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CHANGES IN A PUERTO RICAN CORAL REEF FROM 1936-1979 USING AERIAL PHOTOANALYSIS

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ABSTRACT

Panchromatic aerial photographs of Cayo Enrique, La Parguera, Puerto Rico, were obtained for the years 1936, 1951, 1963, 1971, 1978 and 1979. Enlargements were made to the approximate scale of 1:4000 to differentiate the various reef zones. Features seen in the photographs were substantiated by surface reconnaisance. *Rhizophora mangle* and *Thalassia testudinum* areas, measured with a planimeter, showed the maximum variation of all reef zones for a 43-year period. Hurricane effects appear as boulder-rampart formations on the reef flat composed mainly of dead *Acropora palmata* fragments. Past aerial coverage of coral reefs provides the baseline data needed to assess present-day effects of human interference and natural catastrophes on coral reef ecosystems.

INTRODUCTION

Over the last 40 years, the use of aerial photography in coral reef studies has been limited mostly for illustrative purposes and to map and differentiate reef zones (Steers 1945, Teichert and Fairbridge 1948, 1950, Kelly and Conrod 1969, Kumpf and Randall 1961, Slatter and Phipps 1977, and others). Guidelines for the use of aerial photography in reef studies are provided by Hopley (1977) and Hopley and Steveninck (1977).

METHODOLOGY

This paper attempts to measure changes on the reef morphology and features of Cayo Enrique, La Parguera, Puerto Rico, over a 43-year period using aerial photoanalysis. Vertical panchromatic aerial photographs were analyzed from the years 1936, 1951, 1963, 1971, 1978 and 1979. Old photographs were obtained from the Department of Public Works, San Juan, Puerto Rico, while recent coverage was obtained by the author using a small airplane.

All photographs were enlarged to the approximate scale of 1:4000. To compute a more exact scale for each photograph, man-made structures were measured in the field and compared to their equivalent photographic image measurements. Areas were measured with a planimeter. Field work was essential to properly interpret the features seen in the photographs and to determine the effect of hurricanes. Low altitude oblique aerial photographs were used to define reef zones more clearly. Different reef features and zones were defined in old aerial photographs according to their tones and location on the reef (Table 1).

THE STUDY SITE

Cayo Enrique is located 1.5 km south of the village of La Parguera on the southwestern coast of Puerto Rico. It is approximately 1.4 km long by 0.4 km at its widest point and aligned almost parallel to shore (Fig. 1).

Cayo Enrique was selected for this study for its relatively large size and presence of various biotic macroassemblages such as seagrass beds and mangrove areas. Due to its proximity to land, it also appears in most old aerial photographs of the area.

The temperature-salinity characteristics of La Parguera are indicative of a mild hydrographic climate (Glynn 1973). A continuous surface current flow over the reef plus the fact that the maximum daily tidal range is only 40 cm prevents marked temperature and salinity differences. This provides reef flat and back reef organisms with a stable environment. Although heavy mortality of reef flat organisms related to midday extreme low tidal exposure do occur (Glynn 1968), their effect on the reef's macroflora and fauna is negligible when compared to other catastrophic events such as hurricanes.

Cayo Enrique can be classified as an apron reef with a shallow (0.5-3 m) area of sand deposition leeward of the reef flat (Fig. 2). These sediments are medium and coarse-grained sands composed mainly of *Acropora*, *Porites* and *Halimeda* fragments (Morelock et al. 1977). Both seagrass beds and small patch reefs occur in this area. *Thalassia testudinum* areas occur at both ends of the sandy lagoon and on

Table 1. Criteria used to define reef features and zones of Cayo Enrique using panchromatic photographs.

Feature	Location	Tone
Acropora palmata zone	Windward side of reef to 3 m depth	Medium to dark gray contrasting with light substrate
Millepora-Palythoa zone	Reef crest	Light gray, usually defined by white line of breaking waves
Living and dead *Porites* and other corals	Leeward and adjacent to reef crest	Light gray mixed with sandy areas
Thalassia-Zoanthus zone	Most of reef flat areas	Medium to dark gray
Mangroves	Limited to reef flat areas	Even medium gray tone, mottled appearance
Thalassia seagrass beds	East and west ends of back reef lagoon	Light to medium gray tones
Sandy areas	Back reef lagoon and slope	White to very light gray tones that vary with depth
Small patch reefs	Back reef lagoon	Dark to very dark spotted pattern over light gray lagoon sands
Boulder ramparts	Reef flat areas behind reef crest	Brilliant white tones with dark edges

