshy algal population. This region stretches approximately fifty meters seaward.

Patch reefs appear when the water depth approachs 5 meters. The algal coverage decreases and the bottom is covered with coarse carbonate sediment, mostly shelly sands and coral fragments. Dotted on this are small rock islands of reef rock that stand 30-50 cm off the bottom. These islands support a dense gorgonian population and about ten species of coral (Photo G). Situated among the reef rock islands are small stands of Acropora cervicornis ranging in size from 0.5-2 meters in diameter. Conspicuously absent are any living colonies of Acropora palmata. An extensive search did turn up a small grove consisting of two or three dead colonies. The encrustation and erosion of their surfaces suggested they died between two and ten years previously. The patch reef region extends for approximately one hundred and thirty meters seaward and ranges in depth from 3-7 meters.

Seaward of the rock islands is an area characterized by soft sediment which supports a very few species of coral at low densities and a luxuriant population of the gorgonian Pseudopterogorgia bipenata (Photo H). This region extends approximately forty to fifty meters.

The coral population becomes more abundant and diverse as the spur and groove region is approached. Species diversity and coverage increase sharply and the reef begins to take on the appearance of a "true" coral reef. The spur and groove region consists of long spurs of coral 2-4 meters in height off the bottom which are 3-15 meters in width and are oriented (120 degrees magnetic) into the prevailing swell. The principal reef building coral species is Montastrea annularis, which appears in a variety of growth forms from knobby multilobate to large flow sheets of the skirted ecotype (terminology after Dustan, 1975). Colonies approach four meters in diameter and appear to be responsible for the construction of the reef spurs (Photo I). The floors of the grooves are sediment covered with occasional pieces of loose coral rubble. In a few locations bare reef rock was observed in the grooves, probably the result of scouring by the prevailing swell. This region extends for approximately one hundred meters and ends at the base of the reef. It is the most diverse and richly populated region. The colony size of most species reaches a maximum in this region as well.

The internal structure of the spurs between 10 and 18 meters is honeycombed with caves due to the profuse overlapping of coral colonies. In many instances it appears that one large coral colony develops into a mushroom shaped structure creating a cave beneath it. The floors of these caves are covered with fine sediment. The walls are covered with sponges and bryozoans. Fluorescene dye was released into these crevices in an attempt to determine the extent of the labyrinth. Dye released into holes would flow out others 5 to 10m away suggesting that the reef structure is open beneath the veneer of living coral. Large coral colonies of a variety of species appear sporadically along the seaward edge of the escarpment. Such species are Madracis decactis (Photo J), Agaricia lamarcki, Stephanocoenia michelinii, Montastrea cavernosa, and Montastrea annularis. Of these, only Montastrea annularis is commonly larger than a meter in diameter in other habitats on the reef.

Discussion of Carysfort Reef

Carysfort Reef marks the northern extent of lush populations of reef-building corals along the eastern coast of North America. Mayor (1914) suggested that reduced water temperature further north limited the northern extent of reef development. South of Key Largo reef development may be limited by tidal passes that allow water from Florida Bay to flow onto the shelf platform on the ebb tide (Ginsburg and Shinn 1964) or, conversely, allow cool subsurface water from the Straits of Florida to intrude into the shallows of the shelf platform (Dustan, et al., 1976). Thus Carysfort appears to be situated at or just south of the thermal tolerance point of active reef development and paradoxically, is one of the most well developed reefs in the entire Florida Keys.

The vertical distributions of coral coverage and number of species are almost independent of each other on the reef flat and in the shallows. Coral coverage and the number of species become more closely correlated in deeper water (Fig.3). Maximal species number occurs at the outer edges of the terraces, seaward of maximal coral coverage, hinting that spatial competition in these areas may be intense, or that subtle environmental differences between a terrace and break in slope may reorder community structure (Porter, 1972).

Substrate heterogeneity at the edge of a break in slope, or water circulation enhancement may create a more favorable environment for larval settlement as well. In any case, it must be remembered that reef growth, with the exception of the reef flat, is proceeding upwards so that today's edge is part of tomorrow's terrace. As such the species composition of the reef may be influenced by the morphology of the reef which, in turn, affects the future species composition. Active reef growth in shallow water on Carysfort is a function of the growth of Acropora palmata and Millepora complanata. The seaward geomorphology of the reef flat and the spur and groove formations are formed mostly by Acropora palmata as first described for Key Largo Dry Rocks by Shinn (1963). Deeper, it appears that Montastrea annularis and other massive corals contribute to the growth of the reef frame.

The species composition of the gorgonian zone on Carysfort is similar to the outer reef slopes of other reefs in the northern Keys: Molasses, Elbow, French Reefs. On these reefs the gorgonian population gradually decreases as water depth increases towards the Straits of Florida. On Carysfort, however, this zone ends abruptly at 10 meters where it is replaced by a diverse coral community. The appearance of a rich coral community and the disappearance of the rich gorgonian community at 10m occurs as a sharp line and is very apparent even to a casual visitor to the reef. This suggests that some environmental parameter change sharply at this depth, strongly influencing reef community development (Photo D).

Waves heading into Carysfort Reef first meet with the outer terrace some 300 meters seaward of the reef (Fig. 2). The shallowest depth of the platform is 10 meters so that wave energy below 10 meters is attenuated. The outer terrace thus shields the fore-reef terrace population from the full force of the prevailing swells and storm seas that pound the other outer reefs. We have witnessed this sheltering phenomena while diving on Carysfort during seas of 1-2 meter wave height. At depths below 10 meters the surge is greatly reduced and occurs as a sharp boundary just at the beginning of the fore reef coral population. In the winter and spring months we have observed sharp discontinuities in temperature and underwater visibility between 10 meters and the top of the escarpment at 15 meters. Whenever these differences in water masses have been observed warmer, clearer water overlays cooler, more turbid water. Either the cold water is intruding into the surface waters along the edge of the Gulf Stream as noted in the Dry Tortugas (Dustan et. al., 1976) or cooler water from the back reef area is becoming trapped in the moat region between the inner and outer platform of Carysfort. The reduction of wave action results in finer sediments on the fore-reef slope and escarpment at Carysfort than on neighboring reefs. Sediments from these zones on Carysfort have sponge boring chips, spicules and fine sedimentary particles in great abundance. The sediments at comparable depths on Molasses Reef consist of much coarser carbonate particles. It is conceivable that the moat region of Carysfort serves as a sink for the deposition of fine sediment and therefore may contain a detailed record of the depositional history of the northern Florida Keys.

