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# Coral Reef Recovery in Florida and the Persian Gulf

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**ABSTRACT** / Long-term observations and study of coral reef destruction by hurricanes in the Florida Keys show, surprisingly, that although corals are devastated on a grand scale during storms, recovery is rapid. Recovery occurs because of the widespread scattering of live fragments, many of which become growth sites of new colonies. Reef recovery from death by chilling in the Persian Gulf was well under way when last observed, but it is not yet known if the recovery rate was as rapid as recovery from the storm destruction in Florida. Recovery from death by chilling requires settlement of transported coral larvae and a substrate suitable for larval attachment. Such resettlement is subject to the effects of currents, predators, pollution, and competition for substrate.

A growth rate of 10 cm per year combined with geometrical progression of branch formation accounts for rapid *Acropora cervicornis* recovery. Although calculated coral proliferation seems unusually high, it has been confirmed by serial underwater photographs spanning ten years. More precise measurements of growth and branching are needed, along with growth data for other common reef-building corals. Such data would be useful for predicting standing crop of a restocked or transplanted reef.

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## Introduction

This report documents coral reef recovery following two different types of environmental disasters: destruction by violent storms in Florida and death by chilling in the Persian Gulf. Recovery of corals following mechanical destruction caused by storms is mainly by asexual regeneration of scattered live debris, while the recovery after chilling requires sexual reproduction and settling of viable planulae derived from distant sources. Although both cases are the result of natural phenomena, the latter example has special relevance to the problem of reef recovery following man-induced reef mortality.

This report also discusses some long-term growth rate measurements of both branching and massive corals in an attempt to explain how coral reefs can recover from almost total destruction within a few years. These observations are important because they imply that man has the means to restock a devastated reef or, through "coral farming," to transplant and produce new reefs in suitable areas where no reefs existed before.

## Hurricane Destruction on the Florida Reef Tract

### Hurricane Donna

Hurricane Donna crossed the Florida reef tract on September 9 and 10, 1960. The eye of the storm passed approximately 48 km to the south of the Key Largo Dry Rocks reef (now listed on official charts as Grecian Rocks), where wind velocities were in excess of 160 kph, with gusts to over 240 kph (Ball, Shinn and Stockman 1967).

Pre-storm conditions were well known at Key Largo Dry Rocks because of a previous study (Shinn 1963) and diving in the area since 1950. In several instances pre-storm underwater photographs were available for exact comparison with post-storm destruction. A study



**Figure 1.** Small *Diploria* sp. with 10-cm long growth-rate implant (photograph May, 1961 at Key Largo Dry Rocks). Note small clusters of *Acropora cervicornis* (staghorn coral) in the background.

of hurricane effects initiated immediately after the storm (Ball, Shinn and Stockman 1967) showed severe devastation of the coral. Many whole colonies of coral broken on the seaward side of the reef were transported about 100 m across the shallow reef flat. After a week the reef was in such a state of destruction that we believed recovery would require decades. Yet within 1 year, storm damage was visible only to those of us familiar with pre-storm conditions. Geologists<sup>1</sup> visiting the reef for the first time could not detect signs of destruction. By early 1965, storm damage had completely healed, and I was unable to recognize any trace of storm devastation.

#### Hurricane Betsy

Five years after the passage of Hurricane Donna, the Key Largo Dry Rocks were again hit by a major hurricane. Hurricane Betsy passed within 16 km of

<sup>1</sup> Between 1958 and 1965 the author co-guided several groups of as many as 20 geologists each year to the Key Largo Dry Rocks as part of his duties while employed by Shell Development Company.

the reef on September 8, 1965, subjecting the reef to waves and currents caused by winds in excess of 195 kph. The effects of this storm were recorded by two colleagues, Perkins and Enos (1968), who reported that coral destruction was almost identical to the destruction caused by Hurricane Donna. By October, 1967 storm damage was not noticeable to me or to other visiting geologists.

In both examples of storm destruction, the majority of unburied fragments remained alive and within months began to re-establish discrete colonies. New colonies actually sprang up over a wider area due to dispersal of the broken living fragments; thus, the effect of the hurricane was to provide (more sites) for reef growth. This was brought about in two ways: (1) resettlement of coral larvae on freshly exposed hard surfaces which, because of long burial, lacked the usual competing encrusting organisms and (2) regeneration of numerous scattered living fragments. These two factors, however, will not result in rapid reef regeneration unless the growth and

branching rate of *Acropora cervicornis* is extremely rapid. It became clear that data on growth rates were needed.

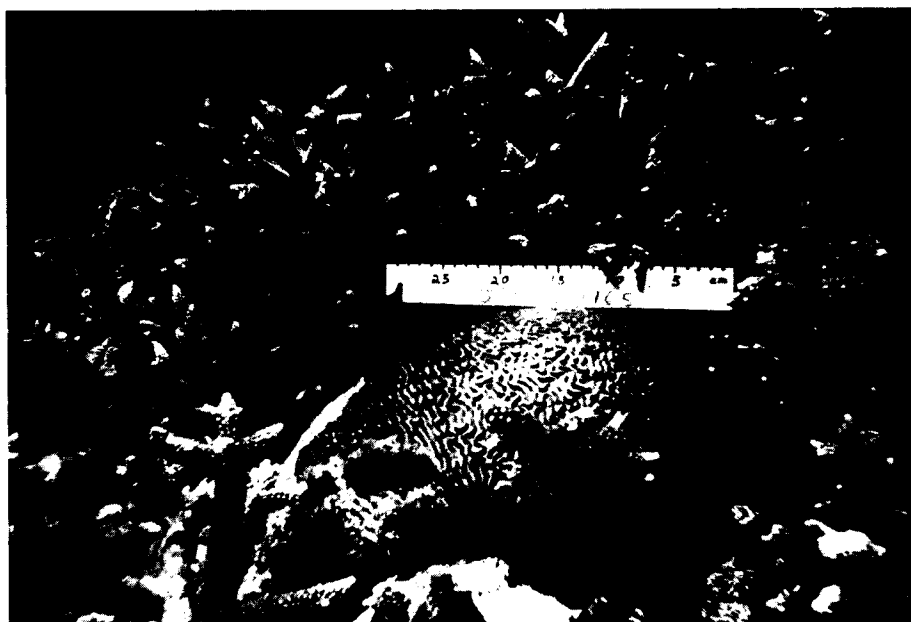
#### Long-term growth at Key Largo Dry Rocks

Three months after the passage of Hurricane Donna (December, 1960) a one-year study was initiated to determine in detail the growth-rate and environmental factors governing distribution of the staghorn coral *Acropora cervicornis*. The study involved transplanting corals into environments where they do not normally live on the premise that changes in rate of growth reflect environmental changes. After a year of monthly observations, it became apparent that seasonal temperature fluctuations could be correlated with changes in growth rate in both transplanted and non-transplanted corals (Shinn 1966). In addition, death of corals transplanted to a near-shore area of wide temperature fluctuations was closely correlated with a drop in water temperature to 13.3°C. The significance of this observation, also determined experimentally by Mayor (1914), has direct application to a massive kill in the Persian Gulf described later.

