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## REEF POLLUTION IN PARADISE<sup>1</sup>

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### R E S U M E N

Los desarrollos de arrecifes son abundantes en las islas costafuera de Venezuela, en el Mar Caribe, pero se encuentran en contados lugares de la costa. Estos son los mismos sitios a los que hordas de gente, en muchos casos sin consideración por el medio ambiente, pueden llegar con facilidad.

En 15 años el pequeño arrecife costero de Chichiriviche ha pasado de un estado de desarrollo creciente y sano, con abundancia de peces y multitud de otros organismos a un arrecife "enfermo" y en muchas áreas "muerto", opacado bajo una mortaja de agua turbia.

Este proceso reciente, y de continuo aumento destructivo es debido al incremento de desechos industriales y de tanques sépticos, no tratados. El desarrollo urbano en otras áreas arrecifales (como en los Cayos de Florida, Estados Unidos, aun con todos sus problemas) indica que la actividad humana en zonas residenciales no necesariamente conduce a la destrucción del equilibrio ecológico local.

### A B S T R A C T

Venezuelan reefs are abundant on its islands, but limited to local favorable sites on the coast. These are the very places where hordes of heedless people can reach easily.

The small reef fringing Chichiriviche has changed in 15 years from a healthy community with a normal complement of fish and other organisms, to a dull, dingy, mostly dead mass under a shroud of turbid water.

This recent and still-growing destruction is owed to increase in industrial and septic-tank, untreated wastes.

Urban development in other reef areas (as in the Florida Keys, U.S.A.,

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even with all its associated problems), shows that human activity in residential areas does not necessarily lead to the destruction of the local ecological equilibrium.

#### INTRODUCTION

Coral reefs and tracts are the delight of tourists and divers, and admired by scientists as complex marine climax communities. Their importance as sites of food production and coastal nurseries receives relatively little attention. Widespread concern for their condition appears limited to events such as the Acanthaster scare in the Pacific. Students of reefs are coming to learn that damage from short-run natural causes may be spectacular locally, but that reefs have sufficient recovery capacity for the larger community to recover, or even flourish (Shinn, 1972; Stoddart, 1965). Long-term changes, of sea level, currents or climate, may overcome this natural resilience; but reefs otherwise persist, rejuvenate and spread.

Even so, reefs are not amenable to many of the works of man. We in the Western Hemisphere continue to act as though frontiers were endless. We overrun nearby ecologic niches because we believe more are to be found. Europeans and Orientals know better.

Massive residential and recreational development in the Florida Keys seems to accumulate at an exponential rate. Many have seen how the substrate is dug out and thrown back upon itself to enlarge and elevate the land. Admittedly, this does not occur close to the reefs, but it alters the littoral and shallow sub-littoral in ways that are destructive and apparently irreversible. Florida boasts the first underwater park, preserved by the government for the enjoyment of all. But establishment and maintenance of the park is not enough, because; 1) the ratio of users to area is unfavorably high, and 2) natural communities cannot remain stable if bordered too closely by artificial and destroyed communities.

Workers at the West Indies Laboratory on St. Croix attribute the unusual abundance of Diadema to destruction of control species by overfishing for food and sport and to harvesting of helmet snails for souvenirs (Ogden and others, 1973; Ogden, pers. comm., 1974). Thus the Diadema are locally responsible for overgrazing of both bottom vegetation and of corals. Significant, although not irreversible, damage can occur without the massive capital development seen in the peninsula of Florida, but only by a demand for food and trophies too intensive for the size and productivity of the community.

Are these of no matter, because they are isolated occurrences in the abundance and breadth of the Caribbean, and need concern only the local owners and the transient users? Not so at all. Herein is described an example of rapid and still-growing destruction that results neither from gargantuan Yankee-style development, nor from excessive harvesting of animals from the top of the food pyramid. It results indirectly from the best of all possible human motives - a healthful public water supply. This model likely already occurs in many places in the Caribbean, and is certain to spread with the spread of wealth. Governments should be cognizant of the results of development, and scientists interested in coralgal reefs will have to

carry the word.

#### THE SETTING

The Caribbean coast of Venezuela has rather localized coralgal reefs, because of the hydrography and the substrate, and in the western part because of abundant turbid stream input. The conspicuous reefs, still largely unspoiled, are on her offshore islands. A small cluster of coralgal fringing reefs and keys lies off Chichiriviche (Fig. 1).