Discussion of Long Key Reef

The species zonation on Long Key Reef follows the classical pattern first described for West Indian coral reefs (Goreau, 1959), but there are some distinct differences. Most conspicuous of these are the absence of Acropora palmata and an associated reef flat community. The reef flat appears to be formed by the accumulation of coral skeleton rubble rather than infilled, cemented Acropora palmata skeletons in growth position as seen at Carysfort and so characteristic of other Florida Keys Reefs (Shinn, 1963, 1977). Seaward of the reef flat where one would expect to find groves of A. palmata the substrate is covered mostly with algae and gorgonians, and a few scattered corals. Observations along the edge of the reef flat subsequently turned up a stand of dead A. palmata (in addition to the one known living stand mentioned earlier) in growth position suggesting that while this species may inhabit the zone it suffers high mortality and never reaches the population densities found elsewhere in the Florida Keys. Reports of a massive coral mortality as a result of "black water" are mentioned in the first Carnegie Reports of the Dry Tortugas (Mayer, 1902), and in 1977 a cold water (13 degrees C) intrusion resulted in the death of almost all the Acropora cervicornis on the platform (Davis, per. comm). Thus periodic climactic fluctuations, possibly combined with severe storms, may prevent Acropora palmata from establishing itself as a major reef-building species in the sediment laden water of the Dry Tortugas.

Along with the noted absence of Acropora palmata is the absence of a Millepora-gorgonian species association commonly seen in the Keys and Bahamas. Both species occur in the Dry Tortugas but do not form the assemblage so common elsewhere. The assemblage is commonly found on the tops of shallow reef flat spurs constructed by Acropora palmata. Possibly the absence of Acropora palmata and the habitat its structure creates results in the deletion of the Millepora-gorgonian species complex. Conversely, the lack of a similar necessary ecological condition (high surf, clear water, favorable temperature) may be the controlling factor in the distribution of both assemblages.

Coral coverage is closely correlated with species number on Long Key Reef (Fig. 5). The absence of high coverage in shallow water is attributed to an absence of Acropora palmata and its associated Millepora-gorgonian species complex. Coverage is highest deeper than 10m where the most active reef accretion appears to be occurring.

CONCLUSIONS

The species composition and zonation patterns of a coral reef are the result of species' differential abilities to settle, adapt, and survive the prevailing environmental conditions. The environmental parameters of light, water temperature and wave action, sedimentation, and food availability all have been thought to be of primary importance to corals. Biological interactions between and among species operate at organizational levels within this adaptive framework (Porter, 1974; Glynn, 1976; Connell, 1978). The interplay of biological and physical factors result in higher order interactions that determine community structure (Futuyma, 1979). Coral communities at both study sites show a positive correlation between average colony size and percentage cover. On Long Key Reef increases in coral coverage are the result of all species becoming more abundant. On Carysfort Reef increases in cover are sometimes the result of single species dominance, as in the <u>Acropora palmata</u> zone, or a general increase in all species as seen on the fore-reef terrace.

The differences in patterns suggest that different environmental and biological pressures control the development of these two reef communities. Part of the reason for the differences in these two reefs may lie in their positions relative to the path of the Gulf Stream. Carysfort Reef lies at the edge of the Gulf Stream and is often bathed in its waters, while the Dry Tortugas are approximately 10-20 miles north of the edge of the Gulf Stream and only occasionally experience clear oceanic water. The prevailing patterns of water movement over the Dry Tortugas result in a northwest to southeast flow so that the water passing over Long Key Reef has drained from the Dry Tortugas Platform. Thus there appears to be major differences in the quality of the water over the two reefs. In addition, the Gulf Stream buffers the population at Carysfort against cold water intrusions in the winter so that even though it is much farther north than Long Key, the minimum water temperatures are somewhat higher. There are reports (Mayer, 1914) of elevated water temperatures occurring in the Dry Tortugas in the summer coincident with periods of calm and low spring tides which resulted in the death of corals. Temperatures in shallow parts of the reef ranged from 33-38 degrees C. On Carysfort Reef this type of localized water heating seems unlikely as the reef is situated far from any other large geomorphic structures and the water is kept moving longshore by the Gulf Stream.

Both reefs (Long Key and Carysfort) face into the direction of the prevailing winds and swell. However, Carysfort does not receive the full force of the swell at depths below 10 meters as the fore-reef terrace is protected by the second platform seaward of it. This platform blocks the deeper swell and may help to explain the absence of well defined surge channels on Carysfort Reef. Observations on the species composition of the seaward slope of the outer platform have shown it to be similar to the outer slopes of neighboring reefs that are not protected from the swell. These regions are sparsely covered by coral and give the appearance of being "wave battered". The rich and diverse coral population on the fore-reef terrace of Carysfort Reef below 10 meters is not typical of other reefs in the Keys. Whether or not this atypical species assemblage is the direct result of a decrease in wave shock, change in food supply or sediment composition, or some other factor cannot be determined at this time; but remains as an intriguing question to be attacked at a future date.

One of the initial objectives of this research was to study differences between the two reefs in an attempt to dissect out the impact of man on Carysfort Reef. However, upon completion of the Long Key Reef survey it became apparent that the two reefs are very different in structure and form as a result of a suite of different environment parameters. There are some general observations that deserve comment however, and though they have not been quantified, they may be instructive as to the mechanisms behind man's impact on coral reefs.

The incidence of broken coral colonies is high on Carysfort Reef. Broken colonies must expend metabolic energy to their wounds and regrow skeleton lost to damage. It is hard to single out the greatest cause of physical damage to reefs by man but it is fair to say that constantly occurring damage as a result of anchoring, diving, and fishing is slowly but surely decreasing the amount of framework carbonate that corals add to the reef structures of the northern keys, and it is apparent on Carysfort Reef. Commensurate with these observations is the high incidence of corals with broken or damaged tissue as a result of excess sedimentation, algal overgrowth and algal disease (Dustan, 1977). Again, such mortality factors were occasionally seen in the Dry Tortugas, most notable is the havoc caused by anchoring in the lee of Loggerhead Key (Photo K, Davis, 1977).