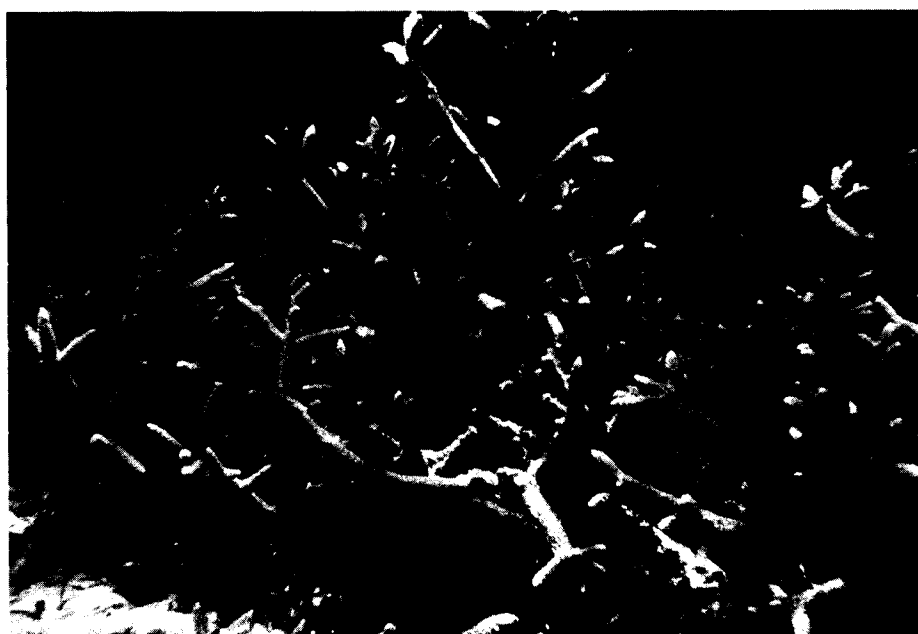
Since 1962 I visited the study area at the Key Largo Dry Rocks about four times a year, except between March, 1965 and October, 1967. Sequential photography of selected reef areas during the past fifteen years has provided several non-quantitative examples of rapid *Acropora cervicornis* growth and branching habit.

Various massive coral heads were spiked with measuring devices (described below) and photographed at intervals from as close to the same angle as possible. The spiked coral heads thus provide a fixed point which facilitated

**Figure 2.** Same coral as in Fig. 1 (photographed January 26, 1965) after growth-rate spike had been removed by divers. Note encroachment of *Diploria sp.* by branching *Acropora cervicornis*, new branch buds on the tips of most branches and dead spot (white area) on (lefthand side) of *Diploria sp.*



**Figure 3.** Same area as in Figs. 1 and 2 (photographed July, 1968): *Diploria sp.* was barely visible, and largely dead, beneath extensive branches of *Acropora cervicornis*.



comparison with the rapid growth of nearby *Acropora cervicornis*, some of which grew so rapidly that it eventually covered and killed small head corals. Figure 1, for example, shows a small spiked *Diploria sp.* as it appeared in

May, 1961: note the scattered staghorn coral in the background. Figure 2 was taken from the same position in January, 1965. In four years, staghorn coral had encroached upon the small brain coral and by 1968 (Fig. 3), the *Diploria* head

had been completely covered. In August, 1971 the brain coral was located behind a wall of staghorn that had advanced approximately 1.2 m from its position in 1965 (Fig. 4). Only a tiny patch of the *Diploria sp.* about 5 cm in



**Figure 4.** Same area as Figs. 1, 2, and 3 (August 6, 1971): diver is pointing to *Diploria sp.* which was hidden by *Acropora cervicornis* that had advanced approximately 1.2 m. Only a small spot on the *Diploria sp.* (about 5 cm in diameter) was alive.



**Figure 5.** (above) Head coral *Montastrea annularis* at Key Largo Dry Rocks with growth-rate implants and nearby sediment sampler in cinder block (photographed May, 1961). Note *Acropora cervicornis* at right of head coral.

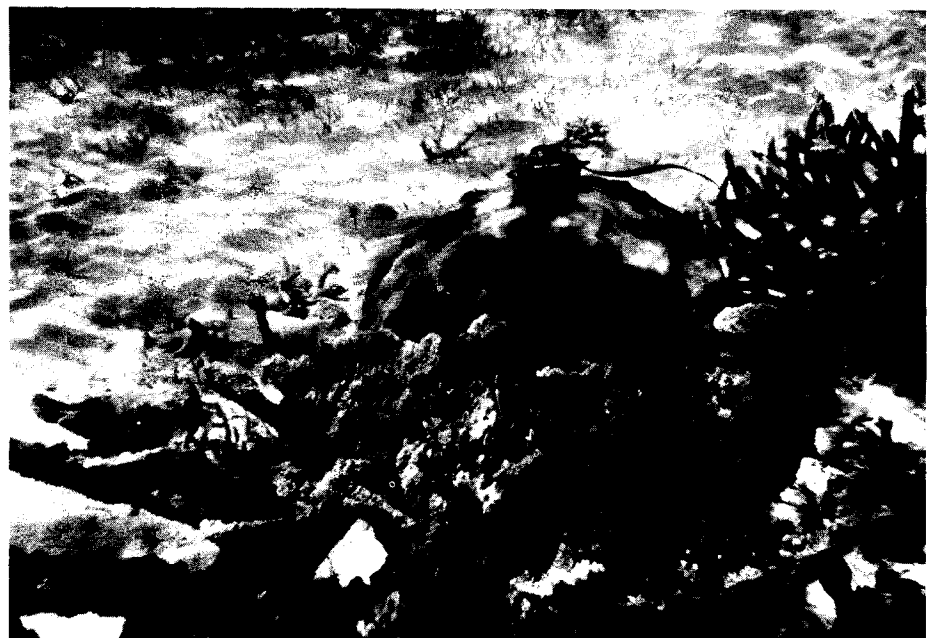
**Figure 6.** (below) Same coral, growth spikes removed, as in Fig. 5 (photographed from approximately the same position in January, 1965). Notice encroachment of *Acropora cervicornis* at right and *Acropora palmata* in foreground.