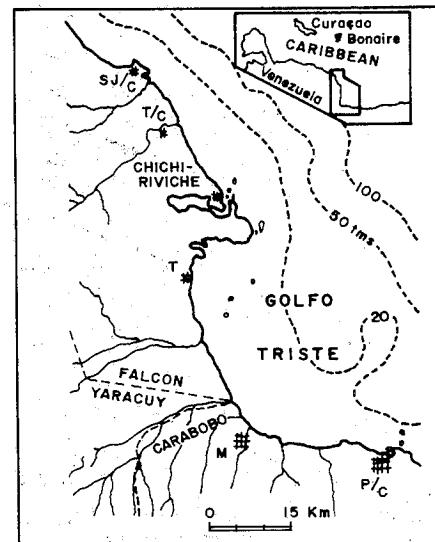


Figure 1 Index map. Islands of Curaçao and Bonaire shown in inset.

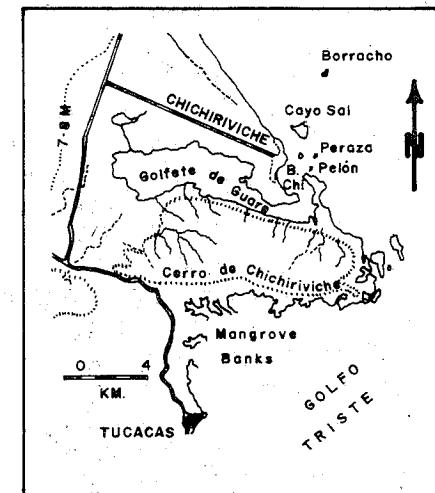


Figure 2 Index map of Chichiriviche area.

The fringing reefs and the five coralgal keys off Chichiriviche were studied by Weiss and others (in press), and the bathymetry of the area has been revised and refined (Weiss, 1973). The development of fringing reefs and some keys, here and southward toward Tucacas (Fig. 2), is largely a consequence of the interruption of the turbid north-westward longshore drift by the Cerro de Chichiriviche (Fig. 2). The close juxtaposition off Chichiriviche of three primary sources of sediment -- the coralgal community, the quartzose alluvium of the coast, and the mollusc-Halimeda sediment of the Golfete de Guare -- has developed a number of sedimentary facies, fully described in Weiss and others (in press). During the field work for that report, in 1972, a number of coralgal masses were mapped (Fig. 3). Some of those closer to land showed clear records of recent damage (Fig. 4).

#### NATURE OF THE DAMAGE

The patch reef closest to the town of Chichiriviche, here called the "city reef", (Figs. 2, 4) has suffered the most. It is a dingy mass of mostly dead coral, generously coated with fat, soft floccules of sediment, covered by turbid water that is discouraging to swimmers. Local inhabitants

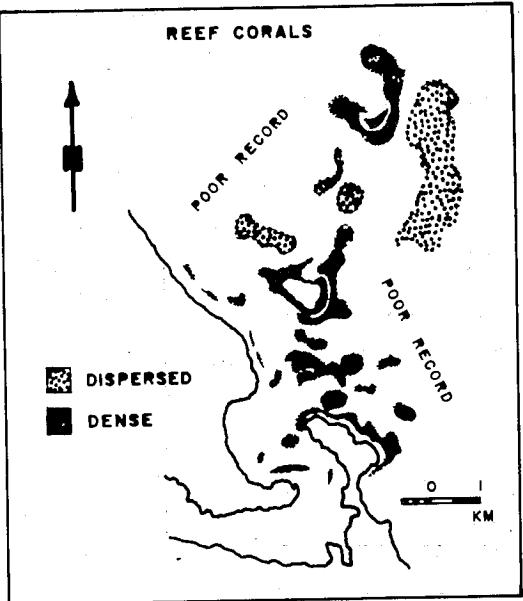


Figure 3. Reef corals of the Chichiriviche area, including the 5 keys, fringing and patch reefs. Areas of dense coralgal development are distinguished from those of scattered head-forming species, at 10-25 m depth.