The comparison presented in this study has provided an initial look at the community structure of two reefs at the opposite ends of the Florida Keys. Differences in community structure appear to be the result of local environmental differences and local geomorphological features. Severe periodic environmental perturbations may control the distribution of less tolerant species (Acropora palmata and Acropora cervicornis) in the Dry Tortugas. The Gulf Stream may reduce the probability of similar perturbations occurring on Carysfort Reef. Both reefs may be exposed to storms which may also affect their species composition and geomorphology. Resurveys of these communities in the future will begin to reveal their temporal as well as spatial variability.

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Table 1: Coral species coverage on different morphological zones Carysfort Reef, Key Largo

Species	Mean Percent Coverage by Zone						
	RF	A.pal	Trough	Ridge	GZ	FRT	FRE
Acropora palmata	0	36.2	9.0	0	0	0	0
Acropora cervicornis . .	0	0	3.6	0	0	30.4	0
Mycetophyllia lamarckana	0	0	0	0	0.2	<1	<1
Mycetophyllia ferox . .	0	0	0	0	0.2	1.6	<1
Mycetophyllia danana . .	-	-	-	-	-	-	-
Mycetophyllia aliciae .	0	0	0	0	0	0	<1
Solenastrea hyades . . .	0	0	0	0	0	0	1.2
Agaricia agaricites . .	<1	1.0	1.7	2.9	<1	<1	1.0
Agaricia lamarcki . . .	0	0	0	0	0	<1	0
Agaricia fragilis . . .	0	0	0	0	0	<1	0
Helioseris cucullata . .	0	0	<1	<1	0	<1	0
Colpophyllia natans . .	0	0	0	0	0	2.2	<1
C. breviserialis	0	0	0	0	0	7.6	<1
Scolymia cubensis . . .	0	0	0	0	0	<1	<1
Scolymia lacera	-	-	-	-	-	-	-
Mussa angulosa	-	-	-	-	-	-	-
Montastrea annularis . .	<1	0	0	0	<1	17.5	1.7
Montastrea cavernosa . .	0	0	0	1.1	0	<1	1.1
Manicina areolata . . .	-	-	-	-	-	-	-
Favia fragum	0	<1	<1	0	<1	0	0
Siderastrea radians . .	0	0	0	0	<1	0	0
Siderastrea sidera . . .	0	<1	<1	0	<1	3.3	6.8
Dichocoenia stokesii . .	0	0	0	0	<1	<1	0
Stephanocoenia michelinii	0	0	0	0	<1	1.5	2.2
Diploria strigosa . . .	-	-	-	-	-	-	-
Diploria clivosa	-	-	-	-	-	-	-
Diploria labyrinthiformis	-	-	-	-	-	-	-
Isophyllia sinuosa . . .	-	-	-	-	-	-	-
Isophyllastraea rigida .	-	-	-	-	-	-	-
Porites porites	<1	0	0	0	<1	<1	<1
Porites astreoides . . .	3.7	1.5	3.4	4.2	<1	<1	1
Porites furcata	0	0	0	0	0	<1	0
Madracis spp.	0	0	0	0	0	<1	0
Madracis decactis . . .	0	0	0	0	0	<1	<1
Millepora alcicornis . .	0	0	<1	0	<1	<1	0
Millepora complanata . .	3.4	7.2	10.5	48.0	0	7.0	<1
Eusmilia fastigiata . .	0	0	0	0	0	<1	<1
Number of species in each zone	6	7	9	5	11	24	17
Number of transects . .	4	3	3	1	2	5	3
Distance along transect from base of reef (m)	320-260	250-230	200-160	140	100-120	80-40	30-0

Note: RF=back reef + reef flat , A.pal= Acropora palmata zone, GZ= gorgonian zone,FRT=fore-reef terrace, FRE= fore reef escarpment, Dash signifies presence on Long Key but absent on Carysfort Reef.

Table 2: Coral species coverage on different morphological zones
Long Key Reef, Dry Tortugas

Species	Mean Percent Coverage by Zone				
	Patch Reefs	Gorgonian	Spur and Groove 1	Spur and Groove 2	Spur and Groove 3
Acropora palmata	-	-	-	-	-
Acropora cervicornis	<1	<1	<1	4.6	0
Mycetophyllia lamarckana	0	0	<1	<1	<1
Mycetophyllia ferox	0	0	0	2.2	<1
Mycetophyllia danana	0	0	0	<1	0
Mycetophyllia aliciae	0	0	0	<1	0
Solenastrea hyades	-	-	-	-	-
Agaricia agaricites	<.5	<.5	<1	1	<1
Agaricia lamarcki	0	0	0	0	5.2
Agaricia fragilis	0	0	0	<1	<1
Helioseris cucullata	0	0	0	<1	<1
Colpophyllia natans	0	0	<1	2	<1
C. breviserialis	0	0	0	<1	0
Scolymia cubensis	0	0	0	0	<1
Scolymia lacera	0	0	0	0	<1
Mussa angulosa	0	0	0	<1	0
Montastrea annularis	0	0	<1	15.0	10.3
Montastrea cavernosa	0	<1	<1	4.6	6.8
Manicina areolata	0	0	<1	0	0
Favia fragum	-	-	-	-	-
Siderastrea radians	<.5	0	0	0	0
Siderastrea sidera	<.5	<.5	4.5	4.8	7.5
Dichocoenia stokesii	0	<.5	<1	0	0
Stephanocoenia michelinii	0	0	<1	1.2	3.0
Diploria strigosa	0	<.5	0	0	0
Diploria clivosa	1.5	<1	0	<.5	0
Diploria labyrinthiformis	0	<1	<.5	<1	0
Isophyllia sinuosa	0	<.5	<.5	<.5	0
Isophyllastraea rigida	<.5	0	0	<.5	0
Porites porites	<.5	1.2	9	1	<1
Porites astreoides	<1	1.1	1	2.1	1
Porites furcata	-	-	-	-	-
Madracis spp.	-	-	-	-	-
Madracis decactis	0	0	0	<1	<1
Millepora alcicornis	<.5	<1	<1	<1	<1
Millepora complanata	-	-	-	-	-
Eusmilia fastigiata	0	0	<.5	<.5	0
Number of species in each zone	9	12	16	24	17
Number of transects	4	8	6	5	5
Distance along transect from base of reef (m)	370-300	290-180	160-110	100-50	40-0