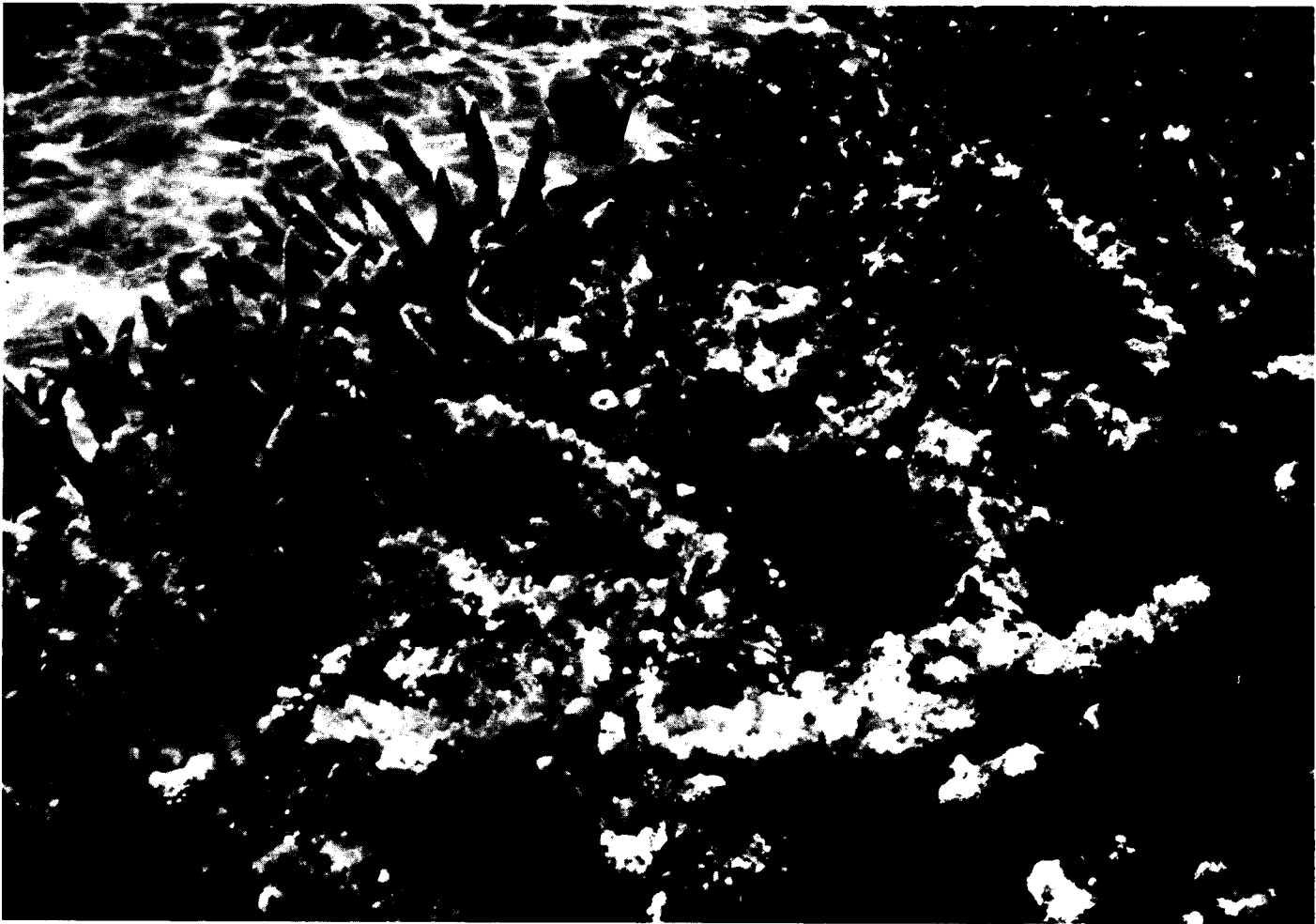
diameter was living in August, 1971. The remainder of the head was dead, apparently because of reduced sunlight and water circulation. By October, 1975 the *Diploria sp.* was completely obscured by the prolific staghorn growth.

Figures 5, 6 and 7 show a similar 15-year example of rapid *Acropora* growth.

**Branching habit and measured growth-rate of *Acropora cervicornis***

For the past 15 years it has been noted repeatedly that staghorn coral forms the beginnings of new branches between December and February. It is not known whether this "budding" is a response to reduced water temperature, reduction in daylight hours, or other factors. As near as can be determined, however, at some time between December and February branching is initiated





**Figure 7.** Same coral, barely visible, as shown in Figs. 6 and 6 (photographed August 6, 1971 from approximately same angle as preceding figures). Massive coral was dying on side under staghorn coral and within a few years the massive head probably will be smothered.

