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POST-HURRICANE CHANGES ON THE BRITISH HONDURAS REEFS AND CAYS: RE-SURVEY OF 1965

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INTRODUCTION

On 30-31 October 1961, Hurricane Hattie crossed the coastal coral reef area of British Honduras, shortly after an extensive survey of the geomorphology of the reefs and reef islands, carried out during 1959-1961 (Stoddart 1962, hereafter cited as ARB 87). Early in 1962 the reef area was re-surveyed, and re-photographed from the air, and many of the islands were re-mapped by ground survey. This re-survey formed the basis of a detailed report on the immediate effects of catastrophic storms on coral reefs and islands (Stoddart 1963, hereafter cited as ARB 95). With Moorhouse's observations at Low Isles, Great Barrier Reef, the work of the Pacific Science Board expedition to Jaluit Atoll, Marshall Islands (Blumenstock, editor, 1961), and the later work of Sauer (1962) and McIntire and Sauer (1965) in Mauritius, this report formed the basis for an understanding of the effects of infrequent events of considerable magnitude on the coral island ecosystem.

It is necessary, however, not only to study immediate effects of such storms, but also to evaluate their long-term implications. How long does it take a coral reef to regain its pre-hurricane state? How permanent are changes in reef and island morphology caused by exceptional storms? What is the sequence of vegetation development or recovery on storm-damaged islands? Do islands destroyed by the storm rapidly re-form? Only at Low Isles, Great Barrier Reef, do we have observations over several decades beraing on these problems (T. A. Stephenson and others 1936, Moorehouse 1936, W. Stephenson and others 1958, Fairbridge and Teichert 1948), but the storm effects there have been comparatively minor. The only study of the long-term effects of a major storm has been at Jaluit Atoll, where the effects of Typhoon Ophelia, first studied in 1958, were re-assessed three years later (Blumenstock and others 1961). Interest in these problems, and the need to add data from the Caribbean to compare with those from Jaluit, led to a further expedition to the British Honduras reefs in March and April 1965. This expedition has been only briefly reported (Stoddart 1965), and the present paper presents the main conclusions in greater detail, and documents the post-hurricane changes on the individual islands studied.

No attempt is made in this paper to draw general conclusions on the long-term significance of catastrophic storms on reefs: re-surveys of the British Honduras coast must continue until equilibrium conditions are again established before this will be possible. The British Honduras

data have been compared with those from other areas and some preliminary conclusions on the role of major storms have been drawn in a separate paper (Stoddart 1969).

Hurricane Hattie crossed the British Honduras coast from the east on the night of 30-31 October 1961. Easterly and northerly winds to the north of the storm track and south and southwest winds to the south gusted to 200 m.p.h., and a storm surge raised sea level up to 15 feet above normal levels within a zone 20-40 miles wide north and south of the storm track, especially on the barrier reef. The track and the sequence of events associated with the passage of the hurricane have been reconstructed in some detail (ARB 95, 7-20). Damage to both reefs and cays resulting from the abnormal wind and sea conditions during the storm was distinctively zoned both north and south of the storm track, as described in detail in ARB 95 and summarized in Figure 1. The present paper should be read in conjunction with this earlier work: no attempt is made here to summarize earlier data, but only to present the new data gained in 1965. The report deals first with reefs; then with changes on the cays of the barrier reef, of Turneffe, and of Lighthouse Reef, respectively; and finally summarizes the morphologic and vegetational changes on the cays between 1961 and 1965.

The 1965 investigation was made possible by generous financial assistance from Cambridge Travelling Expenses Fund, from the Royal Geographical Society, and from the Cambridge Philosophical Society. I thank these bodies for their aid, and also Mr. and Mrs. N. B. Stalker, of Belize, for their great kindness and hospitality, and Miss Evelyn L. Pruitt, Head, Geography Branch, Office of Naval Research, for transatlantic transportation. Dr. F. R. Fosberg and Dr. M.-H. Sachet again determined my plant collections, and helped in many other ways. I thank also Philip and Ronnie Young who ably took me from cay to cay in the Sunshine and the Ramrod. Sir Peter Stallard, then Governor, and the Ministry of Natural Resources, Belize, showed much interest in this project.

RECOVERY OF CORAL REEFS

General Survey

Damage to reefs caused by Hurricane Hattie was concentrated on the barrier reef between English Cay and Rendezvous Cay, where almost all living corals were destroyed. Damage was also heavy northwards to at least St. George's Cay and south to Cay Glory, and also on the eastern side of Turneffe. Moderate damage was noted on the barrier reef from Cay Glory to Curlew Cay. In the area of heavy damage almost all trace of reef-slope groove-spur systems disappeared, leaving a bare slope; whereas in the zone of moderate damage remnants of spurs survived the storm, though flourishing coral colonies had disappeared (ARB 95, 21-29, Fig. 14).

In 1965 reefs were observed from the air along the barrier reef from St. George's Cay to Curlew Cay, a distance of 55 miles, and along the east side of Turneffe. Only a brief observation of the reefs near Half Moon Cay on Lighthouse Reef was possible.

No living coral could be seen on Gallow's Point Reef, formerly the most northerly flourishing linear reef of the barrier reef system. The sea was exceptionally clear and calm, and it was possible to see a vertical cliff-line at the foot of the gently sloping reef face, itself now devoid of corals and with no groove-spur development. At Sergeant's Cay there was some living coral on the south side of the reef patch, but little or none at Paunch, Goff's and English Cays. The numerous patches between English and Rendezvous Cays, once thickly coated with orange Acropora, were bare, with only occasional scattered patches of coral. Between Rendezvous and Cay Glory no growing coral was seen on the barrier, and no trace of groove-spur formation. Groove-spur is first seen immediately south of Cay Glory, and living coral is found on the spurs where the barrier turns southwestwards south of Cay Glory. Most of the spurs are fragmentary and living coral is absent or rare as far south as Tobacco Cay. Living coral approaching pre-hurricane luxuriance is seen on the shallower part of spurs at South Water Cay and Carrie Bow Cay, though the deeper spurs are bare. Rich coral growth is seen at Curlew Cay and southwards. In this area, south of the storm track, dominant storm waves were from the south and southeast, from the lagoon rather than the open sea; and at both Carrie Bow and Curlew Cays the southern sides of the reef patches are bare of corals.

On the east side of Turneffe, conditions in 1965 were similar to those on the barrier reef. Living corals seem almost non-existent, and although traces of reef-face lineation can be seen north of Soldier Cay there was no sign of growing corals.

These data, admittedly incomplete, suggest the following zones of reef damage and recovery:

(1) Total destruction of living corals and absence of regeneration: extending at least 15 miles north of the storm track and 12 miles south; this includes the whole of Turneffe, except for areas of local protection.

(2) Survival of traces of reef-front lineation, but death of corals and almost no regeneration: extending from 12 to 20 miles south of the hurricane track. There are no comparable data to the north of the storm track, where pre-hurricane reef growth was feeble.

(3) Reef-lineation more or less intact, but patchy survival of corals, passing into rich coral growth at a distance of 25 miles south of the storm track.

(4) Damage minor or rapidly repaired: at distances greater than 25 miles from the storm track.

This pattern of zonation is similar to that described immediately after Hurricane Hattie, and suggests that little reef recovery had taken place by 1965. Underwater observations to confirm this conclusion were made at Sergeant's Cay and Rendezvous Cay reefs.

Sergeant's Cay Reef

Sergeant's Cay stands on a small patch reef on the edge of the coastal shelf. Damage in 1961 was considerably less than on some of the patch reefs to the south, closer to the storm track, and Montastrea annularis, Siderastrea siderea and Porites astreoides survived the storm. Acropora palmata survived in places, though much broken, but A. cervicornis disappeared. Agaricia and finger Porites were largely destroyed (ARB 95, 22).

In 1965 the surface of the patch was covered with slabs and sticks of dead coral, covered with pink encrusting algae, with some Halimeda, and, on the lee side, meadows of Padina and Turbinaria. The boulders of Siderastrea and Diploria on the seaward side which survived the storm appeared healthy, though little living Montastrea was seen. New growth of corals is rather sparse. Acropora palmata forms scattered colonies up to 1 foot tall and 1-2 feet in diameter, but only a single colony of Acropora cervicornis was seen. There are many small colonies of Porites astreoides a few inches in diameter, small clumps of Agaricia, and larger patches of Millepora. Nevertheless the areas of living coral are sparse, and separated by wide areas of rubble and algae. Most of the new corals are minor reef-builders, with the exception of A. palmata. No larger sponges were seen, and hardly any Gorgonians, in contrast to their abundance before the storm.

Rendezvous Reef

Rendezvous Reef was studied in detail before Hurricane Hattie, and again afterwards (ARB 95, 23-25, Fig. 15), and it was possible to describe the hurricane damage in some detail using underwater observations and a sequence of low-altitude color air photographs. The air photograph cover was repeated, with underwater observation, in 1965. Immediate post-hurricane changes were summarized in 1962 as follows: "Montastrea annularis has survived all round the reef patch with moderate success, together with Millepora, which may, at least in part, have grown since the storm. More massive specimens of A. palmata have also survived in places. On the surface of the patch, Siderastrea radians can still be found in the turtle grass, but not Cladocora or Manicina. The deeper slopes round the whole patch seem to be bare. . . . As rough estimates of the amount of damage, the total reef damage may be placed at 75-80 per cent; destruction of A. cervicornis 100 per cent; A. palmata 80 per cent; and M. annularis 50 per cent. The extensive rubble banks along the eastern reef crest are now thickly coated with purple algae." (ARB 95, 25).

Comparison of the 1962 and 1965 air photographs shows no major changes in the areas of growing coral. Montastrea annularis has survived on the southwest, east and north sides of the reef, together with a few large Acropora palmata on the east and northeast sides. Some of the

Montastrea colonies are partly dead, some are overturned but still alive, but none seems vigorous. No Acropora cervicornis, once abundant, was seen except on the reef slope at the north point. Small new colonies of Agaricia, Millepora, and Porites astreoides were seen, together with colonies of such unimportant species as Manicina aerolata, Eusmilia fastigiata and Mycetophyllia lamarckana. Sponges and Gorgonians are fairly numerous. The carpet of dead coral rubble on the reef crest and flat is thickly coated with algae, chiefly Padina, and Thalassia is growing prolifically on the surface of the patch. The area south of the cay, and the northwest side of the reef, both stripped of corals by the storm, are still bare. The only reef-building corals found in 1965 were those which survived the storm; all new growth has been of non-frame-building forms.