Note: Dash (-) signifies presence on Carysfort but absent on Long Key

Table 3. Species List for Areas of Study

Species	Dry Tortugas	Long Key Reef	Key Largo	Carysfort Reef
Acropora palmata	*	-	*	*
Acropora cervicornis	*	*	*	*
Mycetophyllia lamarckana	*	*	*	*
Mycetophyllia ferox	*	*	*	*
Mycetophyllia danana	*	*	*	*
Mycetophyllia aliciae	*	*	*	*
Solenastrea hyades	*	*	*	*1
Agaricia agaricites	*	*	*	*
Agaricia lamarcki	*	*	*	*
Agaricia fragilis	*	*	*	*
Helioseris cucullata	*	*	*	*
Colpophyllia natans	*	*	*	*
Colpophyllia breviserialis	*	*	*	*
Scolymia cubensis	*	*	*	*
Scolymia lacera	*	*	*	*
Mussa angulosa	*	*	*	*
Montastrea annularis	*	*	*	*
Montastrea cavernosa	*	*	*	*
Dendrogyra cylindrus	-	-	*	-
Manicina areolata	*	*	*	*
Favia fragum	*	*	*	*
Favia conferta	*	-	-	-
Siderastrea radians	*	*	*	*
Siderastrea sidera	*	*	*	*
Dichocoenia stokesii	*	*	*	*
Dichocoenia stellaris	*	*	*	*
Stephanocoenia michelinii	*	*	*	*
Diploria strigosa	*	-	*	-
Diploria clivosa	-	-	*	*
Diploria labyrinthiformis	*	-	*	*
Isophyllia sinuosa	*	*	*	*
Isophyllastraea rigida	*	*	*	-
Porites porites	*	*	*	*
Porites astreoides	*	*	*	*
Porites furcata	-	-	*	*
Madracis spp.	*	*	*	*
Madracis decactis	*	*	*	*
Millipora alcicornis	*	*	*	*
Millipora complanata	*	-	*	*
Eusmilia fastigiata	*	*	*	*
Oculina diffusa	*	*	*	-
Cladocora spp.	*	-	-	-
Meandrina meandrites	*	*	*	*

* = present, - = absent
1: outer terrace only

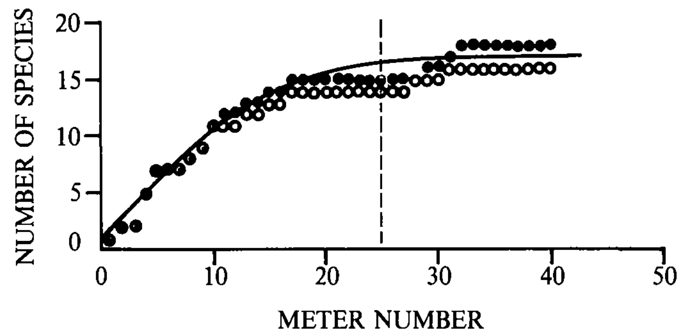

Fig. 1. Species-area curve for reef coral species on Carysfort Reef, Key Largo, Florida. Transects were run at a depth of 17 meters on the fore-reef terrace of the study site.

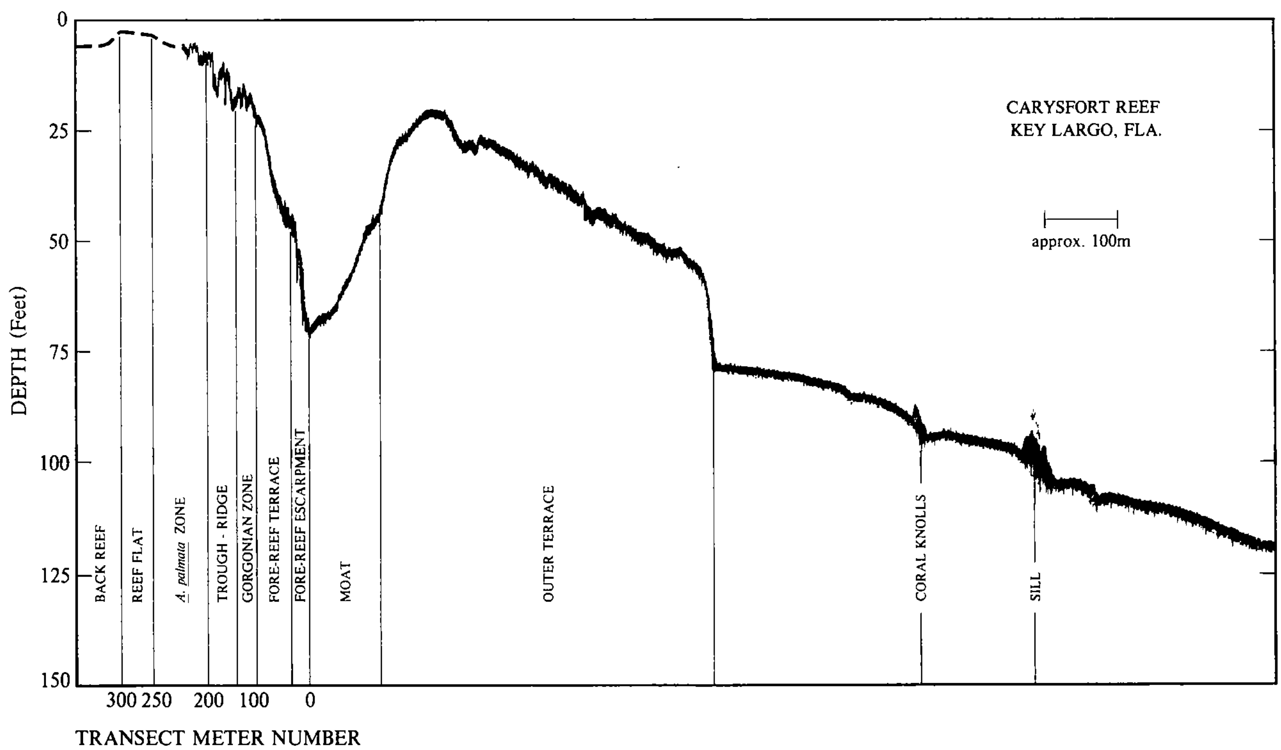

Fig. 2. Fathometer tracing of Carysfort Reef showing the overall morphology of the reef. Note the terrace seaward of the study site which rises to a depth of 10 meters.