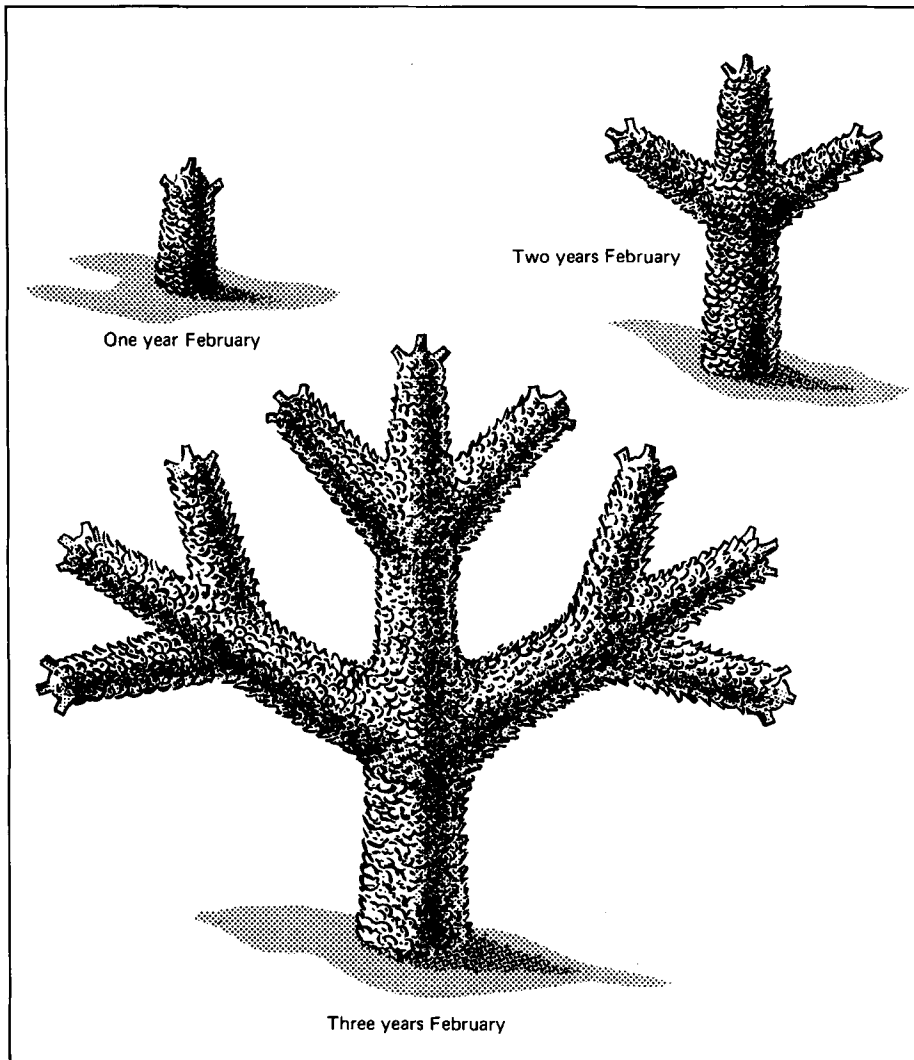
on most colonies within a time span of a week or two.

Branching is initiated by budding of the apical polyp to form between two and four new apical polyps, although not all branches form new branches. Some branches, or stalks, simply continue linear growth, eventually forming 30- to 60-cm long curving stalks with no lateral branches. Measurements of the percentage of stalks forming new branches each year have not been made, but random

observations over the past 15 years suggest that at least half of all stalks form between two and four additional branches each winter. The process of branch formation is shown schematically in Figure 8. Ten-to 30-day old branches are visible in Figure 2. If each stalk buds two new branches, which is considered to be a conservative estimate, and the original tip continues normal growth, there will then be a total of three branches on each stalk (Fig. 8). Each

branch then grows an average of 10 cm per year (Shinn 1966). After a year, each one of the three branches will bud two more branches, resulting in a total of three branch tips per stalk. Thus, by the third year a single branch will have formed 9 branches, and 27 branches after four years.

Extrapolated to the extreme, this geometrical multiplication of branches implies that a small colony of 10 branches could multiply into a colony of 270



**Figure 8.** Schematic drawing of annual branching habit of *Acropora cervicornis* (staghorn coral). Yearly addition of two new branches to each existing branch results in tremendous proliferation of staghorn colonies.

year old colony consisting of 5,904,900 cm of branches would weigh 59,049 kg. Obviously, 59,049 kg of coral branches could not be stuffed into a 1-m high hemisphere. Even a massive coral head of this size (such as *Montastrea annularis*) probably would not weigh more than 900 kg. Thus, although the photographs in Figures 1–7 do demonstrate phenomenal growth of staghorn in the past 10 years, it is physically impossible for growth to approach that indicated in the above calculations. This raises a significant question: how do we reconcile the mathematical consequences of the observed annual branching and a 10 cm annual growth rate?

#### Natural pruning of *Acropora cervicornis*

Besides storm damage, gravity collapse, low tide level and increasing destruction by divers, there is another phenomenon which limits branch preservation. Since the early 1950's I have observed a peculiar whitening and subsequent death of certain staghorn branch tips. In 1961 I made a special attempt to make meaningful observations on the cause of branch death. At that time it was observed repeatedly that certain branch tips up to 10 cm in length sporadically died back to the juncture with the adjoining branch (Figs. 9 and 10). Within a few days the white lifeless skeletons (informally called "white death") were colonized by filamentous and endolithic algae and fungi. Soon after algal infestation, these branches were eaten by the ubiquitous browsing parrot fish. Within one to two months an algal infested branch is completely eaten away and the scar overgrown by living polyps. The selected branches shown in Figure 11 demonstrate the process. I was

ten-cm length branches, a total of 2,700 cm of skeletal branches in three years. Continuing the projection, this colony would consist of 590,490 branches equal to 5,904,900 cm (59 km) of skeletal branches in ten years. This calculation excludes the previous 9 years of branch production; the total amount of branches would actually be 88.6 km. Even though a conservative annual branching number has been used in this calculation, it would be absurd to expect such profuse branching to actually occur. Physical damage caused by predators, storms,

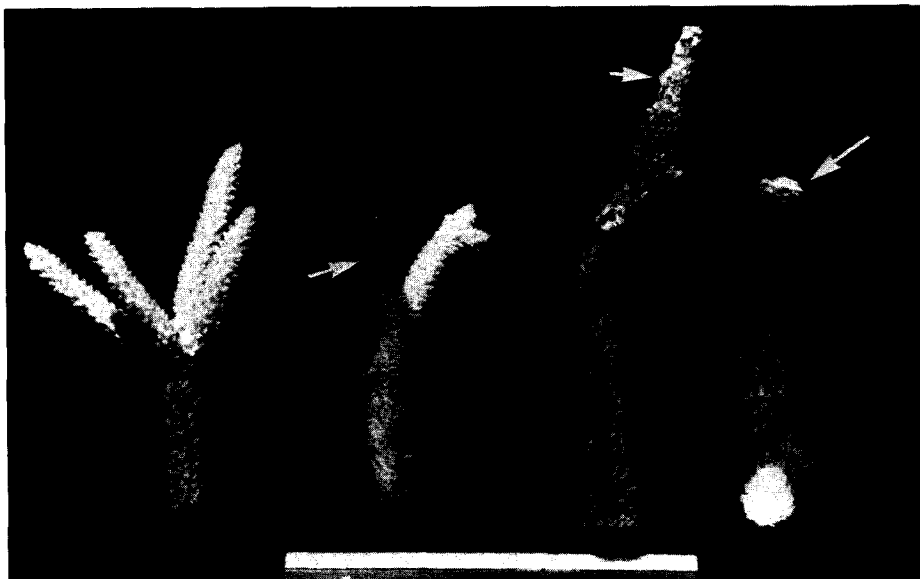
gravity collapse, low tide level, collection and breakage by man, and physical limitations preclude such abundant branch formation. For example, the theoretical 10-year old colony just described could not exceed the gross dimensions of a hemisphere 1 m high (that is, 10 cm annual growth for 10 years equals a colony 1 m high, and similar growth laterally from a central point results in a maximum diameter of 2 m at the base of the hemisphere). Assuming a conservative weight of 100 g per 10-cm length of branch, the total weight of a 10-

**Figure 9.** *Acropora cervicornis* at Key Largo Dry Rocks showing white dead branches (photographed in 1961). Dead branches are thought to be caused by a Polychaete worm (see Fig. 12). This form of pruning has been observed on all Florida reefs during all seasons of the year over the past 20 years.