assured us that as recently as the late 1950's this was a bright, healthy, growing reef with a normal complement of lobsters and reef fish. It was this way also in 1963 (X. Picard, personal communication). That the reef is being suffocated is evident from the fact that the dead coral branches are still in growth position, and some are only partly killed. A rim of dead Acropora palmata about 20 m wide at the top borders the east side of the reef. Its branches are covered with soft algae, flocs of sediment and bryozoa. The reef edge is about 0.5 m deep and the interior is a shallow depression about 1 m deep. The reef front is formed of scattered heads of Siderastrea, Montastrea, and Diploria down to the muddy sand halo 2.7 m deep. Each of these heads is dead above 1.7 m depth. A few small branches of A. palmata are living among the live parts of the massive colonies, but the older parts of each branch are dead. A. cervicornis, both living and dead, is conspicuous on the lower face of the northeast quadrant of this reef. The reef flat carries a few dead A. palmata, but is mostly a very muddy skeletal sand. Some Thalassia occurs; Halimeda opuntia grows on dead coral branches, but is mostly dead and choked with the flocs of sediment; Penicilllus is rather common near the middle of the flat, and some grows on the dead coral branches. Large, presumably old, individuals of Udotea are sparsely scattered on the flat, and are also draped with flocs. Although a few gorgonians and acyonarians persist on the outer face of the reef, fish are uncommon, and the whole presents a rather dismal, dingy scene.

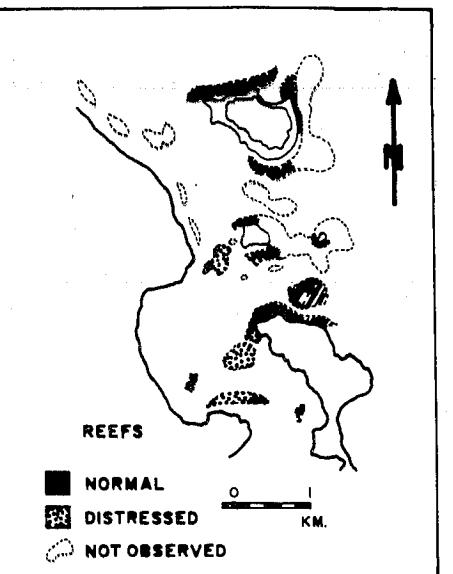


Figure 4. Conditions of selected nearshore reefs. The patch reef just off the easternmost point of town is the "city reef".

The reef fringing the point of land across the bay to the southeast (Figs. 2, 4) shows normal vigor and coral zonation in those parts washed by littoral drift from the open sea, but its western end is impoverished. This has the form of partly dead A. palmata and dead branches in place, replaced westward by great thickets of dead, bored, crusted, and weed-draped A. cervicornis and Millepora. It seems reasonable that the surf-loving species would give way to others westward along this reef, for the agitation of the water diminishes this way. So much dead material still standing in place appears abnormal to us, however. The lower face of the reef is occupied by Siderastrea and Diploria in heads of 1 - 1.5 m in depths of 2 to 4 m. The Diploria heads are alive only above 2 m depth, either as small heads atop larger dead ones or as living tops of larger heads. Alcyonarians, gorgonians and sponges are common at depths mostly more than 4 m. The reef flat shows similar differences between the parts facing the sea and the impoverished western end. The "normal" part of the flat carries Porites, some Goniolithon, Halimeda incrassata and H. opuntia, and some Udotea. Penicilllus is absent from most of this area, but is very abundant in the northwest sector. Small specimens are only 5-10 m apart over many square meters of the Porites and Goniolithon zones there, and numerous larger ones grow on the dead and partly dead A. palmata.

The four reefs lying in Bahia Chichiriviche and the mouth of the Golfe de Guare (Figs. 2, 4) are quite different from the "normal" reef communities that front the open sea, as might be expected. Acropora is scarce to absent, Montastrea and Diploria are diminished in numbers and size, and Siderastrea and Millepora are more conspicuous. The Golfe carries virtually no permanent current, and the tides of the area are of the order of 25 cm. Thus it is a slack-water tidal basin with limited circulation and slightly elevated salinity. We expect the coral reefs here to be marginal because of this change of environment, but the fact many heads are partly dead suggests they may also have suffered some polluting effects.

The western parts of the reef that nearly encloses Cayo Los Muertos (Figs. 2, 4) also show some damage. Acropora palmata with branches of 0.5 - 1.5 m are dead in growth position. On the southern limb of this reef the small- and medium-sized coral heads on the flat behind the reef front are mostly dead and crusted with calcareous algae.

#### CAUSES OF THE DAMAGE

The direct causes of the damage to these reefs are several kinds of disturbance by man, of which the most deleterious seems to be organic pollution of run-off and ground-water that reaches the sea. Such pollution is in the form of mostly household wastes put into either outhouses or into septic tanks. The soluble nutrients have encouraged the microbiota, such that they and organic and organosedimentary floccules have proliferated; the frame-builders of the reef community cannot tolerate current levels of such turbidity, and the community is being destroyed. Before considering the history of such development we must consider the geologic setting that exacerbates the problem.