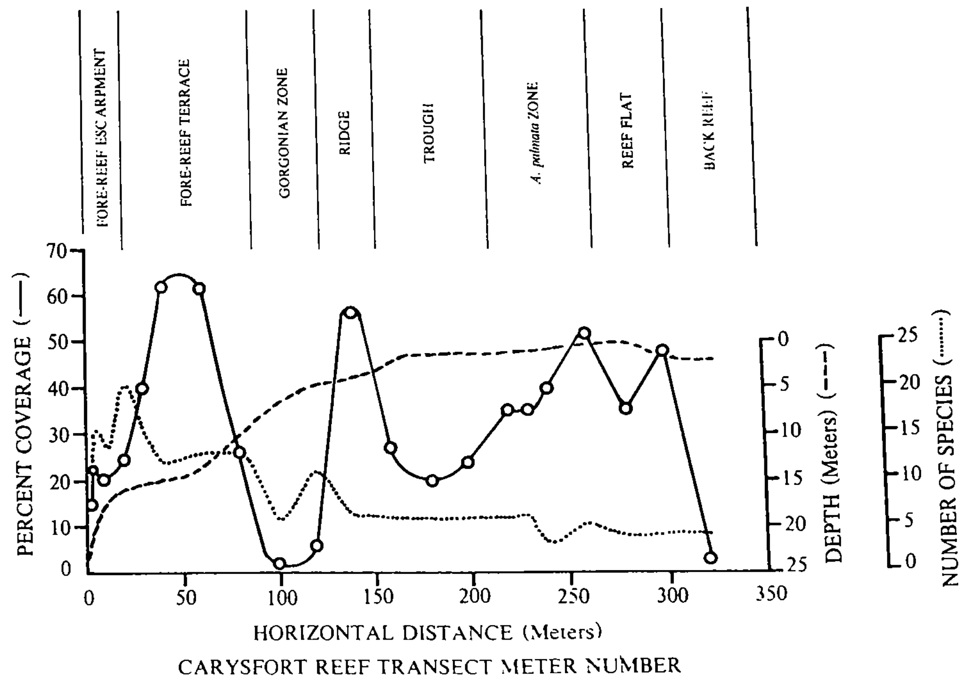

Fig. 3. Graph depicting the percentage coral cover, number of species, and depth profile of Carysfort Reef study site.

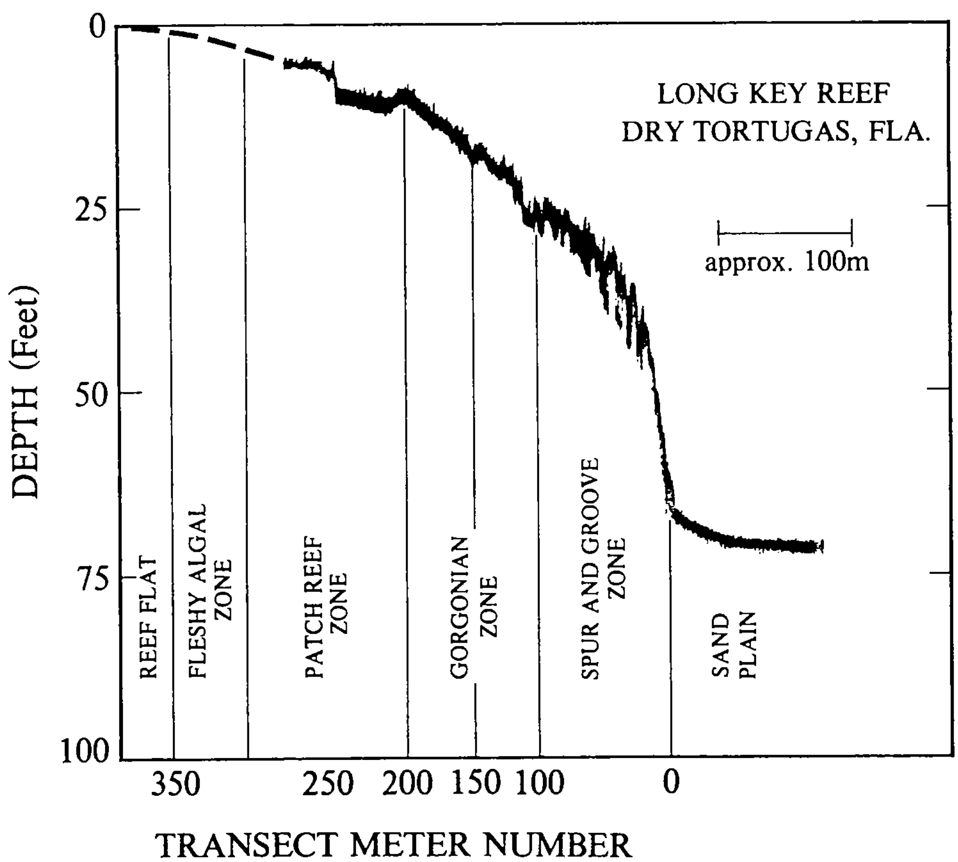

Fig. 4. Fathometer tracing of Long Key Reef, Dry Tortugas showing the overall morphology of the reef. Note the absence of an offshore terrace.