**Figure 10.** A small colony of *Acropora cervicornis* showing extensive predation thought to be caused by *Hermodice carunculata*.





**Figure 11.** Selected branches of *Acropora cervicornis* showing progressive infestation of dead coral branches with boring and encrusting algae. First example on left shows four freshly killed branches. Second example from left shows freshly killed algal-coated and "fish-chewed" tip indicated by arrow. Third example shows algal-coated and "fish-chewed" tip, shown by arrow, of a staghorn branch. The attached object is a plastic growth band used in growth-rate studies. Example at far right, shown by arrow, shows dead algal-coated tip which has been removed, probably by parrot fish.

never able to find the cause, and therefore considered it to be a kind of self-generated natural pruning. Recently, however, Arnfried Antonius (personal communication 1973) and Phillip Dustan (personal communication 1975) observed the Polychaete worm *Hermodice carunculata* feeding on *Acropora cervicornis* branches in what Dustan likened to a "sword swallowing act," in which the worm swallows several cm of branch tip and digests the living coral tissue. The photograph in Figure 12 shows *Hermodice carunculata* eating a branch tip.

Whether all the white death is caused exclusively by *Hermodice carunculata* is not known, but it appears to be a widespread phenomenon in no way related to man. The writer has observed the white death in the Persian Gulf, the Australian Great Barrier Reef, and on the reefs of Jamaica, Barbados, Belize, and the Bahamas, in areas far removed from human habitats.

That *Hermodice carunculata* is an active coral feeder is well known. Glynn (1962) reported *Hermodice carunculata* predation of *Acropora palmata* and Marsden (1962) described similar predation on *Pōrites porites*, during which the

worm swallows the tips in a manner such as that shown in Figure 12. In addition, this writer has observed and photographed a Polychaete worm thought to be *Hermodice carunculata* devouring a branch of *Millipora* sp. on the Flower Gardens coral reef off Galveston, Texas.

#### Massive head coral growth

An attempt to obtain long-term growth measurements of massive corals was made by driving stainless steel spikes into coral heads, so that 10 cm of spike protruded from the living surface. Any subsequent growth could then be noted by measuring the length of spike above the coral surface.

On December 11, 1960 eight spikes were driven into a large *Diploria strigosa* (brain coral, Fig. 13), and two were driven into *Montastrea annularis* of similar size (star coral, Fig. 15) at Carysfort reef in the Florida Keys. These corals were relocated on August 6, 1971. Four spikes remained in the *Diploria strigosa*, whereas only one remained in the *Montastrea annularis* (Figs. 14 and 16). Growth indicated for this 10-year and 8-month period in *Diploria strigosa* was 6, 6, 6, and 4.5 cm, a yearly average of 5.6 cm, or approximately 5 mm. Growth in-

**Figure 12.** *Hermodice carunculata* feeding on branch of *Acropora cervicornis*. Living tissue has been digested and worm has pulled back to expose white coral skeleton. Photo in 8 m of water at Carysfort Reef, Florida, by J. C. Lang and L. S. Land. White portion of coral is about 8 cm long.





**Figure 13.** A large head of *Diploria strigosa* with growth-rate implants (photographed December 11, 1960 at Carysfort Reef in 2.5 m of water).

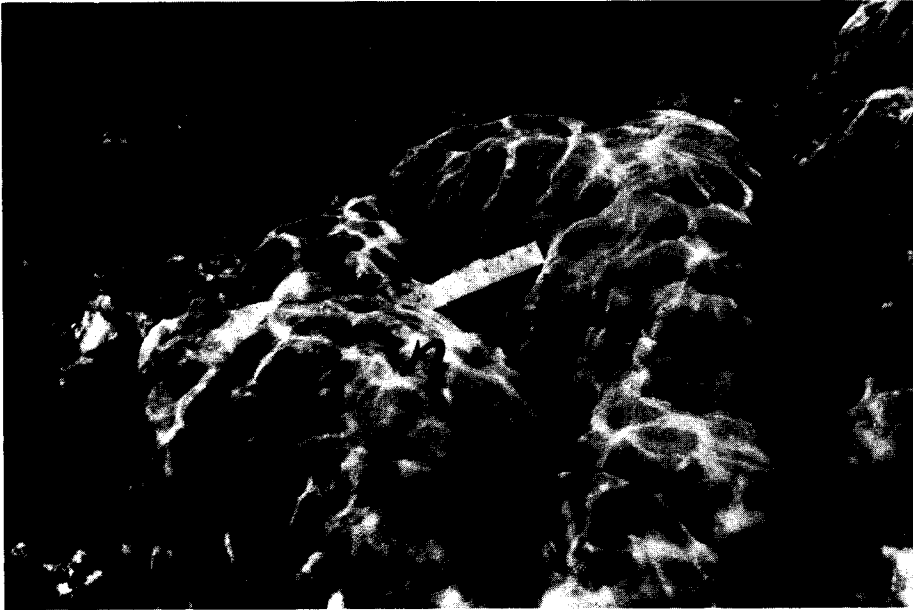


**Figure 14.** Same coral as in Fig. 13 (photographed August 6, 1971). Arrows indicate remaining growth-rate implants. Average growth indicated by implants for the 10-year 8-month period was 5.6 cm. Note also staghorn coral in foreground (Carysfort Reef).