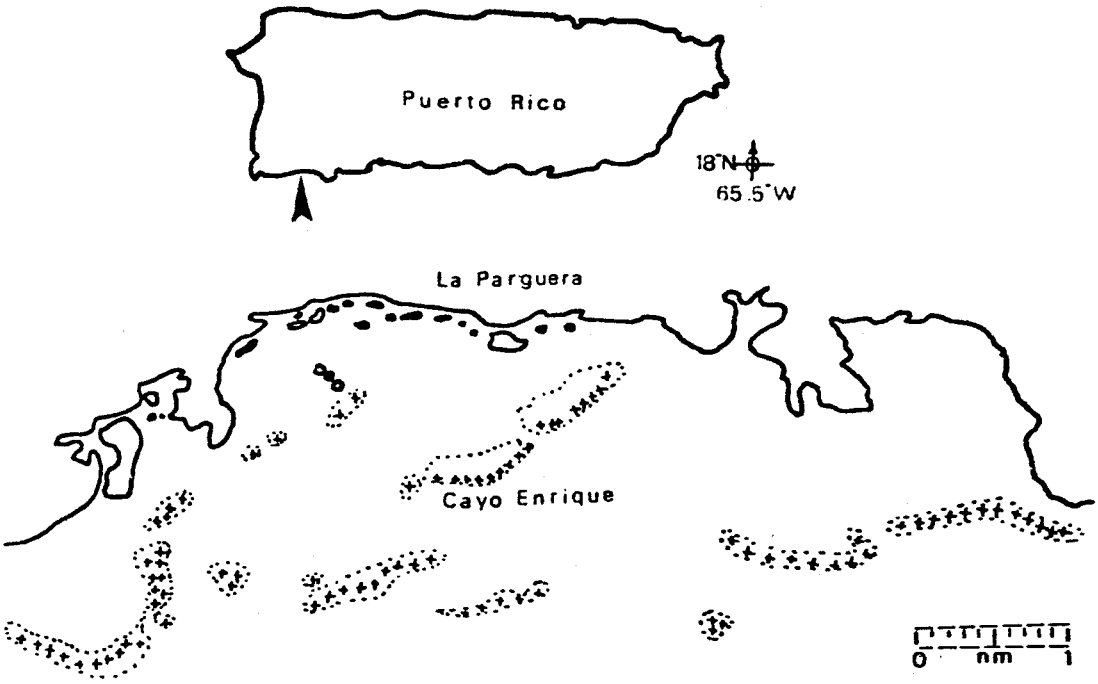

Figure 1. Outline of Puerto Rico with an arrow indicating the location of La Parguera. A detailed map of La Parguera showing the study site, Cayo Enrique, in relation to the coast and other reefs.