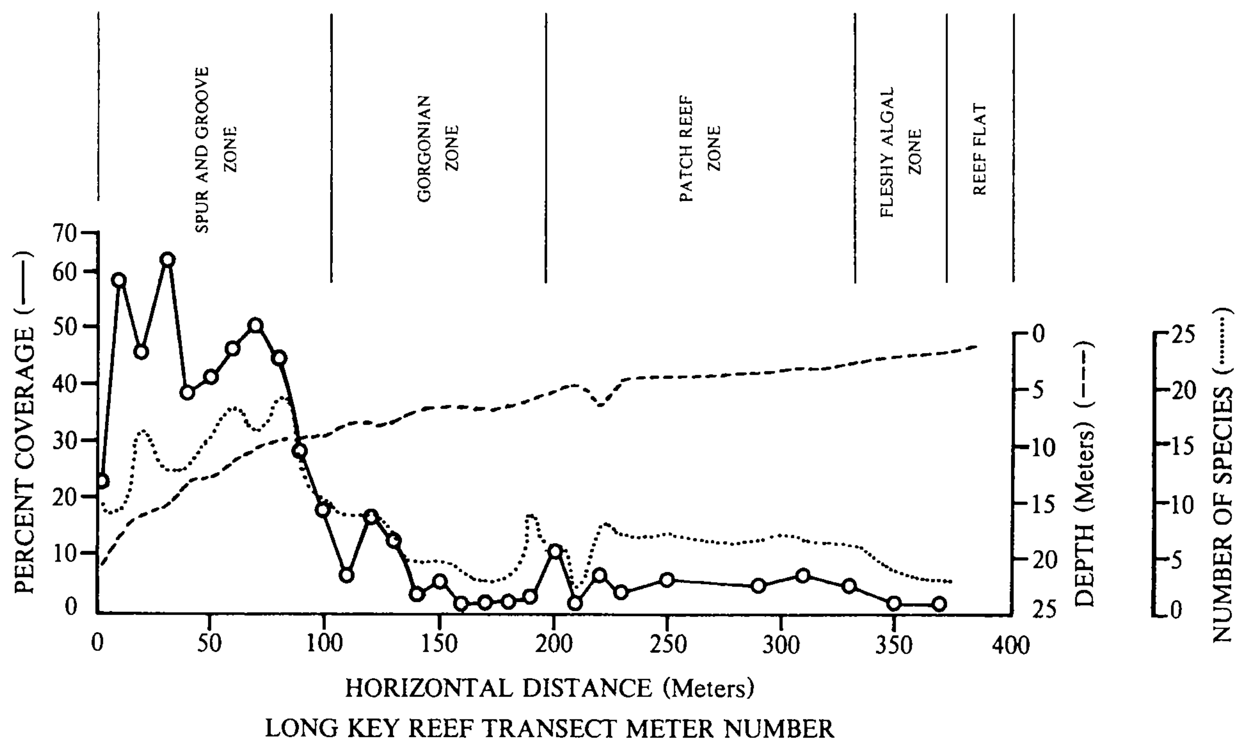

Fig. 5. Graph depicting the percentage coral cover, number of species, and depth profile of Long Key Reef study site.

Photograph Legends

A. Dense thickets of Acropora palmata on the seaward edge of the reef flat of Carysfort Reef.

B. A rich gorgonian, sponge and algal community inhabits the gorgonian zone on the gorgonian zone on the fore-reef terrace from about 5m to 10m. Scleractinian corals such as P. Porites (2) and D. stokesii (1) comprise less than 10% of the total coverage. The colony of D. stokesii is approximately 12cm in diameter.

C. Large colonies of M. annularis occur sporadically in the gorgonian zone of Carysfort reef. Such colonies act as islands on the plain and become centers of focus for fish and invertebrate populations. This colony is approximately 3m high and 6.4m in greatest diameter.

D. The ecotone between the gorgonian zone (right) and the fore-reef slope (left) is extremely sharp (arrows). Coral coverage changes from less than 10% to greater than 25% in less than 3 meters horizontal distance at a depth of 10m on Carysfort Reef.

E. A large spreading colony of Agaricia spp. is covering a large block of reef rock, apparently a talus block from an earlier slump.

F. View of the escarpment of Carysfort Reef, 18m. Virtually every colony in the view is surrounded by fine sediment which collects on the escarpment as a result of wave attenuation by the outer reef platform.

G. A reef rock island on the fore-reef terrace of Long Key Reef. This particular island has been formed by M. annularis and M.alcicornis. 5m

H. Luxuriant population of P. bipenata inhabits a 50m wide zone on Long Key Reef at a depth of 4-6 meters. The largest of these colonies are 1.5 to 2m in height.

I. A narrow sand channel slowly being overgrown by a large colony of M. annularis illustrates the hollowness of the spur and groove zone on Long Key Reef. 12m.

J. Diver Karen Lukas examining an exceptionally large colony of M. mirabilis at the base of Long Key Reef, 18m.

K. An anchor, probably lost by a fishing boat, embedded in a patch of A. cervicornis on Long Key Reef. Note the broken and dead rubble surrounding the shank. The coral is regenerating and will eventually overgrow the anchor, 10m.

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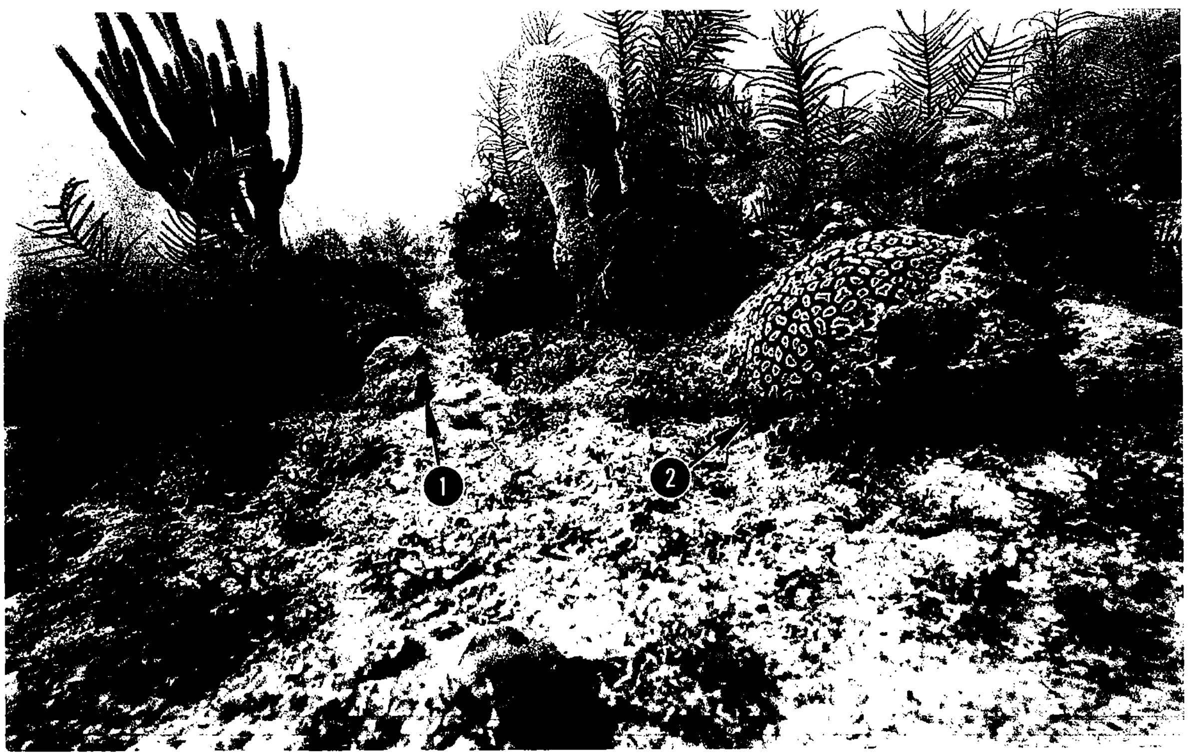