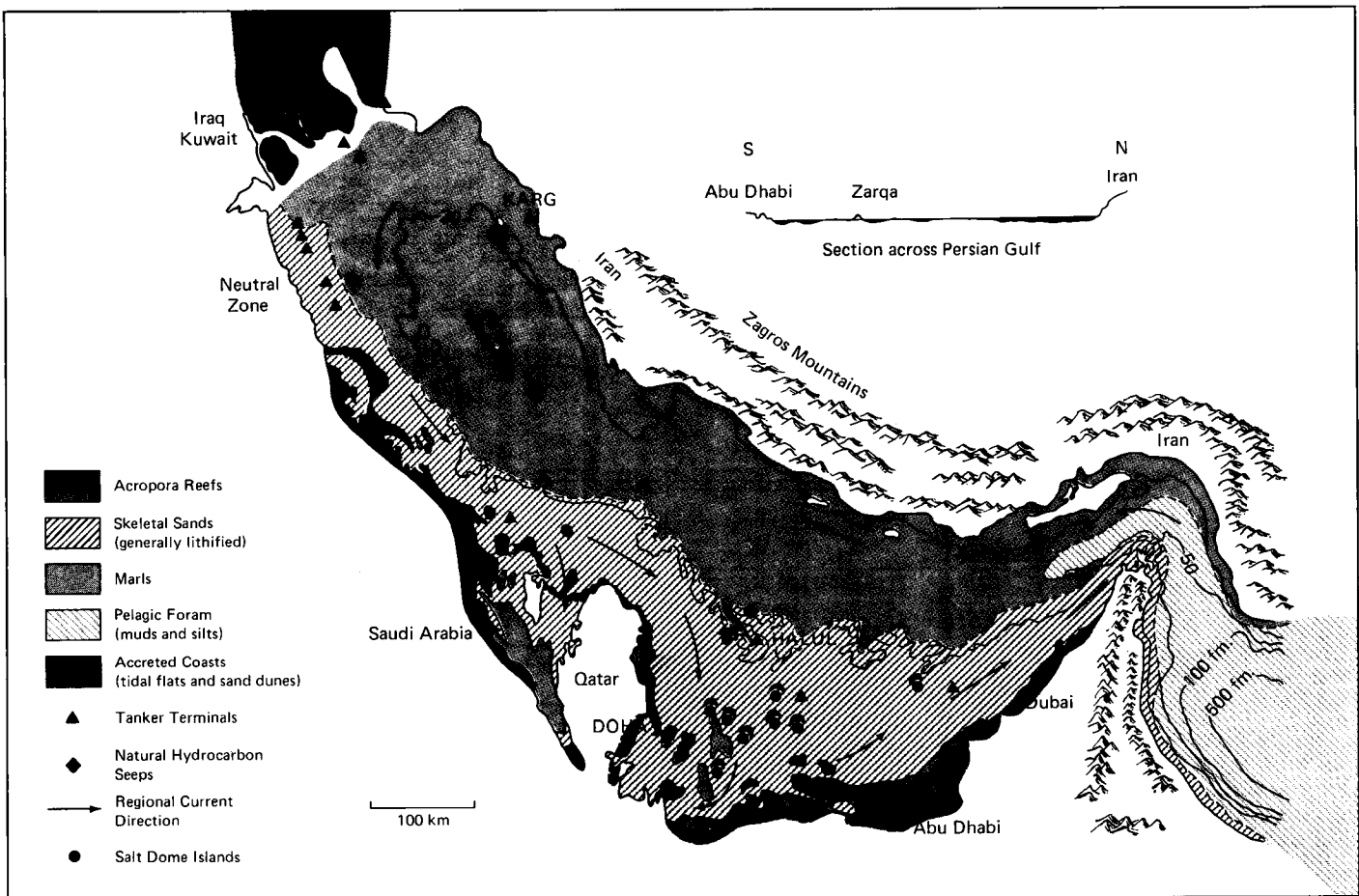
**Figure 15.** A head of *Montastrea annularis* showing growth-rate implants (December 11, 1960, Carysfort Reef in 2.5 m of water).





**Figure 16.** Same coral as in Fig. 15, (from approximately same angle, August 6, 1971). Growth indicated by the single remaining implant shown by arrow was 9 cm in 10 years and 8 months. Note also how growth has almost closed the cavity holding the scale in previous photograph. Closing of gap between this head and larger massive head to the right suggests that both heads will grow together in a few years.

**Figure 17.** Persian Gulf map showing distribution of coral reefs, tanker terminals, and natural hydrocarbon seeps.



**Figure 18.** Typical flourishing coral reef in the Persian Gulf near Dalma Island.

indicated by the single spike in *Montastrea annularis* was 9 cm for this period, or approximately 8.4 mm per year.

Similar spikes, which were subsequently removed by divers, were driven into coral heads at Key Largo Dry Rocks. However, those corals provided the fixed reference points for the sequential photographs shown in Figure 1–7.

These meager growth rate data are not considered conclusive. They serve, however, to indicate that *Acropora cervicornis* proliferates at a rate 10 to 20 times greater than the common massive corals. Thus, complete recovery of a reef composed principally of massive corals could require many years. On the other hand, a reef composed of staghorn corals has the capacity to regenerate in a matter of a few years.

### Persian Gulf

#### *Acropora* reefs

The reefs fringing the Trucial coast and offshore islands in the Persian Gulf are lush (Figs. 17 and 18), though composed of fewer species than typical Caribbean reefs. Kinsman (1964) recorded 11 Genera along the Trucial coast region, where the principal reef builder is a form of *Acropora* sp. very similar to *Acropora cervicornis*. *Porites* sp. and brain corals, which form massive heads similar to those in the Caribbean, are also common.

**Figure 19.** Portion of extensive dead *Acropora* sp. reef off the east coast of Qatar (photographed May, 1965). *Diploria* sp. in foreground was living. Note unbroken branches of dead staghorn, indicating that death was not caused by physical storm damage.