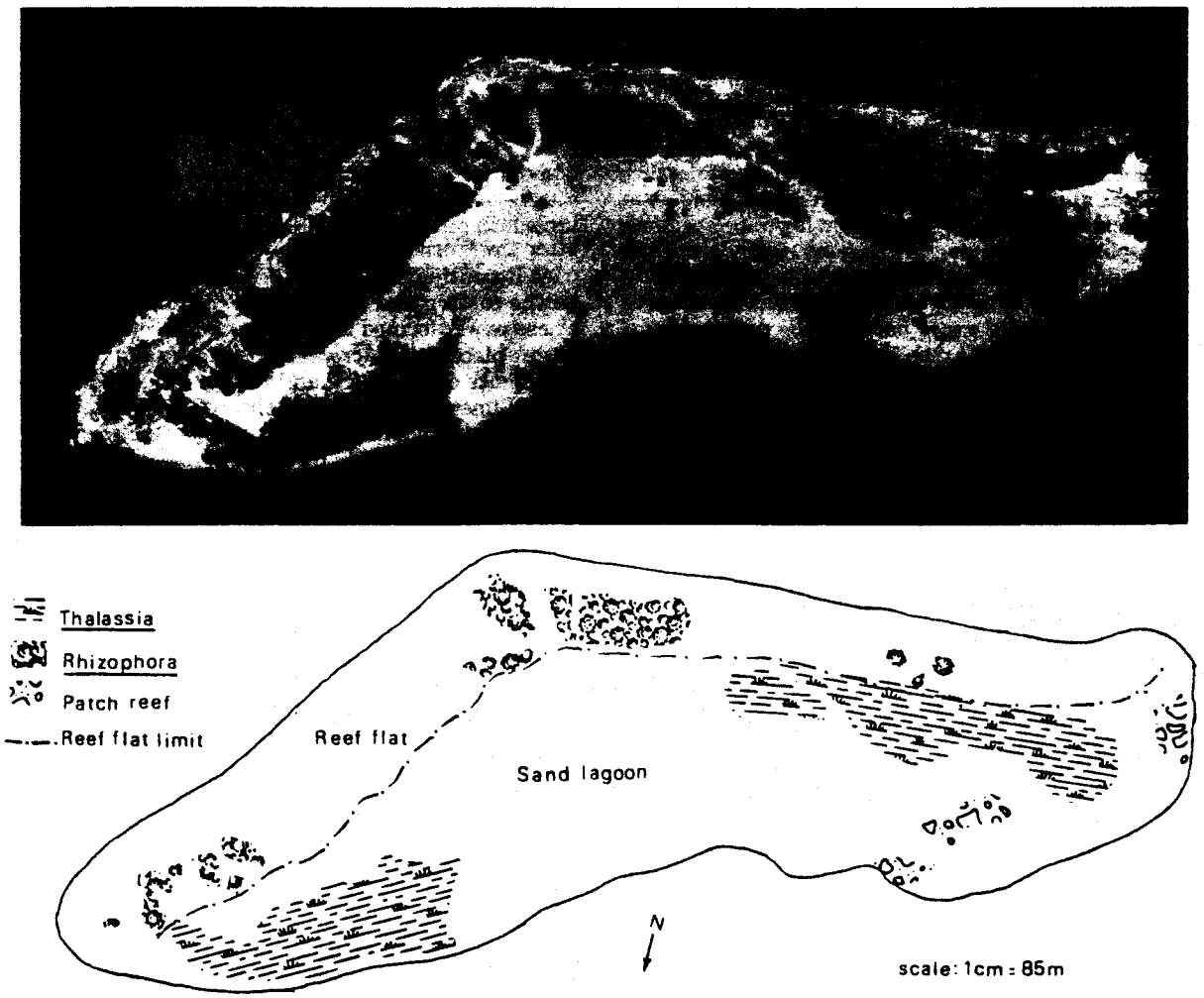

Figure 2. 1978 aerial photograph and diagram of Cayo Enrique showing the various zones and features.

the reef flat while patch reefs occur on the middle and western parts of the lagoon.

The reef flat is composed mainly of living *Thalassia, Zoanthus, Porites* and occasionally *Halimeda* clumps. *Rhizophora mangle* occurs in the middle and both ends of the reef flat.

The reef crest is dominated by the hydrocoral *Millepora complanata.* The zoanthid *Palythoa caribbea* is found near the reef crest encrusting on dead corals.

At the eastern end, the fore reef of Cayo Enrique is relatively broad and gradually slopes to a depth of 20 m while it gets narrower and steeper moving westward. This reef lacks a spur and groove development of the fore reef but has a well defined coral zonation. *Acropora palmata* occurs seaward of the crest to a depth of 3 m followed by *Acropora cervicornis* to a depth of 5 m. A zone of massive corals occurs from 5 to 15 m and is composed mainly of *Montastrea, Diploria* and *Agaricia.*

The lagoon coral patch reefs are dominated by the coral *Montastrea annularis* in addition to numerous sponges and gorgonians. Other corals present include *Acropora cervicornis, Siderastrea siderea* and *Diploria labyrinthiformis.* Dead coral heads covered with algae are common in this area.

RESULTS

1. *THALASSIA TESTUDINUM* AREAS:

Approximately a two-fold increase in lagoonal seagrass areas occurred in Cayo Enrique (Table 2

and Fig. 3). This represents an average increase of 756 m^2/year over a 43 year period. The eastern *Thalassia* bed doubled its area between 1936 and 1951 while on the western end of the reef, an almost complete disappearance of *Thalassia* occurred during the same time period. Since the meteorological record shows no major hurricane affecting the area during those years, an alternate mechanism for such a widespread destruction is yet to be found. One possibility is overgrazing by reef fishes and echinoids that underwent a population explosion.

In Florida, Camp et al. (1973) observed massive destruction of sea grass beds by the urchin *Lytechinus variegatus*. Areas hundreds of meters long were heavily grazed by these urchins.

Table 2. Mangrove and *Thalassia* area measurements for each photograph.