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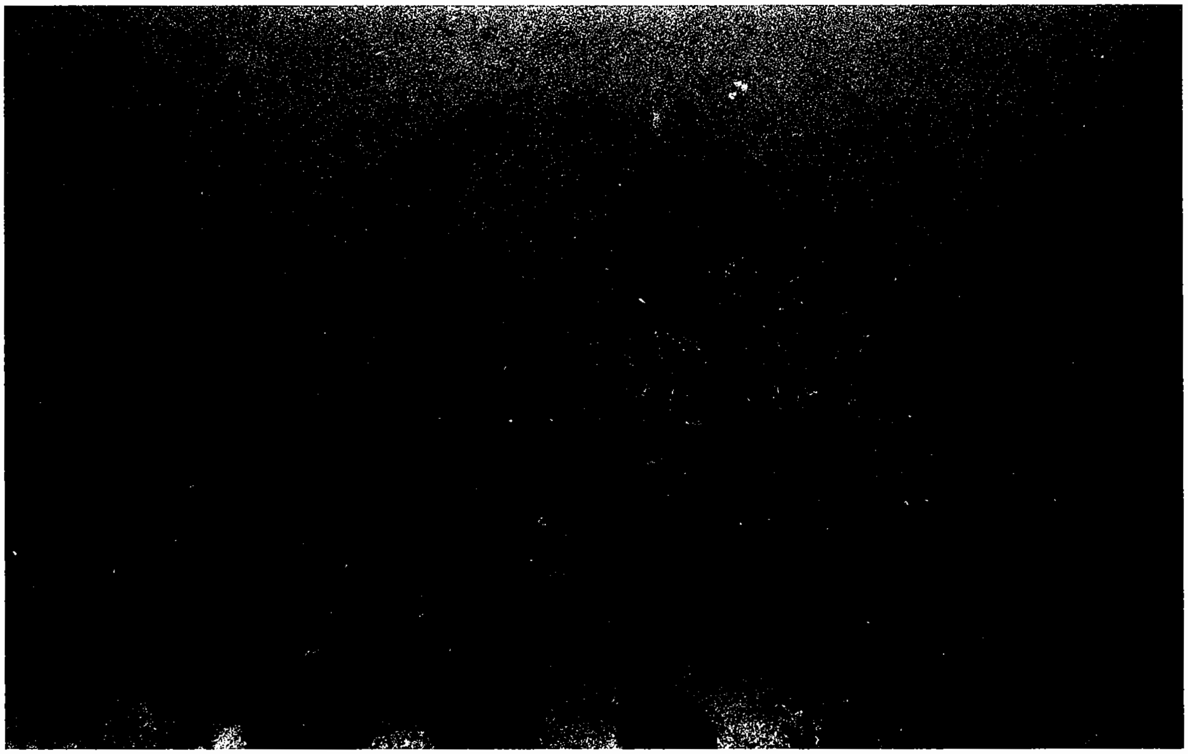

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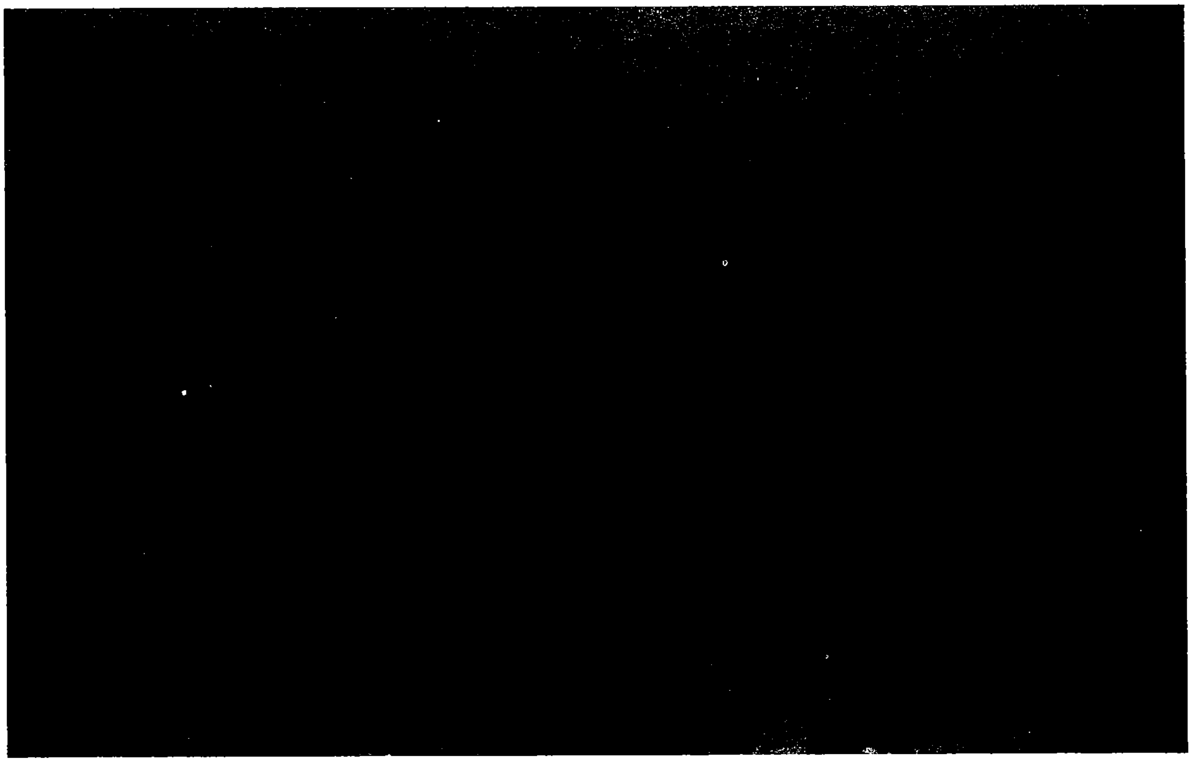