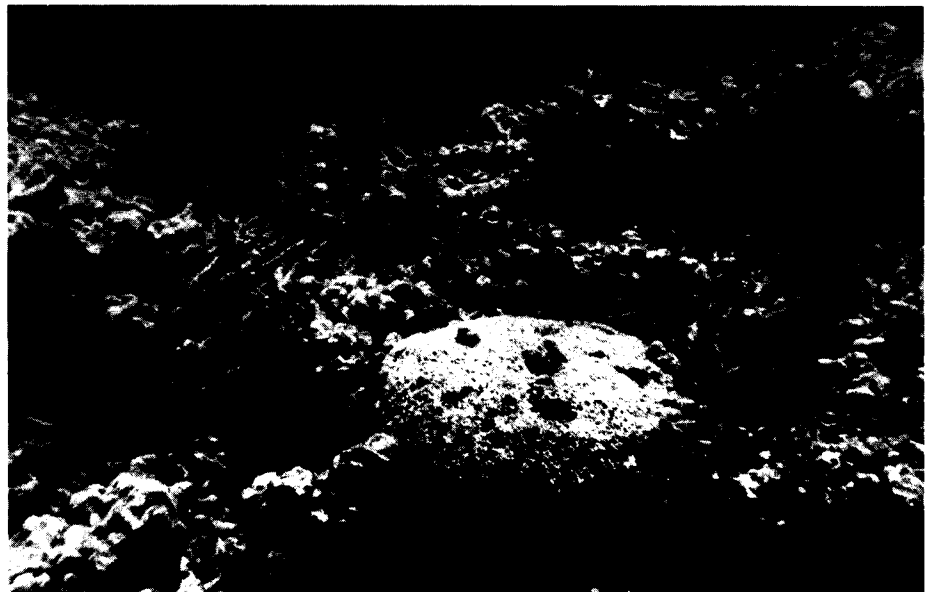


#### Widespread mortality due to chilling

An initial survey around the Qatar Peninsula in May, 1965 consisted of offshore transects extending out to a depth of approximately 7.6 m (Fig. 17). All transects extending from the east and

northern part of the Peninsula crossed extensive reef areas consisting of many miles of *Acropora* thickets. Corals are largely absent on the western coast, probably due to unusually high salinities which average about twice the salinity of normal sea water.

On this first reconnaissance, not a



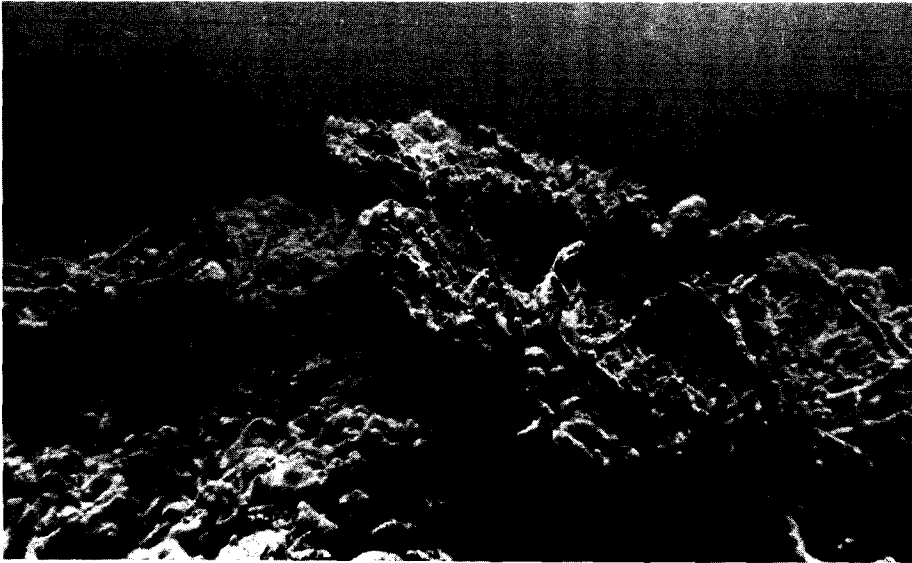


Figure 20. *Acropora* sp. similar to that shown in previous figure (photographed May, 1965).

single living *Acropora* was seen. The vast thickets consisted of in-place dead *Acropora* colonies covered with soft green and brown algae as well as encrusting coralline algae [Figs 19, 20, and 21(a) and (b)]. Massive head corals, though less abundant, were living and apparently healthy.

From natives, from the meteorological staff of the Shell Qatar Petroleum Company and from geologists who preceded our expedition we learned of an unusually severe shemal (cold front with strong northerly winds) which had occurred the previous year. The shemal started on January 19, 1964 and reached full force January 20. Wind velocity did not exceed 65 kph, but ships at sea reported 6-m seas. Air temperature on January 20 was 0.5°C, the lowest temperature ever recorded in Qatar. Dr. Walter Gigon, geologist with Shell Qatar Petroleum Company, recorded 4°C water temperature in the shallow waters of Doha Bay. Water temperature 1 m from the bottom in about 18 m of water was recorded at 14.1°C by observers aboard the *Zenatia* some 80 km offshore.<sup>2</sup> The

<sup>2</sup> From "Information Bulletin of the Co-ordination of Oil Company Meteorological Activities in the Arabian Gulf" relating to the storm of January 19, 1964.

shoreline around Qatar was littered with dead fish, including coastal pelagics, such as mackerel, sea snakes, and cuttle fish; a dead dugong (sea cow) reportedly was washed ashore on the northern coast.

Lack of obvious physical damage similar to that observed after the passage of Hurricanes Donna and Betsy suggested that wave action was a minor cause of mortality. On the basis of the recorded low temperatures and presence of living head corals, which have been shown to be more temperature tolerant than *Acropora* (Mayor 1914), it was concluded that death was related to chilling on or about January 20, 1964. Transplant experiments with staghorn coral in Florida (Shinn 1966) showed that death could be correlated with a chill that lowered water temperature to 13.3°C. Mayor (1914) had shown by laboratory experiments that temperatures between 13.3°C and 15°C for nine hours were sufficient to cause mortality in this species. In addition, Mayor demonstrated that the common massive corals were more temperature-resistant. Mayor's data thus are in agreement with the observation that head corals commonly grow in near-shore areas of the Florida Keys, where water temperatures often fall below

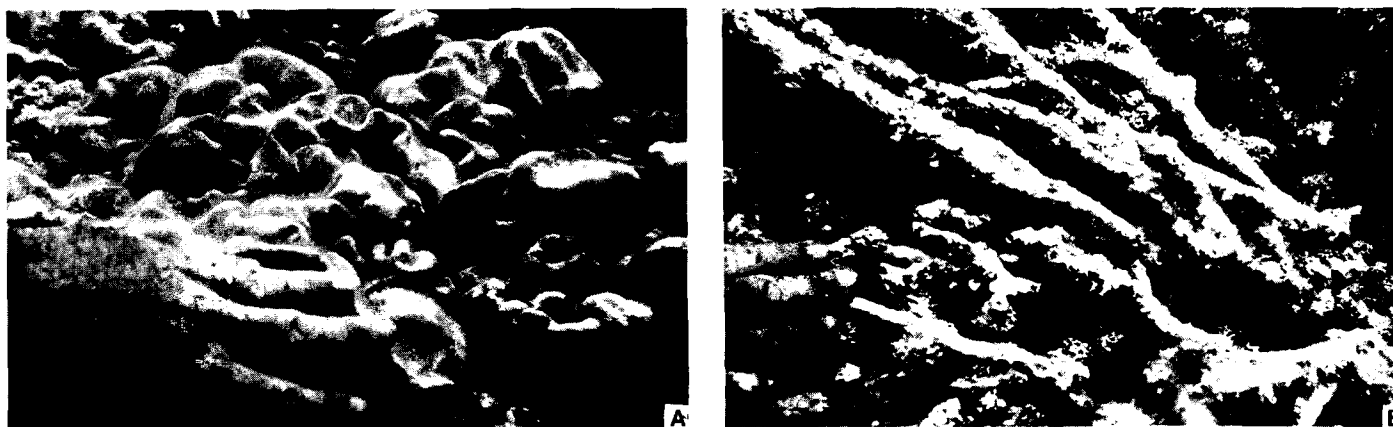
15°C. On the other hand, *Acropora cervicornis* does not occur in these areas in Florida.