Chichiriviche itself is built on the edge of a quartzose alluvial plain of older stages of the Rio Tocuyo. Much of this alluvial mass has been

modified near the shore by coastal processes, such that low beach scrolls and ridges typify the 200- to 400-meter-wide belt immediately adjacent to the coast. This means that the permeable alluvial materials are even better sorted near the sea, where they are prevailingly fine sand and silty sand. This entire area also has elevations of less than 2 m above sea level, and much of that is less than 1 m. Together these two facts provide that whatever waste is put on or into the land infiltrates quickly, and moves laterally toward the sea quickly. It passes seaward along the shortest possible inclined path, *i.e.*, through the minimum volume of soil and alluvium that might be expected to purify the effluent. Some surface and ground-water waste, it is true, moves westward from the village to low, almost littoral, mudflats bordering the central part of the Gofete de Guare (Fig. 2). There is little sanitary advantage to this route, however.

The impact on the four inhabited keys (all by Cayo Borracho, Fig. 2) is even more direct. Habitations are all at levels of less than 1 m above sea level, and built on skeletal carbonate sand that has very high permeability. Insofar as we have been able to determine, these habitations are served by outhouses, although probably the hydraulic difference between an outhouse and a septic tank in these shallow masses of permeable sand is more academic than effective.

Village of Chichiriviche. - This remained a tiny fishing village through World War II (Fig. 5), with only a foot trail to the nearest town several kilometers away. Household water was supplied by a well (Fig. 5) and doubt-

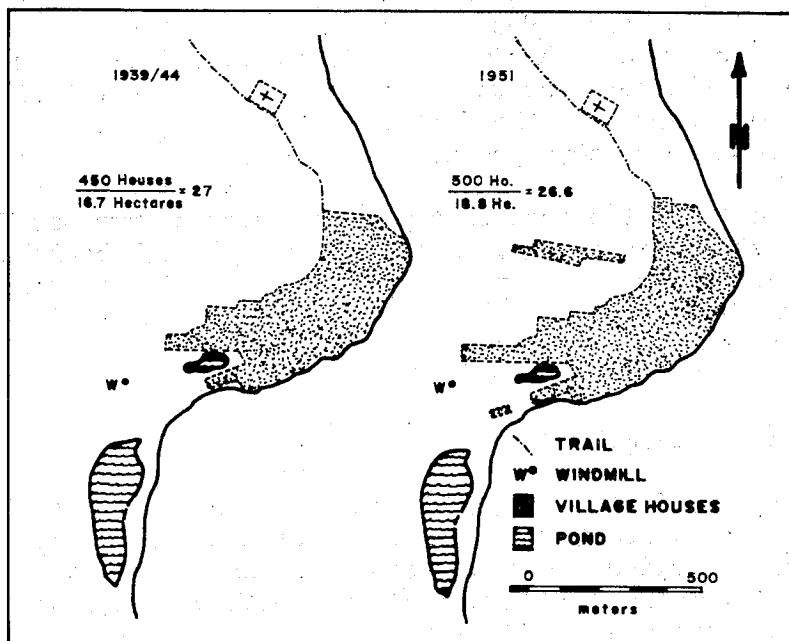


Figure 5. Development of Chichiriviche: 1939/44 and 1951.

less also by the catchment of rain. The only industrial development was a petroleum pipeline (Fig. 6), installed much earlier and abandoned in 1943/44. It led from the old Mene de Acosta oilfield to a dock south of the village. No damage to reefs is known from those years.

Several dramatic changes occurred sometime between 1951 and 1964 (Fig. 5, 6). These figures were prepared from aerial photos taken in those years, and no photos exist for any of the intervening years. In order of decreasing apparent significance, these changes were: 1) the substitution of pipeline from the interior and a water tank for the well and the rain (1963), 2) the construction of a portland cement plant and dock (1957), 3) the completion of a highway into Chichiriviche from the coastal trunk highway. Thus was Chichiriviche opened up to the world and development. A small pond that appeared on the low flat behind the beach ridge, between the water tank and the cemetery (Fig. 6), was likely the result of increased use and discard