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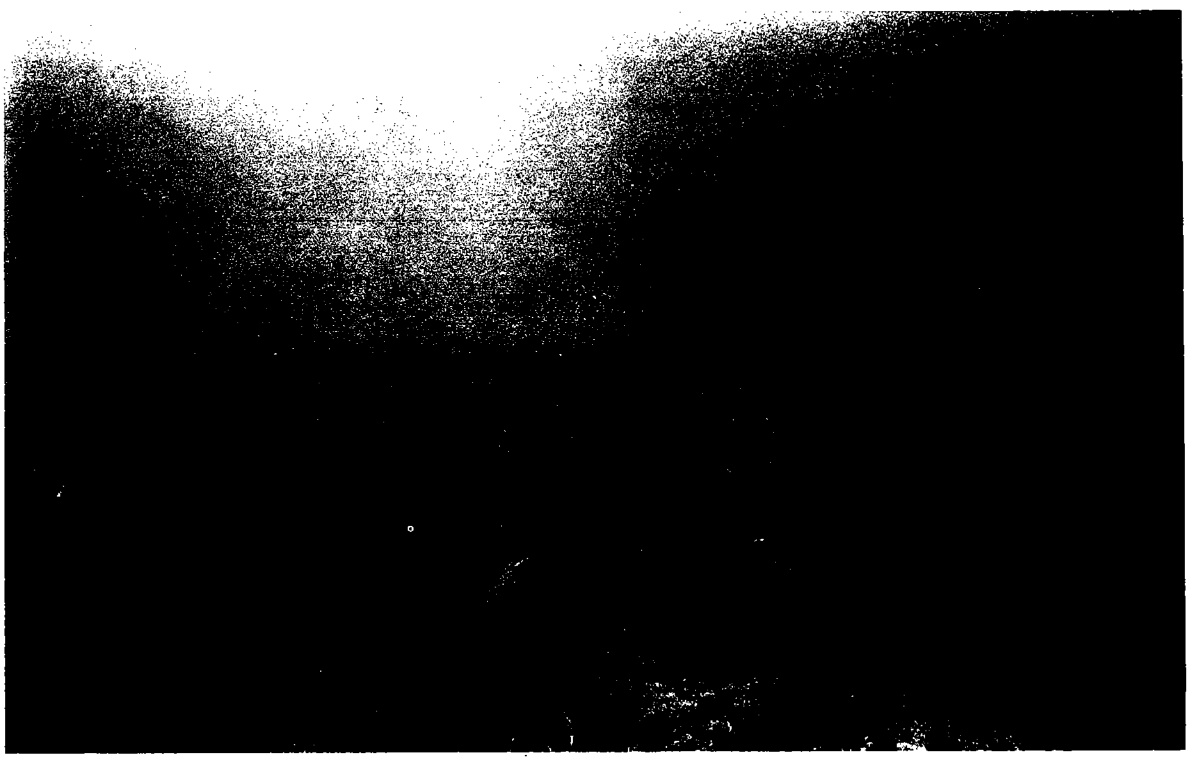

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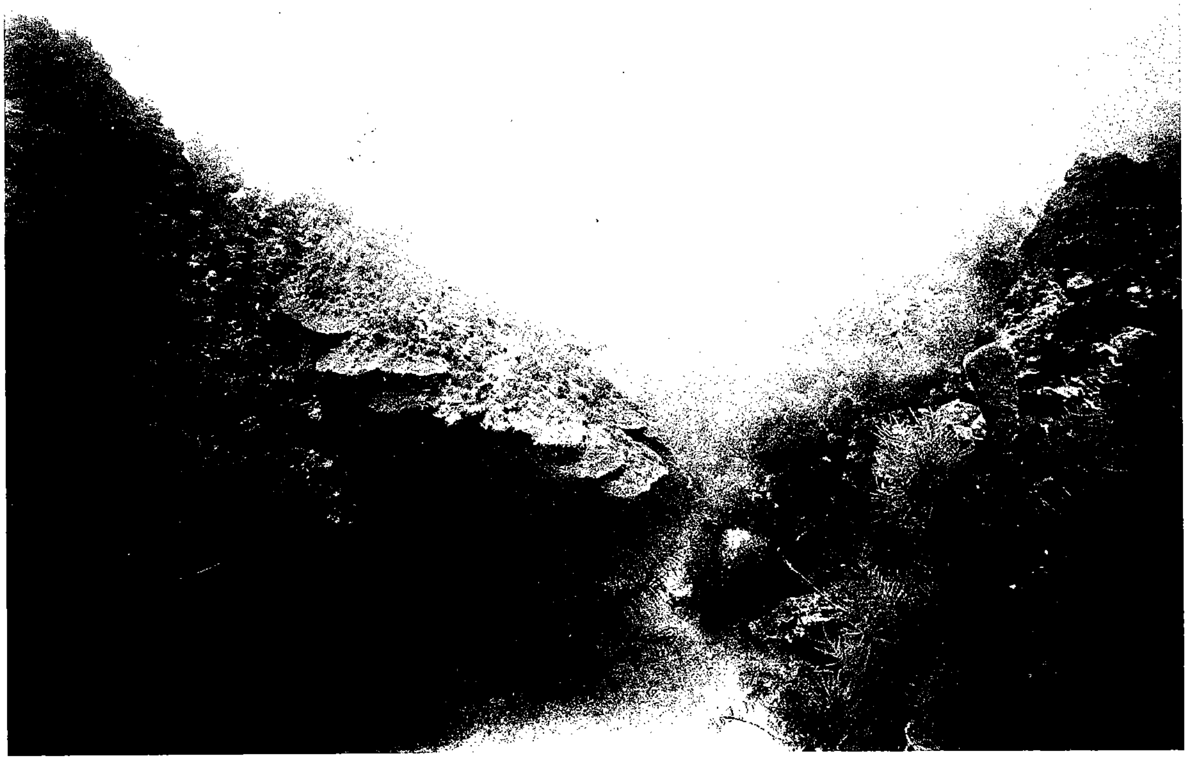

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