Comment

The slow rate of reef recovery requires explanation, in view of the known rapidity of growth of coral colonies, especially of branching forms such as Acropora cervicornis. Following the 1950 cyclone at Low Isles, Great Barrier Reef, Stephenson and others (1958, 304) suggested that the large quantity of mobile debris produced by the storm would inhibit coral colonization and thus delay reef growth. They also suggested that a more severe storm might sweep debris off reefs completely, and that as a result recovery could then be more rapid. In addition, there may be active competition for available substrates between corals and more rapidly growing algae, particularly Padina. It is also possible that increased water turbidity may inhibit coral colonization; and, finally, there are no data on how long a species such as A. cervicornis, which suffered major damage, takes to spread from a "reservoir" such as that of the southern barrier reef to sites 50-100 miles away.

It is thus not possible to predict how long reef regeneration may take in the badly damaged areas. Stephenson and others' estimate (1958, 261) of 10-20 years in the case of Low Isles is probably too low in the British Honduras case. Applying alternative reasoning, the Rendezvous Cay reef, which was flourishing when studied in 1959-1960, must have been severely damaged by the major hurricane of 1931, suggesting a recovery period of perhaps 20-25 years. Continued observation of reef recovery is clearly needed before conclusions can be drawn.

CAYS OF THE BARRIER REEF

Ambergris Cay (ARB 95, 31-33, Fig. 16)

Ambergris Cay is the largest mangrove-sand cay on the British Honduras barrier reef, consisting of a seaward sand ridge, with coconuts and littoral woodland, and a leeward area of mangroves and drying sand flats. Hurricane damage was confined to minor shoreline retreat, nearshore sand-stripping, and the felling of nearshore coconuts. Damage was greatest at San Pedro village, where the seaward sand ridge is highest and widest, and where considerable damage was caused to buildings.

During the hurricane, beach retreat further exposed low areas of cay sandstone which had been partly visible before the storm. In 1965 this rock was still very friable, though darker in color, near San Pedro itself. Farther north it had been eroded to small residual mounds, more strongly lithified, and close to Boca Bacalar Chico these mounds formed small headlands 10 yards long between sandy bays 30-50 yards across. The zone of surface sand stripping is here about 50 yards wide along the shore, and terminates inland in an irregular cliff 1-2 feet high. Above this cliff there is a 100 per cent vegetation cover, scarcely affected by the storm. Most of the coconuts survived, though a number lack crowns. Over the stripped zone the surface vegetation cover is not more than 25 per cent, dominated by Tournefortia up to one foot high (compare three feet above the cliff) and Euphorbia, with Ambrosia, Suriana, Sporobolus, Ipomoea and Flaveria linearis. Other plants seen at San Pedro include Hymenocallis, Cordia, Ipomoea tuba, Sophora and Suriana. The littoral woodland not planted with coconuts includes Borrichia arborescens, Hamelia patens, and a Solanum 10-12 feet tall. Buildings have been repaired at San Pedro, and a large new jetty built on the seaward side.

Cay Caulker (ARB 95, 33-35, Fig. 17)

Post-hurricane changes at Cay Caulker have been minor. This is a mangrove-sand cay with windward sand ridge, in places fronted by Rhizophora and half the leeward mangrove is dead, and contrasts with the greenness of the sand-area vegetation. Trees and shrubs identified on the sand area in 1965 included Cordia sebestena, Casuarina equisetifolia (in the village), Coccoloba uvifera, a species of Reynosia, Borrichia arborescens, Suriana maritima, Tournefortia gnaphalodes, Lantana involucrata, Turnera ulmifolia, and a Solanum. There has been some recovery in stripped areas of grasses, sedges, herbs and vines, which are densest south of the village where hurricane effects were minor. Those identified in 1965 were Cyperus ligularis, Fimbristylis cymosa subsp. spathacea, Chloris petraea, Eragrostis dominguensis, Wedelia trilobata, Crotalaria verrucosa, Stachytarpheta mutabilis v. maxonii, Sida acuta, Ageratum maritimum, Ageratum littorale, Philoxerus vermicularis, Euphorbia blodgettii, Euphorbia mesembrianthemifolia, Pithecellobium sp., Spermacoce suaveolens, Ernodea littoralis, and Vigna luteola. New jetties have been built on both the seaward and lagoon shores at Cay Caulker village.

Cay Chapel (ARB 95, 35-36, Fig. 17)

Cay Chapel is a largely sandy island with a narrow leeward mangrove fringe. About half the sand-area vegetation was cleared, except for some coconuts, shortly before Hurricane Hattie, in order to establish tourist facilities. The hurricane caused considerable shoreline retreat, stripping of surface sand near the seaward shore, and felling of coconuts.

On the northern, cleared, part of the island there is a zone 15-20 yards wide, along the seaward shore, of roots exposed by sand-stripping, separated by a low cliff from the main island surface. At the foot of

the stripped slope a bank of Thalassia had accumulated in 1965, followed immediately landward by a continuous zone of colonizing Tournefortia gnaphalodes 5 yards wide and 1-2 feet high. In places the Tournefortia is replaced by Suriana up to 6 feet high, Conocarpus up to 8 feet high, or low Borrichia; the cover on this lower slope is about 80 per cent. Between this shrubby zone and the eroded cliffline, the vegetation is much less dense, with large bare areas between patches of Ernodea, Cassytha, some Wedelia, and low Conocarpus. The coconut roots forming a network over the surface are rotten and can easily be pulled apart. The clifflet is lined with coconuts and dwarf Coccoloba, with an intermittent fringe of Conocarpus and some Tournefortia. The main cay surface, previously cleared, is now quite densely covered with grasses, Ernodea, and clumps of Conocarpus and Suriana. A belt of Rhizophora at the north end of the cay is dead. The creeper Merremia dissecta and the shrub Rivina humilis were collected in 1965.

Farther south, shore retreat during the hurricane revealed an exposure of cay sandstone well above high water on the seaward shore (ARB 95, 35-36). This is now separated from the sea by a belt of Tournefortia 1-2 feet high, with some Borrichia 6 feet tall, Suriana, grasses and Wedelia. The area of outcropping sandstone is scattered with seedlings of Tournefortia and Suriana. The rock is better cemented than in 1962, but still friable. The undisturbed cay vegetation inland consists of Coccoloba, coconuts, Suriana and Tournefortia, with grasses and Ageratum.

A rapid traverse was made along the west side of the cay about 100 yards from the lee shore. The vegetation cover in the former cleared area is low, with a 60 per cent cover of Ernodea, Cakile and Conocarpus. Salt efflorescence or algal binding gives a crusty surface to the silty sand.

St. George's Cay (ARB 95, 37-40, Fig. 19) Figure 3

St. George's Cay consists of an arcuate mangrove island with a sandy area at its northern end. Long cleared for use as a holiday resort, the low sandy area, only 50-100 yards wide, was cut by five deep channels when overtopped by the storm surge during Hurricane Hattie and almost all man-made structures were swept away. The northernmost point escaped extreme damage, and retained a turf of grasses, with Euphorbia, Wedelia, Hymenocallis and many coconuts. Elsewhere only patches of pre-storm ground vegetation survived, with Ageratum, Cakile, Euphorbia, Cyperus, Wedelia, and Hymenocallis, though most coconuts disappeared.

By 1965, two of the channels (B and C) had been closed by artificial fill, and the others were noticeably shallower and less sharply defined. Channel A was the deepest. The cones of submarine sand on the seaward side had altered in shape and their outlines were no longer clear, and similar deposition had taken place on the lagoon sides of D and E. Most of the mangroves are dead, except at the northern end. Ground vegetation is luxuriant except in ill-drained areas. Thus in the old cemetery, north of Channel D, there are broken Coccoloba and Conocarpus, with

Ageratum, Ipomoea, Wedelia, Stachytarpheta, Hymenocallis, Euphorbia and grasses. Farther north, outside the cemetery, the ground cover consists of Sesuvium, Ageratum, Cyperus, Batis maritima, Euphorbia and grasses. Between Channels B and C, both filled, the ground is lower and waterlogged, with Sesuvium, Batis, grasses, and even Rhizophora seedlings.

Several large houses and substantial jetties have been built since 1962, and some coconuts have been planted. Clearly it is intended to make the cay a holiday resort again, but, lacking trees, it is still an unattractive place.

Sergeant's Cay (ARB 95, 41-42, Fig. 22) Figure 4

Sergeant's Cay almost completely disappeared during Hurricane Hattie, and reformed as a smaller sandbore, which in 1962 was beginning to be colonized by plants. Four months after the storm the main colonizer on the fresh sand surface was Portulaca oleracea, in patches 1-2 feet in diameter, with small areas of Sesuvium portulacastrum and Euphorbia mesembrianthemifolia, and a single Rhizophora seedling. The 1962 island was two-fifths the area of the pre-storm cay, and lay to the west of the old island site. Aggradation and erosion of the shores was taking place, and the island was clearly not stable.

By 1965 the cay had shifted back towards its original position, though its area continued to decline, from 4500 square yards to 2600 square yards in 1962 and 2200 square yards in 1965. The vegetation had developed considerably. On a small central area, where part of the pre-storm surface can still be seen (560 square yards, or 25 per cent of the 1965 area), there is a continuous herb mat of Ipomoea (I. tuba and I. pes-caprae), Wedelia trilobata, and Euphorbia (E. mesembrianthemifolia, E. blodgettii). Both Portulaca and Sesuvium are absent. Shrubs, absent in 1962, are represented by three Conocarpus up to 10 feet tall, six Suriana maritima up to 5 feet tall, and three Tournefortia gnaphalodes less than 3 feet tall. There is a single seedling of Coccoloba uvifera 2 feet high. Both Euphorbia and Ipomoea are beginning to colonize the bare sand surrounding the vegetated area, and at the eastern end there is a conspicuous white-flowered clump of Eustoma exaltata. Other herbs collected included Cakile lanceolata, Batis maritima and Philoxerus vermicularis. In three years, therefore, the number of species on the cay increased from 4 to 13. The island is still mobile, however, and further changes can be expected.