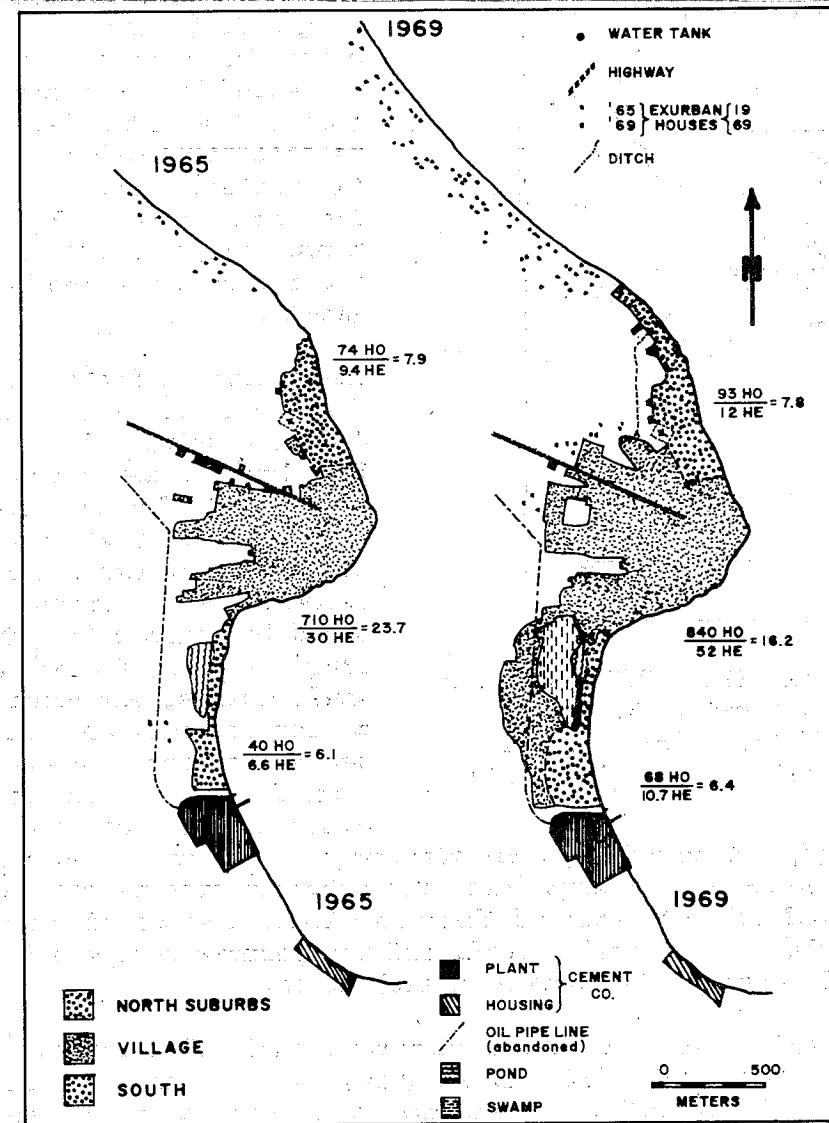


Figure 6. Development of Chichiriviche and suburbs: 1965 and 1969. Total houses, respectively, are 843 and 1070; we estimated 1155 in 1972.

of water in the village.

A number of changes of the shoreline occurred also (Fig. 7). Construction just north of the eastern extreme of the village has created a projection difficult to maintain and destructive erosion just to the north of it.

The prevailing longshore drift there is to the northwest; in Bahia Chichiriviche it sweeps counterclockwise along the mainland shore. Some area has been reclaimed from the sea in the bight in the northwest corner of the bay, at the south edge of the old village (Figs. 5, 7); in 1972 and 1973 this required constant refilling and grading to avoid reestablishment of the old shore. The changes made in the west side of the bay for the cement plant (Figs. 5, 7) have persisted because they were more massive and protected by the docks and a groin. The net effect has been to concentrate shore erosion on the western shore, just north of the cement plant. Hotels along there have a hard time maintaining a road and a beach for their guests.