	Rhizophora (m^2)	*Thalassia* (m^2)
1936	1,227	19,129
1951	2,478	13,150
1963	8,022	35,770
1971	13,264	45,569
1978	15,432	51,596
1979	13,873	51,667

2. *RHIZOPHORA MANGLE:*

Mangrove areas increased fifteen times between 1936 and 1978 (Table 2 and Fig. 3). An approximate decrease in mangrove area of 1,560 m^2 occurred in 1979 due to catastrophic effects of hurricane David. While some mangroves were completely uprooted, most damage was caused by hurricane winds and sea spray scalding of the leaves with subsequent defoliation. Mechanical damage of *Rhizophora* prop roots resulted from abrasion and piling-up of coral boulders against them.

Levine (pers. comm.) reported increase in mangrove area of 1,960 m^2/year for Joyuda lagoon on the west coast of Puerto Rico. While this rate is more than five times the average rate of mangrove increase for Cayo Enrique, the difference is easily explained when one considers the two environments: a calm, nutrient-rich, protected lagoon compared to an exposed, high energy reef environment.

3. HURRICANE EFFECTS:

The effects of hurricane Edith on the reefs of La Parguera were documented by Glynn et al. (1964). Although extensive coral destruction on the outer reefs was observed, Cayo Enrique and other inner reefs suffered *Acropora* destruction to the extent of 10-50 percent. No coral shingle islet formation was reported for Cayo Enrique. Analysis of old aerial photographs reveal no detectable changes due to the passage of hurricane Edith in 1963.

Sixteen years later, hurricane David (Aug. 25-Sept. 8, 1979), considered one of the severest storms of the century, passed approximately 120 km south of Puerto Rico. A survey of Cayo Enrique after the storm showed the following effects:

A) Recently dead corals formed boulder ramparts on the eastern and middle windward reef flat areas. These newly formed islets were composed mainly of large pieces of *Acropora palmata* and smaller fragments of *Millepora* and *Porites* (Figs. 4 and 5).

B) Numerous dead invertebrates, mostly echinoderms and mollusks, were present on the reef flat.

C) *Thalassia* and *Syringodium* blades accumulated on mangrove roots and boulder ramparts. These seagrasses probably broke free from the outer reefs due to wave action and were carried downcurrent and deposited on Cayo Enrique.

Four phototransects made on the western fore reef of Cayo Enrique showed a significant ($p<.001$) difference in *Acropora* coverage while no significant difference was observed in the massive coral zone (Ramirez, pers. comm.).

The following changes were detected on the 1979 aerial photograph of Cayo Enrique taken one month after hurricane David: 1) boulder rampart accumulation on the reef flat, 2) a decrease in mangrove area as explained previously in this paper and 3) no major effects on the lagoon's *Thalassia* beds. This agrees with Thomas et al. (1961) report of light damage to the *Thalassia* beds of Biscayne Bay after the passage of hurricane Donna. Oppenheimer (1963) states that after hurricane Carla, not only did the grass flats remain intact, but that they appeared more healthy than at any time during the last three years. He suggests that the wave motion apparently removed the old and unattached grasses and algae leaving clean grass flats.

4. HUMAN INTERFERENCE:

Cayo Enrique is frequently visited by pleasure boats that stay up to 3-4 days anchored on the calm, sandy lagoon. No detrimental effects on the reef have been observed that can be related to boating activities. They tend to avoid *Thalassia* beds in favor of sandy areas that provide a better holding ground for anchoring. Destruction of *Thalassia* caused by boat propellers in shallow bays has been reported by Phillips (1960). This was not observed in Cayo Enrique probably due to the deeper distribution of *Thalassia* there.

Local fishermen frequently walk on the reef flat searching for octopus and other edible mollusks.