Goff's Cay(ARB 95, 43-44, Fig. 23) Figure 5

Before the hurricane, Goff's Cay was a small coconut-covered sandy island, with a thin ground vegetation of herbs, vines and grasses. During the storm it was severely eroded, and the vegetated area reduced from 2100 to 950 square yards. By 1962 much fresh sand had accumulated around this remnant to give a total area of 2650 square yards. In 1965 slight recession of the southern shore had been balanced by considerable aggradation of new beach ridges on the north side, giving a total area of 3250 square yards, very slightly less than the pre-storm area. The

rubbly shores of 1962 are now covered with sand, and the beachrock seen in 1962 has been covered with rubble and cobbles.

The immediate post-hurricane vegetation consisted of dead coconuts, a broken Coccoloba, and patches of Portulaca oleracea, the only colonizer. By 1965 the core-area was covered with a mat of Euphorbia, Sesuvium, Ipomoea, and Ernodea littoralis. Ipomoea vines are spreading out on to the fresh sand. Eighteen coconuts planted since the storm have grown up to 3 feet tall. The number of plant species had thus increased from 1 in 1962 to 5 in 1965.

As in 1962 there is an unvegetated sandbore north of the cay, apparently migrating in position with weather changes.

English Cay (ARB 95, 44-45, Fig. 24) Figure 6

Before Hurricane Hattie, English Cay was a settled, coconut-covered island with little ground vegetation and a resident population of pilots and lighthouse keepers. In the storm the area of the cay decreased from 5750 to 3150 square yards by shore retreat on all sides. Eight out of 98 coconuts remained, together with a single broken Coccoloba and an ancient Rhizophora. By 1965 there had been little change in the morphology of the island, except for the leeward sandspit. Eighteen coconuts had been planted, and there is a patchy ground cover of Sesuvium, Euphorbia, and Portulaca oleracea. The old Rhizophora and the Coccoloba are dead; but a surviving pawpaw tree (Carica papaya) was found. With the reoccupation of the cay by people it is clear that natural regeneration of the vegetation is not taking place.

Rendezvous Cay (ARB 95, 47-49, Fig. 28) Figure 7

Like English Cay, Rendezvous before the storm was inhabited, covered with coconuts, and subject to periodic clearing of ground vegetation. Its gross morphology was largely man-induced, with a large dry-land area of dumped conch shells. The area of the cay changed little during the storm, though much surface sand was stripped and deposited along the west shore, partly burying the conch accumulations. All the coconuts disappeared, but the original root-bound surface remained partly intact. Within five months many pioneers had colonized this surface. Portulaca oleracea was most widespread, with the sedge Cyperus planifolius and grasses such as Sporobolus. Other constituents of the ground vegetation in 1962 were Sesuvium portulacastrum, Euphorbia mesembrianthemifolia, Ipomoea pes-caprae, Cakile lanceolata, Fimbristylis cymosa and Philoxerus vermicularis. Solanum lycopersicum was collected, and seedlings of Rhizophora and Tournefortia were seen. Forty young coconuts were planted at this time.

By 1965 the vegetation had changed considerably in pattern and in density. Most of the ground surface was covered with a mat of Ipomoea and Euphorbia, with smaller areas of Wedelia trilobata and Sesuvium. Cyperus, Ageratum, Cakile and Sporobolus were present in patches, but Portulaca was rare. The coconuts had grown up to 10 feet tall, with the bigger trees in the center of the island. At the northern end of the cay there were low bushes of Tournefortia and Suriana, with a lone

Casuarina rapidly being undermined by the sea. One of the broken Coccoloba still lived, together with Rhizophora seedlings. The number of species in 1962 was 12, and in 1965 not less than 16.

Active erosion was continuing in 1965, when the whole of the eastern shore had retreated 10-15 yards from its 1962 position. Many of the newly-established shrubs and coconuts are being undermined by this retreat, which is considerably reducing the width of the northern end of the island. There is a small hut on the island, intermittently occupied.

Tobacco Cay (ARB 95, 53-55, Fig. 31)

Tobacco Cay is a triangular island 300 yards long and up to 150 yards wide in the south, covered with coconuts and permanently inhabited. It was mapped in 1960 and again in 1961, when the main changes were in the size of seasonal sand ridges along the south shore and in the pattern of ground vegetation. In 1960 this was dominated by dense Stachytarpheta up to 3 feet tall, Wedelia trilobata, Hymenocallis, and Ipomoea (I. pes-caprae, I. stolonifera). Smaller and apparently more recently cleared areas had a thin cover of Euphorbia, Canavalia and Vigna luteola. Sesuvium was found around the shores. Changes between 1960 and 1961 showed that the pattern of vegetation was largely a function of repeated clearing by the inhabitants.

Hurricane winds in 1961, from the southwest, blew down many coconuts, and deposited thin carpets of fresh sand up to 15 yards wide along the south and west shores. The east shore retreated up to 14 yards. After the hurricane the surface was covered with fallen coconut trunks, especially in the south. Terminalia survived, even along the south shore. Wedelia was much less widespread in early 1962, when the dominant ground cover consisted of Ipomoea and Stachytarpheta, with some Sesuvium, Vigna luteola, Portulaca oleracea, Euphorbia and grasses.

By 1965 many of the fallen coconuts had been cleared, and other living trees seen included Coccoloba, Cordia, Terminalia, a small Carica, and Bumelia retusa. Wedelia had expanded greatly in the center of the island, except where very recently cleared; and the rest of the surface was covered with Stachytarpheta, Ipomoea, Hymenocallis and Euphorbia. The changes in distribution of these plants since 1962 were very noticeable. Ipomoea and Sesuvium are the chief beach-crest colonizers, together with small areas of Tournefortia gnaphalodes (not previously seen). The southern sandspit, slightly reduced in size, is being colonized by Sporobolus, Euphorbia, Sesuvium, Ipomoea, several Tournefortia seedlings, and a single Sophora tomentosa 2-1/2 feet tall. Other plants seen on Tobacco Cay included Canavalia, Portulaca, Cyperus, Rhizophora, Avicennia and Conocarpus.

Apart from the thinned coconut canopy and the number of broken trunks, the effects of the hurricane are no longer obvious. The fresh sand carpet had already been colonized by Ipomoea in 1962, and even where surface sand was stripped in 1961 there has been colonization by Ipomoea, Euphorbia and other plants.

South Water Cay (ARB 95, 55-57, Fig. 32)

Post-hurricane changes at South Water Cay have been small. The leeward beaches have accreted slightly, and the eastern shore has retreated. There has been slight erosion also at the south point. The northern part of the island, with a thicket of coconuts, suffered little change in 1961 apart from shore retreat. Coconuts, Thrinax and Coccoloba were thriving here in 1965, with Wedelia, Ipomoea, Batis maritima, Euphorbia, and Sesuvium. In the center of the cay, where large houses and paths flanked with Hibiscus were formerly maintained, the surface is now covered with Euphorbia, Ipomoea, Stachytarpheta, Ambrosia and Cassytha, with a few Coccoloba trees and some Hymenocallis. Along the eroding eastern shore there is some bushy Borrichia with much Cassytha, a few Tournefortia seedlings, and a ground cover of Sesuvium, Ipomoea, Euphorbia and Sporobolus. On the southern part of the island, many young coconuts were planted after the hurricane, and in 1965 some were 10-15 feet tall. Two small Casuarina survived on the lagoon shore. One or two Rhizophora are alive on the east shore but there are very few seedlings. Effects of the hurricane are no longer obvious. Though many houses were damaged in 1961, new ones have been built, including two at the north point, and a substantial building has been erected near the south end by a Belize nunnery. A new jetty has been built for this in the west bay.

Carrie Bow Cay (ARB 95, 57-58, Fig. 33)

This island, used as a private holiday resort, was covered with coconuts in 1960. Morphologic changes were slight during the storm, many coconuts still stood, and Euphorbia formed a patchy surface cover in 1962. By 1965 a number of small coconuts had been planted to replace those destroyed, and low Tournefortia bushes were growing along the northern half of the seaward shore. Ground cover included Euphorbia. Ipomoea, Sesuvium and grasses, but is clearly often modified by man.

Bugle Cay (ARB 95, 67-68, Fig. 43)

Bugle Cay is a mangrove island with a small low sandy area at its west end, cleared and planted with coconuts. This sandy area suffered considerable marginal erosion and surface sand stripping during the hurricane; many coconuts stood, but the adjacent mangrove was much broken and defoliated. Coconuts planted since the storm were 2-3 feet tall in 1965. The area between the sand ridge and the mangrove, cleared by man before the storm, is now being colonized by Sesuvium and Batis maritima. There is a small patch of Sesuvium at the northern end of the sand ridge, with Batis, Euphorbia and Cyperus, but the rest of the surface is kept artificially cleared. A substantial hurricane-proof concrete house has been built for the lighthouse keeper since the storm.

Scipio Cay (ARB 95, 66-67, Fig. 42) Figure 9

Scipio Cay is a low-lying, sandy island, covered with coconuts, with a large central Avicennia swamp. Beach ridges on the east and southeast sides are covered with Thrinax. The hurricane caused

considerable beach erosion and cliffing along the east shore, followed by the deposition of a ridge of fresh shingle up to 20 yards wide and 2 feet thick on the scoured surface, with a ridge of shingle and rubble 10 yards wide and generally less than 3 feet high forming a new shoreline. This outermost ridge in 1962 was discontinuous and also enclosed a large pool at the south point; it was unvegetated. By 1965 this fresh shingle ridge had been pushed landward and undergone minor changes in outline. Near the east point 50 yards of the outer ridge have disappeared, but farther south gaps have been infilled. The main colonizer of the bare shingle is Sesuvium, followed by Sporobolus and Euphorbia. Shrubs are represented by a single Sophora seedling. It seems likely that the ridges will continue to migrate towards the old cay shore, and thus ultimately replace the zone eroded in 1961. The wedge of perched shingle on the old cay surface is now being colonized by neighboring vegetation.