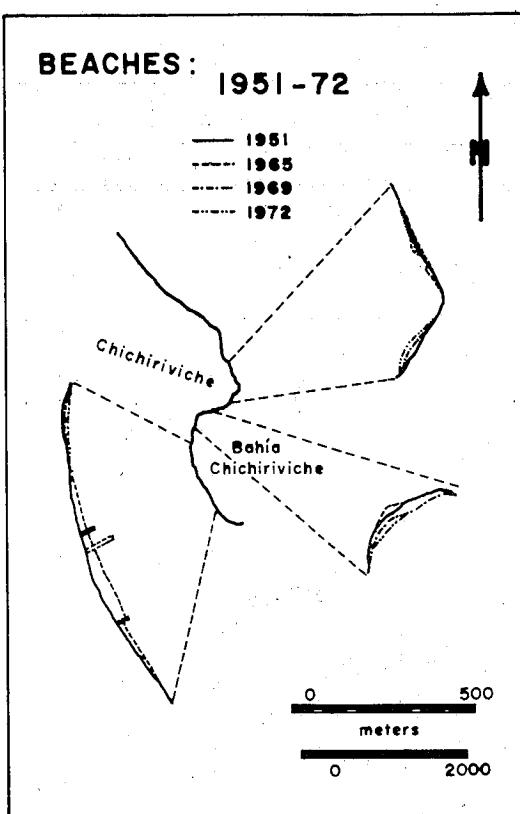


Figure 7. Beaches: 1951-1972. Shows recorded changes of configuration at a large scale, and their locations on the mainland beach at a smaller scale.

widely scattered, but owned and used similarly. The exurban houses typically have septic systems, and doubtless many suburban ones do too. On favorable weekends and holidays each of these may house a dozen or more persons. Together with the several small hotels and the permanent population, Chichiriviche may hold nearly 6000 people at such times.

Figures 5 and 6 show that the concentration of polluting sources has existed close to the nearby "city reef" (Fig. 4) throughout the time span of our information. Irreversible damage, however, seems only to have begun about the time that the population increased sharply, that the road brought numerous transients to town and that a major improvement and increase in water supply made possible the serving of large numbers of people. We believe that a change probably also occurred in water-use habits, such that significantly larger amounts were put down the drains. The public water supply was completed in November, 1963.

Development continues but less rapidly. In 1972 we estimated about 85 more houses in the area, some still under construction (Table I). They are

TABLE I

	Year	Area (H)	Houses	Houses/Hectare	Houses/Acre
CHICHIRIVICHE (excl. suburbs)	1951	18.8	500	26.6	10.8
	1965	30	710	23.7	9.6
	1969	52	840	16.2	6.6
	1972	52	905	17.4	7.1

distributed as follows (Fig. 6): 20 in the exurban area north of town; 45 in the western and southwestern quadrants of the older part of the village, near the highway access; 20 along the road built in the southwest part of the town on the old pipeline grade. The two latter groups are for permanent residents. Construction had exceeded water-supply capacity, and the water to outlying areas was cut off part of each day.

Cayo Los Muertos. - This tiny coralal key exhibits a most alarming rate and concentration of development (Fig. 8). Like the many other Venezuelan coastal islands, it belongs to the Navy. While access to and services

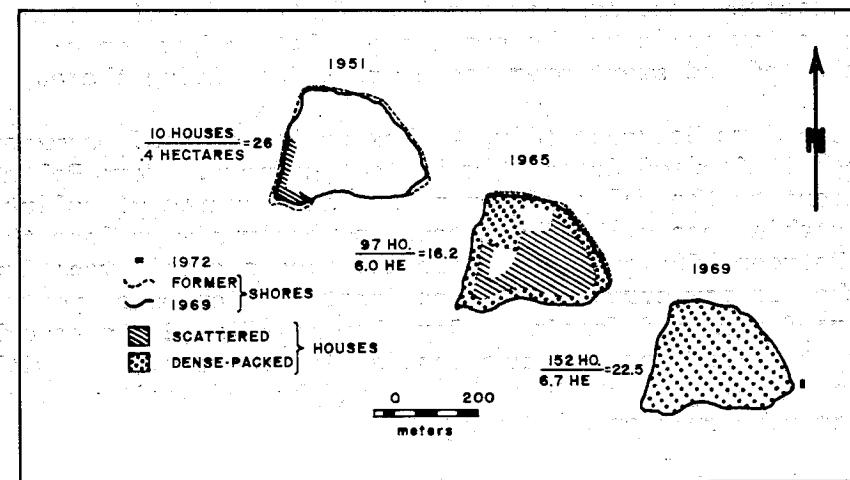


Figure 8. Development of Cayo Los Muertos:  
1951-1972.

in Chichiriviche remained primitive, so did the islands. With the rapid development of marine recreation and a seashore playground, wealthier and more influential persons got leases from the Navy and built island homes. The earliest record of structures on Cayo Los Muertos is the 1951 air photos; 1939/44 maps and photos show none. The explosive increase of the last 15 years shows clearly in Figure 8. The packing is much more dense than in the suburbs of Chichiriviche, and many of the houses have more than one story. The island was jammed in 1969, but one stilt house had appeared by 1972 (Fig. 8; Table II).