Normal seasonal minimum water temperature along the Trucial coast of the Persian Gulf is 16°C (Kinsman 1964). It seems reasonable, therefore, to conclude that the shemal which caused the lowest recorded air temperature in Qatar also reduced water temperature several degrees below the usual minimum of 16°C, resulting in death of Acroporid corals.

#### Recovery

During the 18-month period from May, 1965 to September, 1966 the writer made numerous dives on the reefs along the eastern coast of Qatar. By September and October, 1965 small *Acropora* sp., one to two cm in height, which had attached to dead *Acropora* branches and other suitable hard substrates, were common. By September, 1966 there were abundant *Acropora* colonies ranging in height from a few cm to approximately 20 cm.

These colonies were not regenerated portions of partially living colonies but rather a population that had grown from coral larvae. These larvae had to arrive from distant sources of living coral, the



**Figure 21.** (a) Detail of bulbous green algae which covered extensive areas of dead *Acropora* sp. (b) Detail of encrusting coralline red algae which also covered large areas of dead *Acropora* sp. (May, 1965).

**Figure 22.** Living *Acropora* sp. photographed by Dr. Mike Hughes Clark in May, 1968 near power plant at Doha Qatar. When Dr. Clark and the author explored this area in 1965 no living staghorn corals were seen.



closest sources being Halul Island approximately 61 km to the east and the reefs near Bahrain Island approximately 61 km to the west. In as much as the predominant current movement is from the west (Fig. 17), reefs near Bahrain Island probably were the source of planktonic coral larvae.

The condition of the reef today is not known, but based on its appearance in 1966 and observations of the living reef in 1968 (Fig. 22) by Dr. M. H. Clark (personal communication 1970), it is assumed that the reef has recovered.

## Discussion

The great storms and temperature extremes, particularly in marginal climatic zones where unusual hydrospheric and atmospheric conditions sporadically produce temporary lethal temperatures, are probably the most significant destroyers of live coral in the Atlantic.

As of summer, 1975, Key Largo Dry Rocks and Carysfort reefs, the most prolific of the Florida reefs, were more lush than the author has observed since 1950. This seems surprising in light of increased

tourism which has resulted in damage by boats, anchors and by divers standing on corals in shallow areas. Studies by Ball, Shinn and Stockman (1967) and Perkins and Enos (1968), which showed the extreme devastation caused by hurricanes, provide background for understanding the reefs' present lush condition. Ball, Shinn, and Stockman (1967) pointed out that on the average hurricanes have affected any particular Florida reef once every 6 years during the Holocene period (the past 10,000 years). As of 1975 it has been 10 years

since such a storm affected the reefs off Key Largo. These reefs thus have had an unusual amount of time for uninterrupted growth. Consequently, when the inevitable hurricane does hit these reefs, the degree of destruction will appear unprecedented and will most likely make current damage by man seem insignificant by comparison. Yet research by Ball, Shinn, and Stockman (1967) and by Perkins and Enos (1968) indicates that no matter how severe the destruction may seem, rapid recovery will occur.

#### Future work

In order to obtain detailed data on coral reef recovery and for the purpose of coral farming and transplant programs, more precise measurements should be made on coral branching and growth rate in various areas of the Florida reef tract. Representative areas should be staked out, and length and number of branches determined at least quarterly. Such studies could determine:

1. Whether there are times, other than winter, when branching is initiated;
2. Exactly what factors initiate branching (such as temperature and light duration) and at precisely what time of year branching begins;
3. Whether branching starts precisely the same time each year;
4. Precisely how many branches are formed, and how many are subsequently lost by predation, erosion or growth interference;
5. How much carbonate is added to the sediments as a result of erosion and predation. (A simple approach is to determine the amount of calcium carbonate produced by *Acropora cervicornis*, based on calculations regarding growth rate and geometrical branch proliferation. The calculated amount could then be compared with the standing crop in a pre-selected area. The difference between what is calculated and what is actually present would be

a measure of the contribution to the sediments by predation and erosion.)

#### Coral farming and transplantation

The data presented here make it clear that restocking devastated reef areas is possible; the work suggested above would have direct application in predicting the success and resulting standing crop of large-scale coral transplants.

Restocking could be one of the few means by which man affects the marine environment in a positive way. However, it is important that restocking by transplantation be attempted only in areas suitable for long-term growth. At least half of the Florida reef tract is unsuitable for prolific long-term coral growth, especially the lower part opposite large tidal passes, such as those which occur between Islamorada and Big Pine Key. Ginsburg and Shinn (1964) pointed out that reduced coral reef growth in these areas is related to silt-laden water of variable salinity and temperature which flows onto the reef tract with each low tide. Corals did flourish in these areas in the past, however, as evidenced by the presence of dead reefs. These reefs flourished until about 3,000 or 5,000 years ago, at which time tidal passes and Florida Bay came into existence because of relative rise in sea level. With creation of the tidal passes water conditions deteriorated and active coral growth became restricted to areas not affected by bay waters flowing from tidal passes. Short of filling in the tidal passes, there is no way to stop the flow of bay water across the dead reef areas.

There are still large areas not affected by waters emanating from tidal passes, where reefs could be restocked. Many of these areas are presently covered by shifting carbonate sand. A suitable stable substrate would have to be provided before corals could be transplanted. Materials such as scrap concrete road building material, culverts, and structural waste could provide suitable substrate similar to that provided by natural rock. Such materials would serve immediately

as habitats for various forms of marine life, while at the same time providing a substrate for transplanted corals. In time, this waste would be overgrown by enough corals to be esthetically pleasing to divers.

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