Colson Cay (ARB 95, 67, Fig. 42) Figure 10

Colson Cay is very similar to Scipio, being formed of a peripheral coconut-covered sandy area and central Avicennia marsh. Much of the southeastern shore is covered by Thrinax. As at Scipio, beach retreat and cliffing in 1961 were followed by deposition of a shingle wedge, especially on the east side, and formation of a shingle ridge offshore. The ridge itself was 2 - 2-1/2 feet high, and separated from the undercut shore by a low carpet of shingle 15-20 yards wide, by closed pools, or by open water. Part of the ridge, on the southeast shore, was eroding in 1962. Considerable changes had taken place by 1965 in the ridge morphology. The long spit at the east point had been welded to the shore, enclosing a pool 6-12 inches deep filled with algae. Southwards from the east point, where erosion was noted in 1962, the shingle shoreline has retreated 5-10 yards, and is now cliffed and still retreating. North of the east point, however, a new low ridge of fresh white shingle has been built against the grey hurricane ridge of 1961, so that there has been a general advance of the shore of about 5 yards. Sesuvium is again the main colonizer of the shingle, with some patches of Euphorbia, Sporobolus and Cassytha, and two small Tournefortia bushes. Little change was noted in the main cay vegetation; though broken Cordia sebestena trees were in flower.

CAYS OF TURNEFFE

Pelican Cay (ARB 95, 72-73, Fig. 44) Figure 11

Pelican Cay is a sandy island with a thicket of Cordia sebestena, Bursera simaruba and Thrinax, and a belt of Rhizophora to leeward. The vegetation was badly damaged during the hurricane, when much of the surface sand on the seward side of the cay was eroded (leaving remnants of cemented shingle standing above the new beach level), and fresh rubble and shingle was deposited along the margin of the vegetation thicket. The Rhizophora was completely defoliated during the storm. No morphologic changes were noted in 1965. The most striking change was the colonization of the shingle-carpet areas by Tournefortia

gnaphalodes, and to a lesser extent by Sesuvium. Much of the broken Cordia was in flower, some of it being found in the Bursera area. Ipomoea tuba was conspicuous, climbing on the broken trees and extending out over the shingle carpet. A single seedling of Sophora was seen. The osprey nest seen in 1962 still existed, and a newly hatched green turtle was seen close to the shore in 1965.

Cockroach Cay (ARB 87, 46, Fig. 25; ARB 95, 73-74, Fig. 45)

Cockroach Cay is a sandy island, densely covered with coconuts before the 1961 hurricane. During the storm all the coconuts were removed by overtopping waves, which eroded much of the surface sand. In early 1962, the surface on the seaward side was formed of bare coconut roots, and that to leeward of coarse rubble and roots. One or two Cordia survived, much broken, together with patches of the original turf cover; but immediately after the storm the only vegetation consisted of sparse Euphorbia, Cyperus and Sesuvium, and one or two Rhizophora seedlings. The seaward shore was cliffed, exposing a soft incipient sandstone at the northwest end. In 1965 morphologic changes had been minor, though the degree of cementation of the outcropping rock had increased to form a hard rock ledge 4-6 inches above low water. The densest vegetation is at the north end of the cay, with a continuous cover of Ipomoea, Canavalia and Sesuvium. Along the seaward shore there is a fringe of Tournefortia, Sophora and Suriana bushes, with Sesuvium and Ipomoea, but most of the cay surface still has but a sparse cover of Cyperus, Euphorbia, Ageratum and Canavalia. Broken Cordia stumps are in flower, especially along the lagoon shore.

On the adjacent Cay V of the Cockroach Group, the pre-hurricane vegetation of bushes was largely killed and partly blanketed by storm shingle in 1961; leeward mangrove was defoliated. In 1965 the fresh shingle was colonized only by a small patch of Sesuvium. In the vegetation thicket Tournefortia was most luxuriant, forming patches up to 4 feet high and 10 yards in diameter. Suriana, Conocarpus and Coccoloba are also present, with a ground cover of Euphorbia and Cyperus. About half of the leeward Rhizophora is alive.

Soldier Cay (ARB 87, 43-44, Fig. 21-23; ARB 95, 74-76, Fig. 46)

The coconut-covered sandy island of Soldier Cay was stripped of all vegetation by Hurricane Hattie and transformed into an eroded surface, with exposed coconut roots, flanked by a wide shingle carpet on the lee side and a narrow ridge on the seaward side. Four coconuts only survived the storm, and in 1962 there was a sparse and patchy growth of Sporobolus, Cyperus, Ageratum and Portulaca. In 1965 vegetation on the old cay surface was still sparse. Much was still bare, with patches of Ipomoea, a grass (probably Sporobolus), Cyperus and Ageratum. Along the seaward margin of the old cay, overlooking the hurricane shingle, there is a shrub zone dominated by Tournefortia, together with Suriana less than 3 feet high, and a ground mat of Sesuvium spreading out onto the shingle. Vegetation is more extensive on the leeward shingle area, with a 50 per cent cover of Sesuvium, Euphorbia, Cyperus, Ipomoea and Wedelia, two clumps of Tournefortia and two of

Suriana, and a single Sophora in flower, 3 feet tall. There is also a small patch of very fleshy Sesuvium on the shingle bar or islet east of the cay. Conocarpus, Avicennia and Coccoloba survived on the main island from before the storm. Morphologic changes since 1962 have been limited to slight shoreline retreat around the leeward shingle area and some changes in the shape of detached shingle islets.

Little Calabash Cay (ARB 87, 44, Fig. 19; ARB 95, 76-77, Fig. 47)
Figure 12

Little Calabash Cay was formerly the center of the Turneffe copra industry, with houses, a jetty, and coconut palms. All human installations were destroyed during the hurricane, and so were all the coconuts. Considerable surface and marginal erosion reduced the size of the island, and in 1962 the surface was low-lying, with exposed roots and two brackish pools. A large fresh sandspit built up at the northeast end of the cay following the storm. In 1962 the only vegetation was a scatter of Ageratum, Wedelia, Cakile and grasses over the old land area. By 1965 minor shoreline adjustments had taken place, with some sediment accretion at the southern end. The pools had disappeared, and the surface was covered with patches of grasses and herbs. Two areas of Sesuvium, an area of grass, and a large area of Batis maritima on the site of the largest pool were distinctive. In addition there is a mixed area of Ageratum, Euphorbia and Wedelia. Shrubs are represented by two bushes of Borrichia arborescens, seedlings of Tournefortia and Suriana, and low Conocarpus. The number of species present has thus increased from not less than 4 to not less than 10 in three years. A small hut has been built on the island, and natural regeneration of the vegetation will thus not take place.

Big Calabash Cay (ARB 87, 42, Fig. 20; ARB 95, 77-78, Fig. 48)

Before the hurricane the vegetation of Big Calabash resembled that of Little Calabash, being dominated by coconuts with a ground cover of grasses and herbs, but the island was much larger and hurricane damage was therefore less intense. Though the shoreline retreated and there was some scouring and channel-cutting by overtopping water, much of the original turfed surface survived, though almost all the coconuts, and the Rhizophora seedlings between it and the adjacent small island, were swept away. In 1965 there was a 90 per cent ground cover of coarse grasses, all sterile, together with Ageratum, Batis maritima and Euphorbia. The southern end of the island has a fringe of shoreline Borrichia, some Conocarpus, and a mat of Sporobolus, and elsewhere there are some Borrichia and young newly-planted coconuts. On the seaward shore a new Rhizophora has grown to a height of 3 feet. A small house has been built on the cay by a resident fisherman.

On the adjacent island (East Cay I) there is a ground cover of Sesuvium and Euphorbia and a number of Borrichia bushes. The pre-hurricane Rhizophora is all dead. East Cay II now consists only of dead shrubs and rubble.

Deadman I (ARB 87, 37-38, Fig. 16; ARB 95, 79-80, Fig. 49)

The post-hurricane surface of Deadman I consisted of bare roots and fresh shingle, and an incipient "promenade" of cay sandstone was exposed by beach retreat on the south and east shores. A few spider-lilies (Hymenocallis) survived at the eastern end, with some Borrichia bushes, a patch of Sesuvium, and sparse Euphorbia, Ageratum and Cyperus. By 1965 the incipent promenade at the east end had disappeared through erosion, but that along the south shore was more strongly lithified. The northern ridge of hurricane shingle had been eroded slightly, but otherwise there were no morphologic changes. In the area of stripped roots, ground vegetation cover was still patchy: species present included Ageratum, Euphorbia, Sesuvium, Ernodea, Wedelia, Cyperus, and Echites umbellata. Much of the shingle was bare, except for a few small Borrichia and Tournefortia bushes and some Hymenocallis. Two coconuts are still alive, and two Thrinax; the old Avicennia at the east end still has some leaves. A single seedling of Sophora was noted.

Deadman II (ARB 87, 38, Fig. 16; ARB 95, 80, Fig. 50)

At Deadman II the hurricane killed most of the vegetation thicket and deposited a carpet of shingle over the seaward side of the cay. Beach retreat also exposed an incipient promenade. Borrichia, Hymenocallis, Ageratum, Sesuvium and Sporobolus were noted in 1962. In 1965 much of the incipient promenade had gone, particularly in the south, though the rock which remained was more strongly lithified. On the fresh shingle area there are patches of Tournefortia, Conocarpus, Borrichia, Hymenocallis, Euphorbia and Sesuvium. In the thicket area there is a 100 per cent ground cover of Ageratum and Euphorbia, with Conocarpus along the west shore, and some Thrinax 3-4 feet tall. Of four coconuts which survived the storm, one was fruiting.

Deadman IV (ARB 87, 39, Fig. 17; ARB 95, 81, Fig. 51)

Deadman IV closely resembles Deadman II in both pre- and post-hurricane characteristics. The fresh shingle had in 1965 been colonized by a belt of Tournefortia, with a single Suriana, and a ground cover of Sporobolus, Euphorbia and Ipomoea. New Thrinax had reached heights of 2-4 feet. In the thicket area there is a cover of grasses, Euphorbia and Ageratum, with some Borrichia, and small Rhizophora along the west shore. Four of nine coconuts which survived the storm were fruiting.