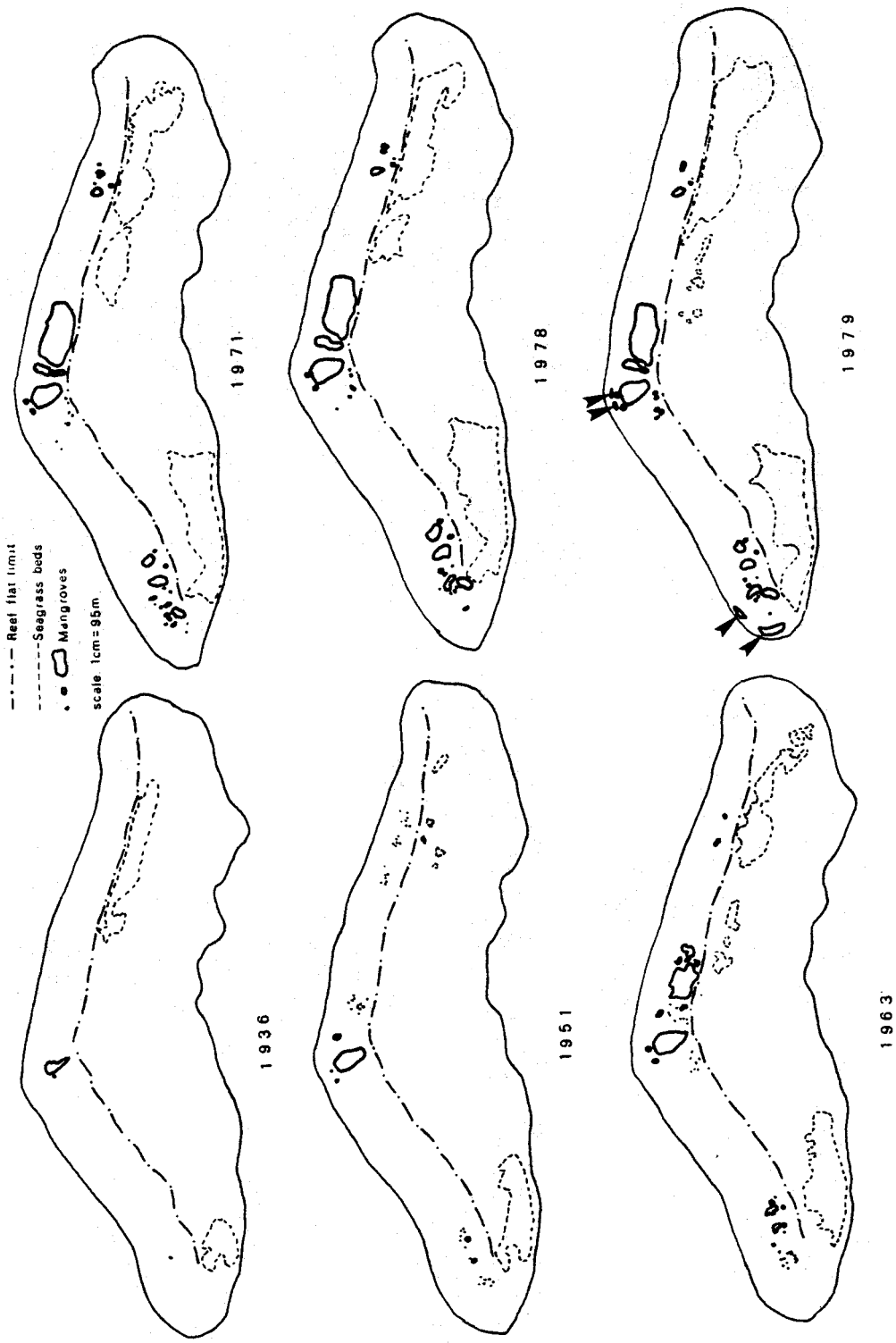

Figure 3. Relative changes in *Thalassia* and mangrove coverage for a 43-year period. Arrows indicate location of boulder ramparts formed by hurricane David in 1979.