TABLE II

	Year	Area (H)	Houses	Houses/Hectare	Houses/Acre
CAYO LOS MUERTOS	1951	0.4	10	26	10.5
	1965	6	97	16.2	6.6
	1969-72	6.7	152	22.5	9.1

Rather few houses are permanently occupied, except by caretakers, but the island holds several hundred vacationers and renters on weekends and special holidays. The intermittent occupancy and the exposure to the open sea (Figs. 2, 3) have prevented pollution damage to the reefs except on the leeward prongs. Doubtless some effect has been had on the destroyed "city reef" close to town, however.

Damage to the beaches has resulted from cutting of the fringing mangrove thicket and construction of walls and foundations at the water's edge. This has led to loss of beach material and reduction of the size of the island (Fig. 8); the sandy southwest point loosened and slumped into the sea about 1955, carrying away several houses. These problems are no more than the owners might have expected, and are not really a factor of reef pollution. Even so, it cannot be favorable to the small reef flat to have once-stabilized sand released and swept over the communities living there.

Other islands. - Cayo Borracho (Fig. 2) has so far escaped permanent structures, although it is used frequently by tent campers. Cayo Pelón (Fig. 2) is a monument to the folly of man more than a source of pollution. The islet is an unstable heap of Halimeda sand, probably always less than a hectare in area. Between 1965 and 1969 there appeared a single vacation residence and yard that is now surrounded by at least two layers of posts and a great deal of barbed wire and fencing. Cayo Peraza (Fig. 2) is somewhat larger and accommodates its 3 or 4 summer residences adequately and without danger of pollution. The residents have broken and buried healthy A. palmata however, during construction of their dock.

Cayo Sal (Fig. 9) is the site of considerable development, because of

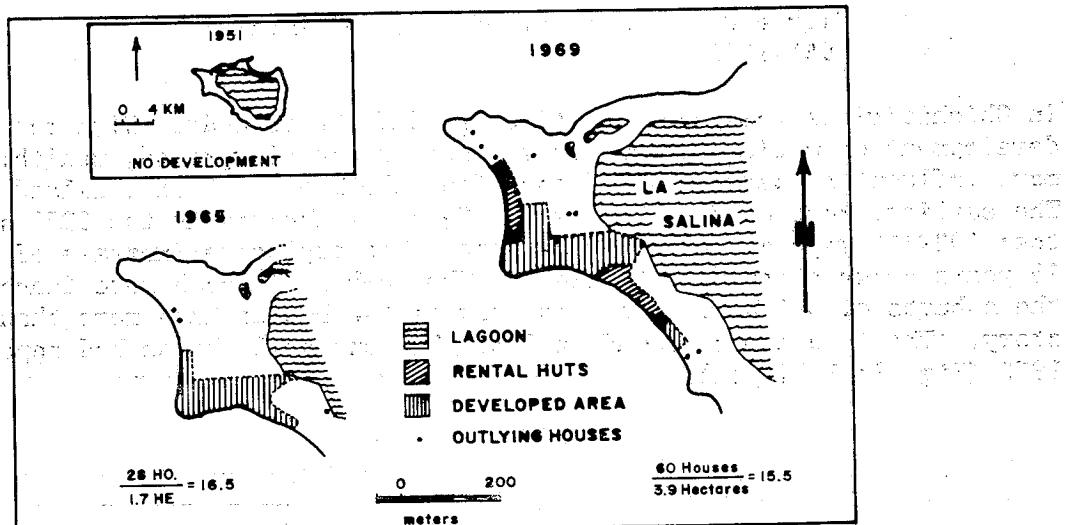


Figure 9. Development of Cayo Sal: 1951-1969. The small-scale inset shows the whole island; the larger scale maps show only the developed western shore.

its size and proximity to town. No serious problem of marine pollution has yet developed, although the beaches, shrubbery and the shores of the saline lagoon are loaded with trash. The reasons are that most of the habitations are used only by vacationers and the community is on the lee side of the island, at the upper edge of the skeletal sand apron in the lee of the atoll. Only a small group of men, engaged in fishing and caretaking, live on the island regularly. In 1972 we saw a very few more houses than are mapped for 1969 (Fig. 9), but a few expensive vacation houses were scattered southeast along the leeward beach. In 1973 still another 8 had been built on the shore of the lagoon, and even 2 on the narrow sand ridge at the northeast of the island (Fig. 9, inset) (X. Picard, personal communication). Clearly, the trends are unfavorable to the atoll.