Deadman V (ARB 87, 39-40, Fig. 18; ARB 95, 81, Fig. 52)

After the hurricane, Deadman V consisted of a western sector of defoliated mangrove, and an eastern sector of sand formerly covered with coconuts, and in 1962 partly covered with Euphorbia and Sporobolus and partly bare. By 1965 the Euphorbia and Sporobolus had colonized much of the bare area, and several patches of Sesuvium had appeared. There are single bushes of Borrichia and Suriana. Four coconuts were still alive. Most of the mangrove is dead, but seedlings of Rhizophora are numerous in shoal water south of the cay.

CAYS OF LIGHTHOUSE REEF

Sandbore Cay (ARB 87, 56-58, Fig. 28; ARB 95, 89-91, Fig. 56) Figure 13

Sandbore Cay at the north end of Lighthouse Reef is an island of complex geometry much altered by Hurricane Hattie. Before the hurricane it consisted of three spits of unequal size extending leeward from a sandy seaward beach, which had itself been retreating westwards (lagoonward) for some decades. The island had a dense vegetation of coconuts, shrubs, herbs and grasses. During the hurricane the two northern spits were cut off from the rest of the cay by a channel 65 yards wide, and the southern spit was cut into two parts by a channel 50 yards wide. The first channel had filled with fresh sediment by early 1962, but the other remained open, the former shorelines being marked by lines of beachrock. The scoured cay surface retained only a few patches of grasses and Euphorbia at the eastern end; but on the larger northern spit coconuts, Coccoloba and Conocarpus still stood. Most of the shoreline Tournefortia and Suriana had been swept away, but the ground surface inland was patchily covered with Sporobolus, Cakile, Euphorbia and Ambrosia. Ipomoea appeared to have declined in abundance, Cenchrus to have increased. Tournefortia seedlings were noted along the northwest shore in May 1962.

Considerable changes had taken place in morphology and vegetation by 1965. The leeward sandspits had altered position; the northeast shore had continued to retreat, exposing fresh beachrock; but the main change was the growth of a sandbar across the narrow entrance to the bay between the northern and southern spits. This bar is 1 foot high and 35 yards wide, still unvegetated in its central part. The body of water thus enclosed is orange-brown in color and stagnant, with foul-smelling margins. The main part of Sandbore is thus effectively a single island with an interior pool. The gap between this main island and the relic of the southern spit is still 2-3 feet deep and kept open by vigorous water movement; the beachrock in the gap is densely covered with Diadema.

On the main island it is convenient to discuss vegetation changes in terms of (a) the southern spit and eastern end, and (b) the large northern spit. In 1962 the southern spit and east end of Sandbore had a surface of bare roots, thinly covered with rubble, and with little vegetation except for grasses and Euphorbia. It is now covered with a dense growth of Ipomoea, Euphorbia and grasses, with at the east end areas of Ambrosia and Sesuvium. There are several Tournefortia bushes up to 3 feet tall, and Sophora tomentosa 18 inches tall. The neck of sand filling the northern channel has been colonized by grasses, Ipomoea, Suriana and Cassytha, with some small Tournefortia. The density of vegetation on the northern spit varies considerably. Patches of Coccoloba and Conocarpus which survived the storm on the margins of the interior pool are now thriving. Over the rest of the area, vegetation is still sparse where sand was stripped and coconut roots were exposed, but is more luxuriant where original pre-hurricane vegetation maintained a ground cover and soil was not lost. Superficial scour channels are

still visible in the stripped areas. Most of the northern spit is covered with an assemblage of Ambrosia hispida, Ernodea littoralis, Ageratum maritimum, Euphorbia sp., and grasses (including Sporobolus). There are several Borrichia bushes, and, along the northwest shore, patches of Tournefortia up to 6 feet in diameter and 18 inches tall. The sandspit at the west end is being colonized by Ipomoea, Euphorbia, Cenchrus tribuloides, Sporobolus and Tournefortia. The remnant of the southern spit has a dense vegetation of Borrichia, Suriana, Tournefortia and Sophora, with a ground layer of Ipomoea, Wedelia, Canavalia, Ambrosia and Ernodea.

A new lighthouse has been built on the north spit to replace that destroyed in Hurricane Hattie, together with a jetty on the lee side. The light is automatic, and there is no provision for a resident keeper. The remains of the "hurricane-proof" house destroyed in 1961 still stand near the east point.

Northern Cay (ARB 87, 58-62, Fig. 29; ARB 95, 92-94, Fig. 57) Figure 14

Post-hurricane changes at Northern Cay are only considerable at the northeast point. This was cut back 120 yards by the storm, but by 1965 had built out again at least 80 yards. The surface of this new spit, together with the bare area formed by the storm, is a source of blowing sand which has accumulated at the edge of the vegetation cover, around bushes and grass tussocks, to form dunes several feet high. The bare nearshore areas are being colonized by Suriana, Tournefortia and Borrichia, with Sporobolus and Euphorbia. Along the east coast, much battered Coccoloba is still alive, and Pithecellobium is distinctive. Inland, there has been no interference with vegetation since the storm, as the cay is no longer inhabited, and there is a dense growth of shrubby vegetation, with Conocarpus up to 10 feet tall, Thrinax, Coccoloba, and some new coconuts. Ernodea littoralis is prolific on the ground.

Half Moon Cay (ARB 87, 64-77, Figs. 30-34; ARB 95, 94-98, Figs. 58-59)

At Half Moon Cay the three main vegetation types are (a) Cordia-Bursera woodland, (b) coconuts with ground vegetation, and (c) coconuts with no ground vegetation. During the hurricane the Cordia-Bursera woodland along the southeast side of the cay was much damaged, especially near the shore. To the north of this, in the area of uncleared ground vegetation, many coconuts were felled by the storm. On the eastern part of the cay, with no ground vegetation, few coconuts were felled, but a Tournefortia hedge disappeared at the east point.

Since the hurricane, fallen trunks have been cleared from the east end of the cay and young coconuts planted there and at the south point. Shrubs have colonized much of the shore at the east point and on the western half of the cay. At the eastern end there are several Tournefortia less than 1 foot high, with a littoral fringe of Wedelia, Euphorbia, Sesuvium and grasses. Tournefortia, with Sporobolus and Euphorbia, is found patchily along the southeast shore and forms a tall hedge at the south point. Along the north shore Sesuvium forms a carpet 1-2 yards wide, with some Euphorbia and grasses; immediately inland

there is a stripped zone with sparser vegetation, and then the old cay surface, with a dense growth of Hymenocallis, Wedelia, Stachytarpheta, Euphorbia, Cyperus and grasses. Near the shore there are a few Tournefortia bushes up to 3 feet tall. Sesuvium and Canavalia, with Tournefortia bushes, blanket the low ground at the east end of the island.

Along the south shore, where retreat of the Cordia-Bursera thicket was greatest, changes have been considerable. Bursera broken by the storm is generally dead, but Cordia has usually survived, even when physically badly damaged, and the frigates and boobies were nesting normally in this woodland in April 1965. The outer margin of the woodland is irregular, and after the hurricane there was a zone of fresh sand, shingle and rubble 20-30 yards wide along the whole shore. Curiously this zone in 1965 was almost bare of grasses and other ground-layer plants, except for a little Cyperus and Sporobolus and occasional Iresine diffusa with horizontal roots up to 5 feet long, but there is an approximately 50 per cent cover of Tournefortia gnaphalodes, in patches 2-3 feet high and 10 yards in diameter. This is the most luxuriant growth of pioneer Tournefortia seen on these reefs.

The damaged lighthouse was repaired in 1963, and a new hurricane-proof house erected nearby.

Long Cay (ARB 87, 77-81, Fig. 35; ARB 95, 98-99)

No morphologic changes were noted at Long Cay in 1965. On the eastern ridge no new coconuts had been planted, though there had been some natural regeneration. There is a patchy cover of Euphorbia, Wedelia, sedges, and grasses (Sporobolus virginicus, Eragrostis dominguensis), with much Ernodea littoralis. Conyza canadensis v. pusilla was collected here for the first time. Tournefortia is found occasionally along the shore, with some Suriana. There is surprisingly little Borrichia, and only occasional Sophora tomentosa. Lantana involucrata was also collected. In the northern sandy area, vegetation is dense and tangled with many fallen trunks. Wedelia, Stachytarpheta, Suriana and Ernodea are conspicuous; and other plants seen include Sophora, Borrichia, Tournefortia, Euphorbia, Cassytha, Ageratum, Ambrosia and Cordia. The island is again permanently occupied, and in 1965 a light airplane strip was being cleared with power-saws near the southern margin of the northern sand area.

GEOMORPHIC CHANGES ON THE CAYS

Following the 1962 survey, four zones of hurricane damage on cays were distinguished (Figure 1): (1) a zone of maximum damage 15-20 miles north and south of the storm track, with most intense winds and maximum storm surge, in which small cays disappeared, others were stripped of vegetation and underwent surface sand-stripping, beach-retreat and channel-cutting, and mangroves were completely defoliated; (2) a second zone 15 miles wide, north and south of zone 1, subject to considerable wave and wind action but without a pronounced storm surge, in which the main physiographic changes were limited to beach retreat and nearshore

erosion and deposition, and in which vegetation changes were small apart from defoliation of mangroves in more exposed locations and felling of coconuts by wind; (3) a zone in the barrier reef lagoon 30-40 miles south of the storm track, where vegetation changes and erosional effects were small, but where bars of sand and shingle were deposited on the south and east sides of cays; (4) the zone of no damage, which on the south side lies not less than 40 miles from the storm track. Changes in the period 1962-1965 are best summarized in terms of morphologic types identified in 1962, which roughly correspond to these zones, arranged from the zone of maximum to that of least damage.

Types of adjustment

1. None of the sand cays which disappeared during Hurricane Hattie (St. George's East, Paunch, Glory, Bokel, Saddle) had reappeared in 1965.

2. The vegetated sand cays reduced to sandbores (Sergeant's, Goff's) continue to change in form and location, partly stabilized by the remains of pre-storm root-bound surfaces. The new islands are generally slightly smaller than those before the storm.