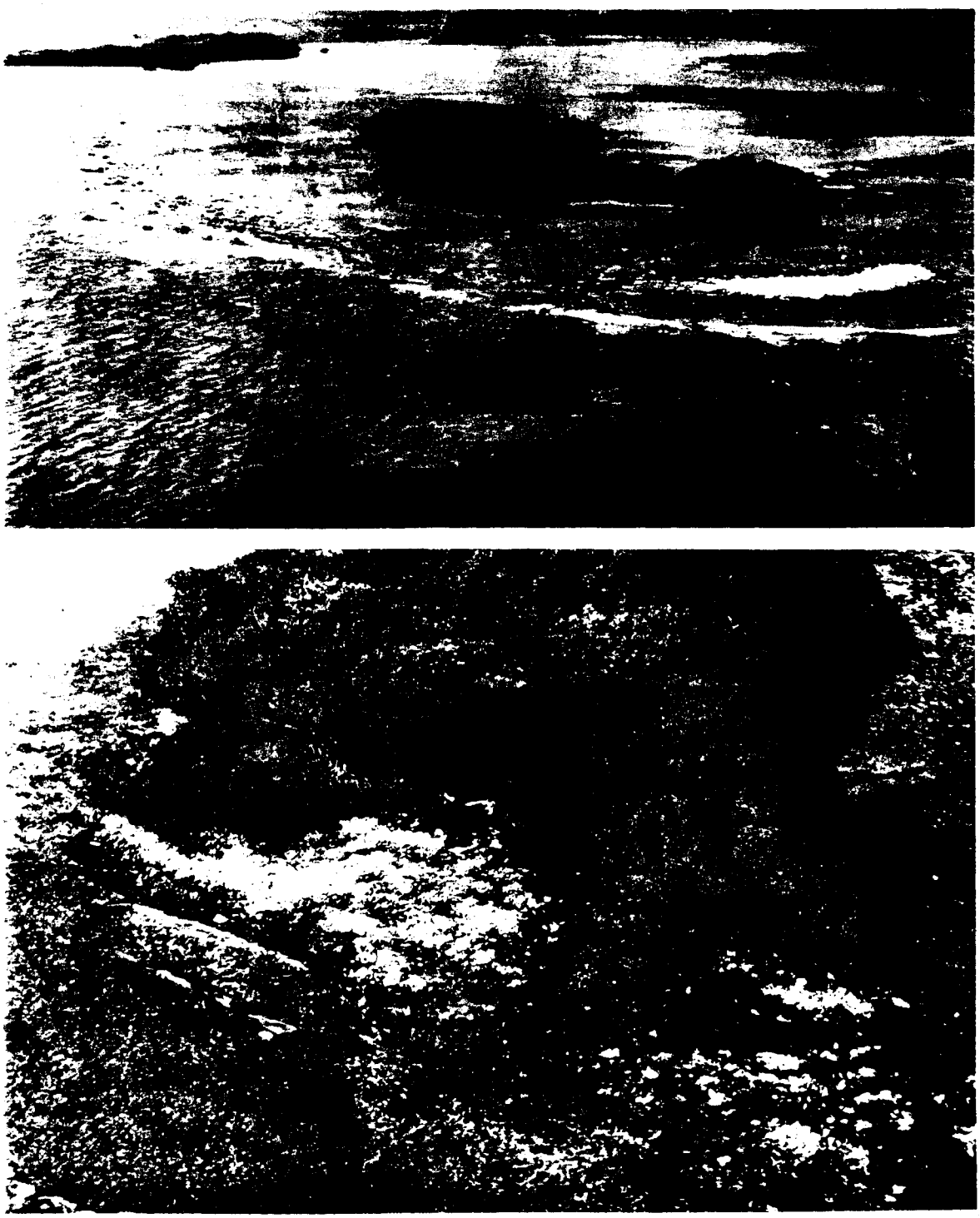

Figure 5. Oblique low altitude photograph of south windward side of Cayo Enrique taken after hurricane David in 1979. Boulder rampart accumulation can be seen on the reef piling up against the mangroves.

Figure 4. Oblique low altitude photograph of Cayo Enrique facing westward. Boulder rampart formation resulting from the passage of hurricane David in 1979 can be seen in the foreground on the eastern end of the reef.

Although these activities could potentially destroy fragile corals such as *Porites furcata* and other reef organisms, its real effect is yet to be determined.

Oil pollution, in the form of tar balls, was observed on the boulder ramparts in the last two years. This could represent, if it continues and increases over the years, a major source of pollution and unnecessary stress on the reef environment.

CONCLUSIONS

Detectable changes in Cayo Enrique during a 43-year period using aerial photoanalysis include an increase in seagrass and mangrove coverage and boulder rampart formation on the reef flat due to hurricane effects. Hurricane David reduced the area of mangroves by 1,560 m^2 while *Thalassia* beds were not adversely affected. Human activities in Cayo Enrique appear to have no detectable effects on the reef environment. Whether this can be said in future years will depend on whatever measures are taken today to protect this reef, as well as the other reefs of La Parguera, from future adverse direct and indirect effects by man.

The rate by which seagrasses are covering lagoon areas and the extent of mangrove colonization of the reef flat could indicate that Cayo Enrique is approaching a climax zonation dominated primarily by plant species.

When available, a series of aerial photographs, taken over the years, is a useful tool in detecting and measuring trends in coral reefs and providing baseline data by which present and future comparisons can be made.

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