Bahía Chichiriviche. - The pollution-induced damage to patch reefs in the bay is more difficult to demonstrate than that on the "city reef". Each of the four reefs (Fig. 4) is in waters that are intermediate between the normal, clear marine waters and the quiet, slightly hyper saline and more turbid waters of the Golfete de Guare. We still believe the bulk of dead and partly dead coral colonies argues for some destructive factors added to the marginal condition of these slack waters.

The prevailing wave paths approaching this coast are aligned to the west or slightly north of west. Consequently, the littoral drift is toward the northwest, unless modified by the shape of the coast. The opening of the bay points north, away from the direct path of the waves, and off it are three small coral keys to dampen the thrust. Nonetheless, a counterclockwise circulation seems to persist in Bahía Chichiriviche. It was observed in operation, and shows in the alignment of wave fronts in air photos. To judge from wave heights, it is strongest in the northwest part of the bay, and diminishes southward and eastward as the water eddies slowly. Because of this sluggish circulation dispersal of the organic pollution of the town and from Cayo Los Muertos must be slow.

Conditions in the bay are also affected by the cement plant, at least in the short run, and it has been in operation since 1957. Its kiln is cleaned periodically and the artificial mineral materials flushed into the bay; the yellowish fines color the surface waters for hours. As with most heavy industries, all manner of trash and discards, of many sizes, are abandoned on the shore or dumped into the bay. Ships in port to pick up cement contribute more refuse. Much of this is probably not poisonous to coralgae communities, but some of it is particulate and contributes to unnaturally high turbidity. In particular, large amounts of organic material lie on the nearshore bottom for some distance either side of the cement plant (Weiss and others, in press). Sediment samples dredged in the western part of the bay, at depths of 4 - 7 m, contain 40-60% of crumbs of water-logged wood, wood macerals, and some clumps of apparently asphaltic material. Our dredge hauls were planned to elucidate the geology, not the pollution, so that we have only a few samples of this sort. We believe they indicate a probably more widespread condition deleterious to the patch reefs in Bahía Chichiriviche. The circulation also carries any deleterious agents to the damaged western end of the fringing reef, where it borders the east side of the bay (Fig. 4).

### S U M M A R Y

We have seen how the reasonable and progressive move of furnishing a good public water supply to a remote community has boomeranged into severe pollution damage of some of the unusual geologic features that make the town attractive and economically viable. Planners failed to consider closing the cycle of water supply/use/degrading of the water/and restoration of the water, i.e., sewage treatment. The problems produced have been exacerbated by inattention to proper zoning and consequent locally very high density of occupation, particularly on the offshore islands. Surely the government of Venezuela will have to act to remedy the basic deficiencies of this system, and hopefully also some of the derivative problems; if it does not, this area is doomed as a national recreation site and possibly even as suitable habitation.

The area of mangrove banks and many inlets between Tucacas and Cerro Chichiriviche (Fig. 2) is another site of similar careless and overintensive development. A government bureau concerned with recreation development issued a plan in the early 1970's to build marinas, a luxury hotel and cottages, etc. in this area, without consideration of the basic question of whether the environment can stand the stress (construction has even begun). Recent history at Chichiriviche suggests that it cannot.

### E P I L O G U E

During final preparation of this report an outbreak of infectious hepatitis occurred among a number of school-and college-age people in Venezuela. It was traced to contaminated oysters from the mangrove thickets of the Tucacas area (Fig. 2), a favorite haunt for the young people. About 1000 houses and huts in this area, built on poles over the shallow waters, have served these guests for years. Sanitary facilities are lacking or insufficient, and the infected oysters have been the result.

In quick succession, during May, 1974, the government closed the stilt-house area and ordered them dismantled, formed a commission to study the scientific and public health factors of the situation, and designated the coastal belt and offshore islands, from Tucacas north to the latitude of Caño Borracho (Fig. 2), a national park. The administration for parks has placed a moratorium on further building until the entire area can be evaluated and zoned; it has also threatened squatters on government land with removal.

Perhaps the most important step has been taken -- the problem has been recognized. Provisional remedies have begun. We hope that the government will follow through with the long-run policies necessary to redress the damages to the marine environment. We also hope that this example will help people in other parts of the Caribbean to foresee and avoid similar difficulties.

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