3. Vegetated sand cays in Zone I stripped of vegetation and subject to marginal and superficial erosion (Big and Little Calabash, Sandbore, Cockroach, English, Rendezvous) generally show only minor geomorphic changes, though in most cases the retreat of windward shores is continuing, particularly at Rendezvous. Features above high water are unchanged, though channels cut through former land surfaces have in some cases shoaled or filled (St. George's, Sandbore).

4. Vegetated sand cays in Zones I and II with major vegetational but minor geomorphic damage in 1961 (Half Moon, Tobacco, South Water) have undergone only slight shoreline readjustments, either of beach retreat or of spit aggradation. At Northern Cay small dunes have been formed by the Trades blowing over a recently developed and unvegetated sandspit.

5. Cays of Zone III with peripheral shingle deposits have undergone adjustments in form of the hurricane-deposited shingle bars and spits, which have migrated landward (Scipio, Colson). No morphologic changes have taken place on the stripped marginal surfaces of the cays themselves.

6. On the larger mangrove-sand cays of Zones I and II (Caulker, Chapel, Big Cay Bokel, Northern Cay), where damage was limited in 1961 by the size of the island, the changes resulting from the hurricane, such as nearshore surface scouring and channel-cutting, above high water, have remained unaltered. Shoreline changes are less marked than on simple sand cays.

Comment

It is clear from the 1965 survey that post-hurricane changes have been negligible above high water mark on the cays: on stripped surfaces, often scattered with hurricane rubble, no subsequent accumulation of

sand has taken place, and no marked soil formation on newly exposed surfaces, while accumulations of hurricane-deposited sand and shingle beyond the limit of wave action remain unaltered. On cay margins changes have been more marked, though generally minor. The evidence of continued retreat of windward beaches, reaching a maximum rate of 9-15 feet/year at Rendezvous Cay, and of the failure of cays destroyed to reappear, suggests that the destruction of reef corals in Zones I and II effectively allows larger waves access to reef flats and beaches. Increased erosion may thus continue until the reefs recover, and in the case of narrow islands such as Rendezvous this could lead to the delayed disappearance of cays as a secondary result of the hurricane. Shingle bars on reef flats, while not widespread, have been pushed landward, and in some cases combed out to form shingle flats; similar adjustments of reef flat shingle bars have been noted in post-hurricane surveys at Jaluit Atoll (Blumenstock and others 1961).

Exposures of partly lithified rocks revealed by Hurricane Hattie in most cases survived in 1965. These include beachrock, promenades of cay sandstone, fragments of a probably phosphatic conglomerate well above sea level on Half Moon Cay and Pelican Cay, and a high-standing cay sandstone on Cay Chapel. In all cases the degree of lithification is greater than in 1962, especially on the surface, suggesting that the incipient bonding below the ground which leads to the survival of the bonded material to form topographic features has been followed by a secondary subaerial or in some cases intertidal cementation process. The ledges of cay sandstone at Big Cay Bokel are of special interest, for the friable root-filled soft sandstone of 1962 is now a compact rock similar to that long exposed elsewhere on the Turneffe eastern sand ridge; the coconut roots penetrating the rock in 1962 have now rotted and are disappearing. These exposures clearly demonstrate that lithification is a contemporary process capable of forming rock ledges above present sea-level without any necessity for sea-level change.

VEGETATION CHANGES ON THE CAYS

The minor nature of geomorphic changes on the cays and of reef growth is in contrast with the considerable and rapid vegetation changes which have taken place in the 3-1/2 years since Hurricane Hattie. These vegetation changes have not, however, been uniform in nature or rate, and may be conveniently discussed in terms of the colonization of different substrates prepared by the hurricane, and the recovery of different vegetation types following the storm.

Colonization

1. Primary colonization of bare islands.

The four cays of Sergeant's, Goff's, English and Rendezvous on the northern barrier reef lost all vegetation apart from broken tree stumps during Hurricane Hattie. By early 1962 Portulaca oleracea was the chief colonizer of their bare surfaces, in places still partly bound by roots, and Euphorbia mesembrianthemifolia and Sesuvium portulacastrum

were also present. The three most damaged cays had 4, 1 and 2 species of plants growing on them five months after the storm; 3-1/2 years afterwards the numbers had increased to 13, 5 and 5, respectively. At Rendezvous, where more of the original bound surface survived, the number of species increased from 13 to 16 in the same period. Of these colonizing species, three were common to at least three of the four islands in 1965: Sesuvium, Euphorbia and Ipomoea; Cocos was found on three islands but had been artificially planted. The formerly dominant Portulaca was found on two islands but was not conspicuous. Other species found on two out of four islands were Wedelia, Cakile, seedlings of Tournefortia and Suriana, and relict Coccoloba. At least 11 other species occurred on only one of the islands: this diverse group includes Ageratum, Euphorbia blodgettii, Ernodea littoralis, Batis maritima, Philoxerus vermicularis, Cyperus sp., Sporobolus sp., Eustoma exaltata, Conocarpus erecta, and Casuarina equisetifolia. On the more badly damaged islands the pioneers of 1962 were often absent in 1965: thus at Sergeant's Cay three species out of four in 1962 were absent in 1965 (Portulaca oleracea, Sesuvium portulacastrum, Rhizophora mangle); and at Goff's Cay the single species present in 1962 (Portulaca oleracea) was not seen in 1965. The greater stability of surface on Rendezvous Cay, which was stripped of vegetation and heavily eroded without being destroyed, is reflected both in the larger number of species present in 1962 and in the small changes and low rate of extinction between 1962 and 1965.

2. Colonization of sandy shores and sand ridges.

Fresh sand ridges were lodged on the windward shores of several cays during Hurricane Hattie, particularly on Tobacco and South Water Cays, and fresh sand beaches were prepared for plant colonization at Sandbore and Half Moon Cays. At Tobacco Cay the new sand ridge had been colonized within five months by an almost complete cover of Ipomoea. In 1965 Tournefortia, Sporobolus and Euphorbia were found in all four cases mentioned; Ipomoea and Sesuvium in three. The bushes of Tournefortia varied up to 3 feet in height and 6 feet in diameter. Other plants less typical of this habitat but found in at least one of the cases were Sophora tomentosa, Borrichia arborescens, Wedelia trilobata, Cassytha filiformis and Cenchrus tribuloides.

3. Colonization of shingle bars.

Shingle bars built by the hurricane are rare except on the cays of the central barrier reef lagoon, such as Scipio and Colson; small bars are found close to some larger islands, such as that near Soldier Cay. In 1965 the main colonizer in each of these three cases was Sesuvium portulacastrum, with smaller patches of Sporobolus and Euphorbia in two cases. Seedlings of Sophora and Tournefortia were each found on one of the islands, and Cassytha was seen on the Colson ridge. The amount of growth on shingle bars has been much less than on sand ridges, probably as a result of the greater permeability and also mobility of the former. Ipomoea was not found in this habitat, nor were the herbs characteristic of cay surfaces under woodland.

4. Colonization of rubble and shingle spreads.

Carpets of coarse sediments deposited by the hurricane were formed on several of the Turneffe cays (Pelican, Cockroach V, Soldier, Deadman II, Deadman IV) and at Half Moon Cay, either banked against vegetation or in leeward locations. Tournefortia gnaphalodes was found in 1965 colonizing this habitat on all the islands listed, forming bushes 2-4 feet high and up to 30 feet in diameter. Sesuvium portulacastrum was found in four cases, Euphorbia in three, and Sophora, Ipomoea, Cyperus, Sporobolus and Suriana in two. Six other species were also seen, none of them common, and some, such as Hymenocallis, surviving from the pre-hurricane vegetation under a thin carpet of rubble.

5. Colonization of stripped surfaces.

The most common pioneer habitat prepared by Hurricane Hattie was the surface stripped of vegetation and superficial sediments, covered with exposed roots, particularly of coconuts, and lightly scattered with coral rubble. Because of the loss of soil, colonization of these stripped surfaces has been much slower than on constructional surfaces, and in 1965 many were still conspicuously bare. Regrowth was greatest where stripping had been least severe and where some of the pre-storm surface and vegetation survived. Stripping and colonization were noted on twelve sandy islands (Ambergris, Caulker, Chapel, St. George's, Big and Little Calabash, East I, Deadman I, Deadman V, Sandbore, Northern and Long Cays) and three shingle islands (Cockroach, Soldier, Half Moon). Direct comparison is difficult because of the differences in exposure and degree of stripping (varying from complete to narrow marginal stripping), but the colonizing species are distinct from those of other habitats. The most widespread colonizers in 1965 were Euphorbia (E. mesembrianthemifolia, also E. blodgettii), seen on 12 of the 15 islands mentioned, and Tournefortia gnaphalodes, found on 10. The bushes of Tournefortia vary in height from 1-3 feet and in diameter up to 30 feet, with their greatest development on Half Moon Cay. Other shrubs present were Borrichia arborescens, up to 6 feet tall, on 8 cays; Suriana maritima, up to 6 feet tall, on 7 cays; and Conocarpus erecta and Sophora tomentosa, each on three cays but only as scattered individuals. Borrichia is most characteristic of sandy islands on the atolls rather than the barrier reef. Ground-layer species present on six or more of the fifteen cases studied are Sesuvium, Wedelia, Ageratum, Ipomoea, Sporobolus, Cyperus and Ernodea; and at least 18 other colonizing species have been noted. The pioneer vegetation of stripped surfaces is therefore a diverse assemblage dominated by Tournefortia and Euphorbia, with Borrichia and Ageratum, and containing many of the elements of mature cay vegetation. The importance of Tournefortia by comparison with Suriana is striking; Tournefortia clearly occupies the niche filled in the Indo-Pacific by Scaevola. Tournefortia is mainly a shoreline plant, though on stripped cays found all over the surface, whereas Borrichia is generally found away from shores.

6. Intertidal and subtidal habitats.

Little attention could be paid to the vegetation of marine habitats in 1965. No change was apparent in the Thalassia meadows, where holes and channels eroded in 1961 still survive, clearly outlined by the absence of turtle grass. Intertidal beachrock, which lost its profuse

growth of Turbinaria turbinata and other species during the storm is still bare of larger algae. Subtidal broken coral and rubble have been colonized by Padina and other algae, and encrusting pink algae are widespread.

Recovery

1. Recovery of littoral woodland.

The littoral woodland of Cordia sebestena and Bursera simaruba at Half Moon Cay and Pelican Cay was badly damaged in 1961, with trees defoliated and broken but often not uprooted. In early 1962 it was often difficult to tell whether these trees were dead or alive, though individuals of Cordia were seen in flower even when much broken. In 1965 virtually all the damaged Bursera was dead, while Cordia had made a remarkable recovery. The sea-grape Coccoloba uvifera also showed a similar ability to survive massive physical damage. It is too early to predict what will happen in the dead Bursera stands, which in 1965 were being overgrown at Pelican Cay by Ipomoea tuba. Trees such as Thrinax and Terminalia which survived the storm in nearshore situations were still alive in 1965.

2. Recovery of coconut thicket.

The dominant cay vegetation of neglected or naturally regenerated coconut woodland with a dense undergrowth of shrubs and ground-layer vegetation has changed (a) because of felling or decapitating of many coconuts and (b) because of at least temporary cessation of direct human interference and clearing of undergrowth. Thus thickets on many cays are much denser, with strong growths of Borrichia, Tournefortia, and to a lesser extent Suriana and Sophora. The ground cover of Wedelia, Stachytarpheta, Canavalia and other plants under cleared coconut woodland is commonly reduced by this expansion of shrubby growth. Coconuts planted or naturally germinating after the hurricane were in 1965 commonly 3-5 and exceptionally up to 10 feet tall.

3. Recovery of mangrove.

Mangrove damage in 1961 was greatest in the area of maximum storm surge and wave action, and was much less severe in areas affected only by wind. On small mangrove islands defoliation was total in a zone 25 miles wide centered on the storm track, and rare at distances of 30-40 miles from the storm track. Size of island affected the degree of damage: living mangroves were seen in 1962 on the lee sides of large islands such as Cross Cay, only 12 miles from the storm center, and defoliation was less complete in the interior of the Turneffe lagoon mangroves. Whether the mangroves defoliated by the storm were dead in 1962 was not apparent at that time.

In 1965 the defoliated mangroves in the zone of greatest damage were clearly dead (Figure 15). On the barrier reef itself, the first relatively undamaged mangrove island north of the storm track is Cangrejo Cay, south of Ambergris Cay, about 27 miles north of the storm center; and the first undamaged island to the south is Crawl Cay, 25 miles south of the storm track. Local exposure is, of course, important in determining details of mangrove damage: for example, damage was more intense

at Bugle Cay, four miles farther from the storm center, than at Crawl Cay. The transition between relatively little and relatively complete defoliation is sharp: the zone of mangrove death so enclosed has a width of 50-60 miles.

Within the limit of major defoliation a distinction can be made between areas with living mangroves in sheltered locations and areas where destruction was complete. Large patches of living mangrove are found on the west side of Cay Chapel and Cay Caulker, 20 miles north of the storm track, and at Tobacco Range, the same distance to the south. Within 20 miles of the storm track, however, damage to barrier reef mangroves was total except for very small leeward patches on the largest islands. No mangroves at all survived within a mile or two of the storm center (Middle Long Cay, Stake Bank).

On Turneffe all mangroves were killed on the small eastern sand cays, such as the Cockroach Cays, and all died along the east coast of the "main" except in sheltered places, for example near Calabash Cays. Patches also survive along the sides of some of the western entrances to Northern and Southern Lagoons. From the air there is a marked contrast between the dead mangrove and the green sandy areas where recovery of grasses, herbs and shrubs has been rapid. In the interior of the wider land areas surrounding the lagoons damage was less severe, and in places these areas are quite green. These inland locations have not been studied on the ground but from the air they appear to have a dry-land vegetation with Thrinax rather than mature mangrove woodland. On Lighthouse Reef patches of mangrove survive in sheltered places on Northern Cay and Long Cay, but otherwise all mangroves are dead.

The zones of mangrove damage thus defined are shown in Figure 15. Both Rhizophora and Avicennia, when dead, retain tenacious root holds, and their hard roots and branches are difficult to clear. Recolonization of these areas is thus difficult, and the drabness of the dead mangrove contrasts markedly with the green of sand and shingle cays in the damaged areas. Lack of seedlings for regeneration also delays redevelopment: few seedlings were seen in 1965 anywhere in the damaged area, where previously they had been abundant. Regrowth may also be delayed by fire: considerable areas were burning on the east side of Turneffe in April 1965, though by destroying the dead woody vegetation this may clear the ground for colonization by other plants.

Craighead and Gilbert (1962), discussing the effects of Hurricane Donna in southern Florida in 1960, have also described widespread destruction of mangroves, averaging 25-75 per cent over large areas and locally reaching 90 per cent. They state that defoliation alone is not a sufficient cause of death, since some trees put forth new leaves and suggest mechanical damage, root damage, and oxygen deficiency resulting from marl deposition as additional causes. They found, as on Turneffe, that on slightly higher areas covered with buttonwood hammock, damage was very much less than on coastal mangroves. The Mauritius cyclones apparently caused little damage to mangroves (Sauer 1962), but damage comparable to that seen in British Honduras was reported by Gleghorn (1947) from the northern Great Barrier Reef, following a cyclone in

December 1943. There is little information on mangrove recovery in reef areas following storm damage. The 1934 cyclone at Low Isles caused mechanical damage to larger trees and defoliation of small ones (Moorhouse 1936); but a decade later no sign of the damage could be seen (Fairbridge and Teichert 1947). In British Honduras the flourishing mangroves of 1959-1961 had probably developed since 1931. Near Punta Gorda, where mangroves are lower than elsewhere, they may have developed largely since the major hurricane of 1945.

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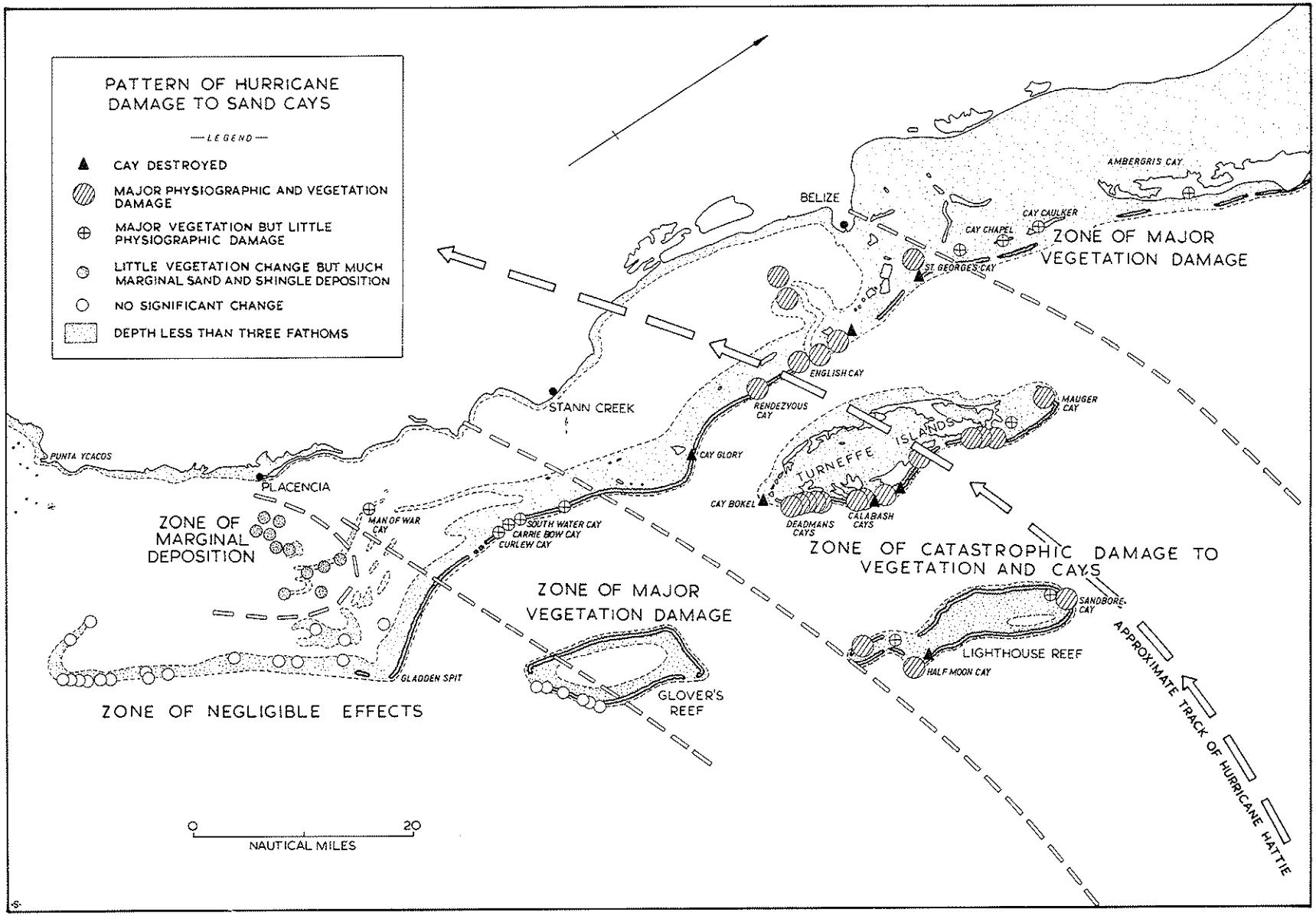
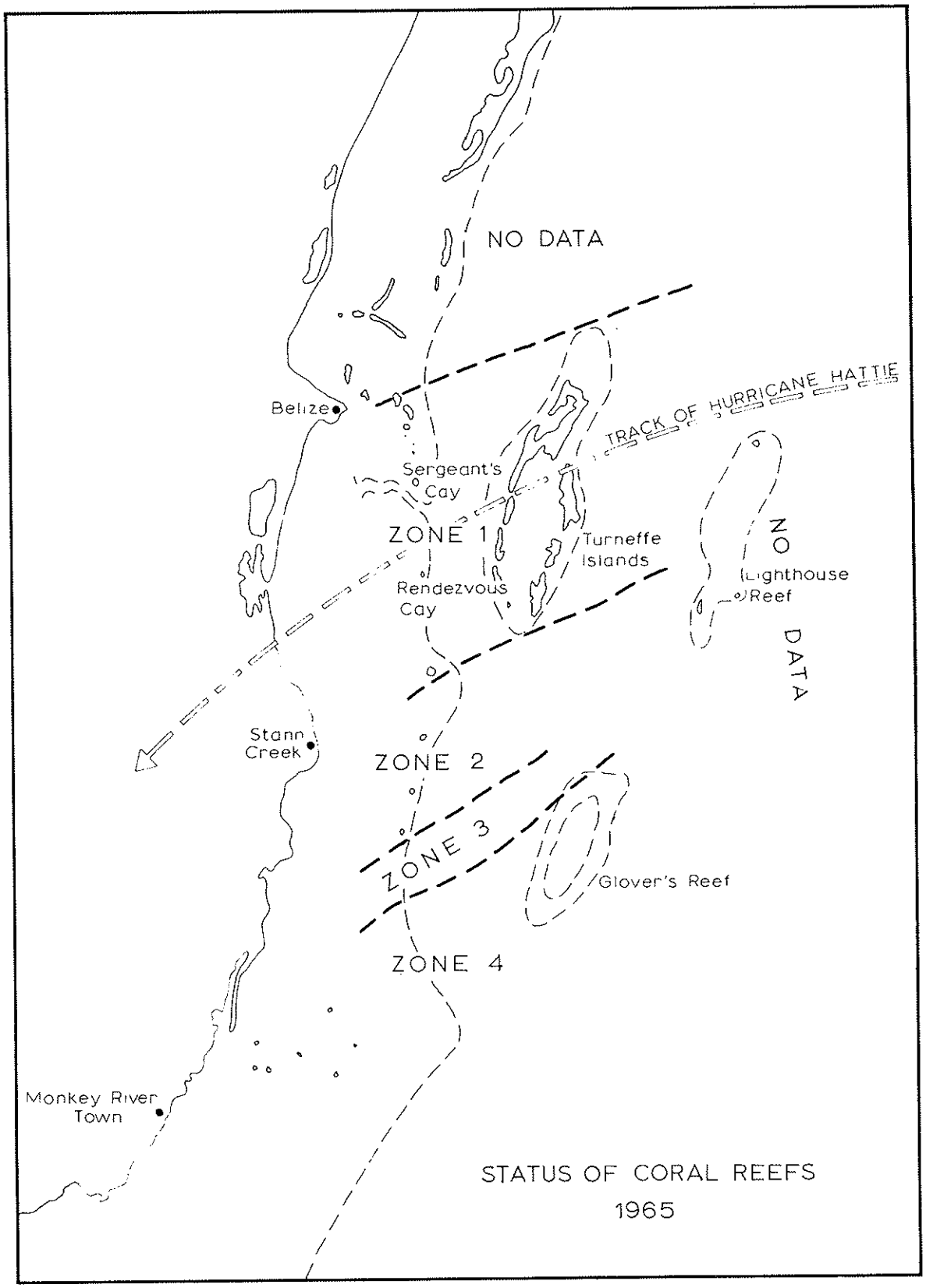
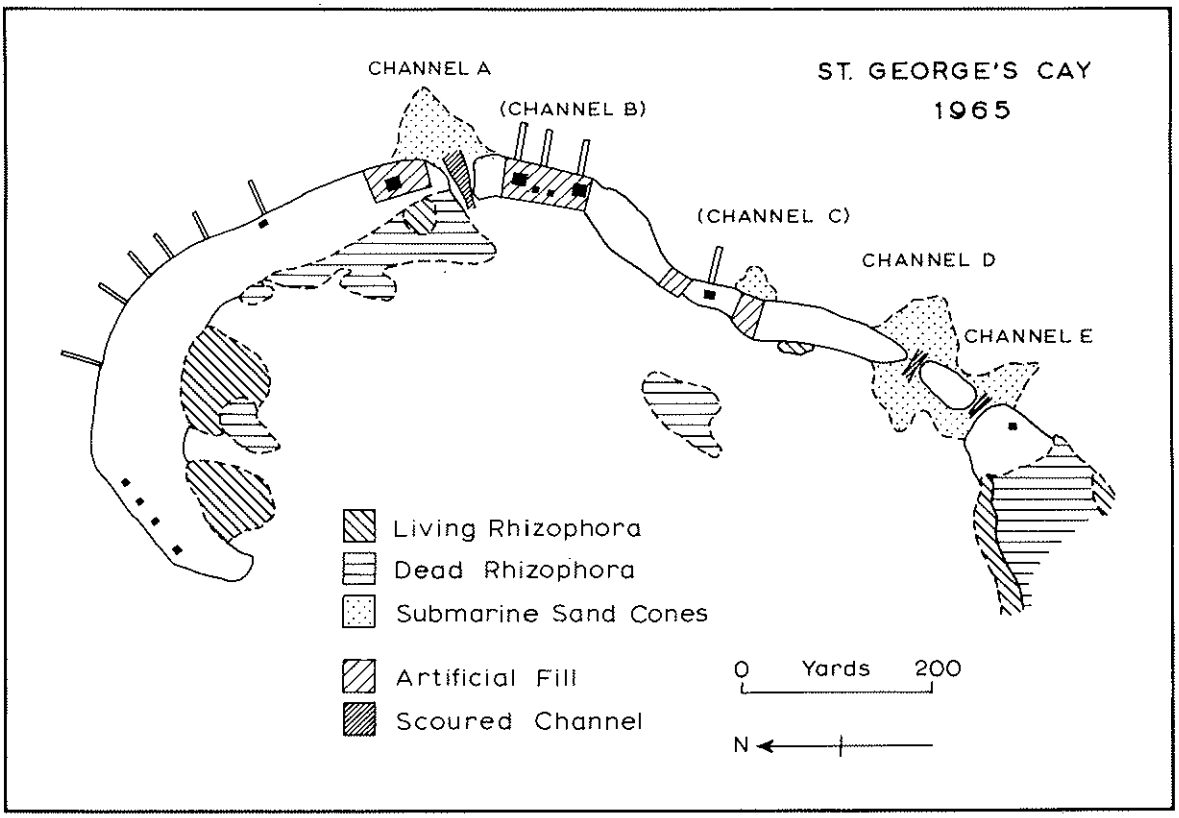


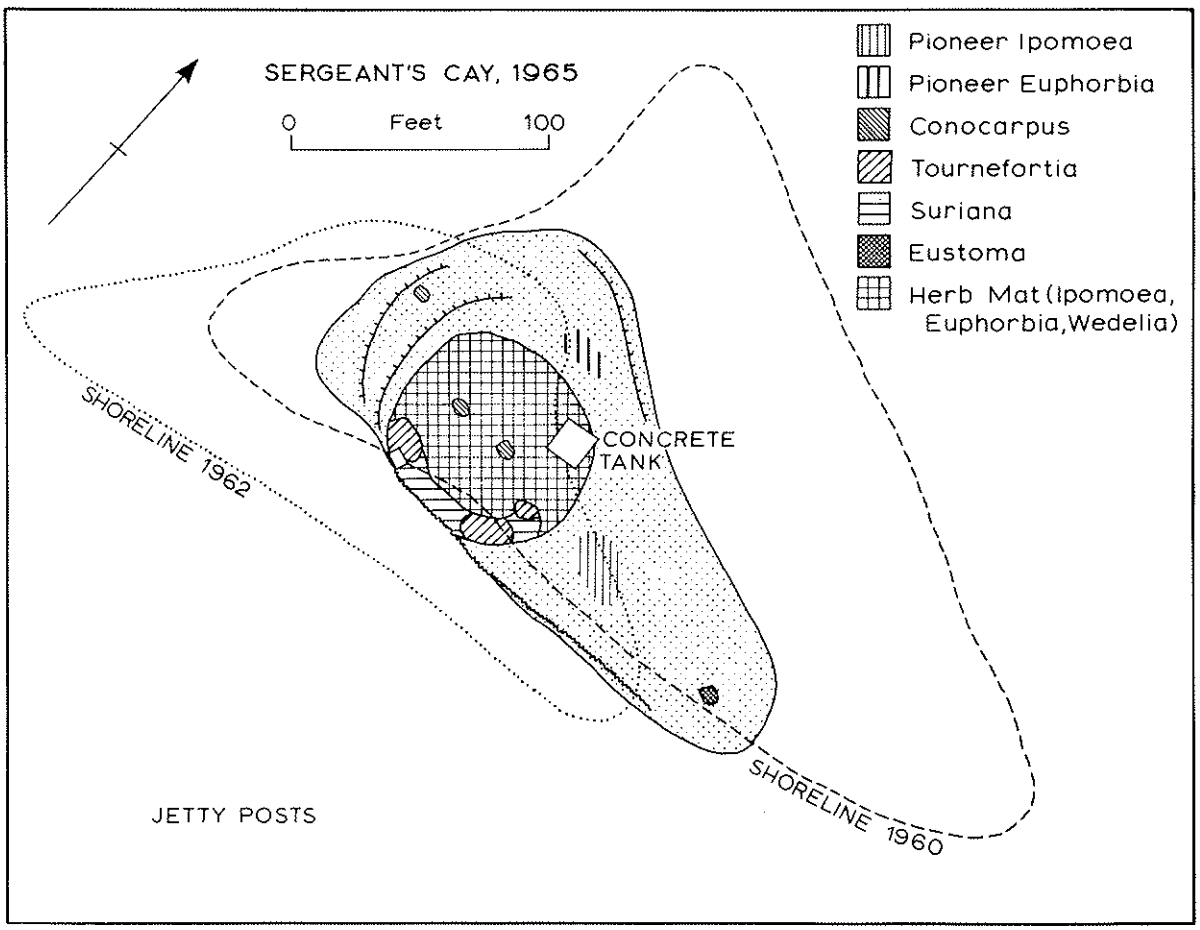
1 Pattern of hurricane damage to sand cays (from ARB 95, Fig. 62)



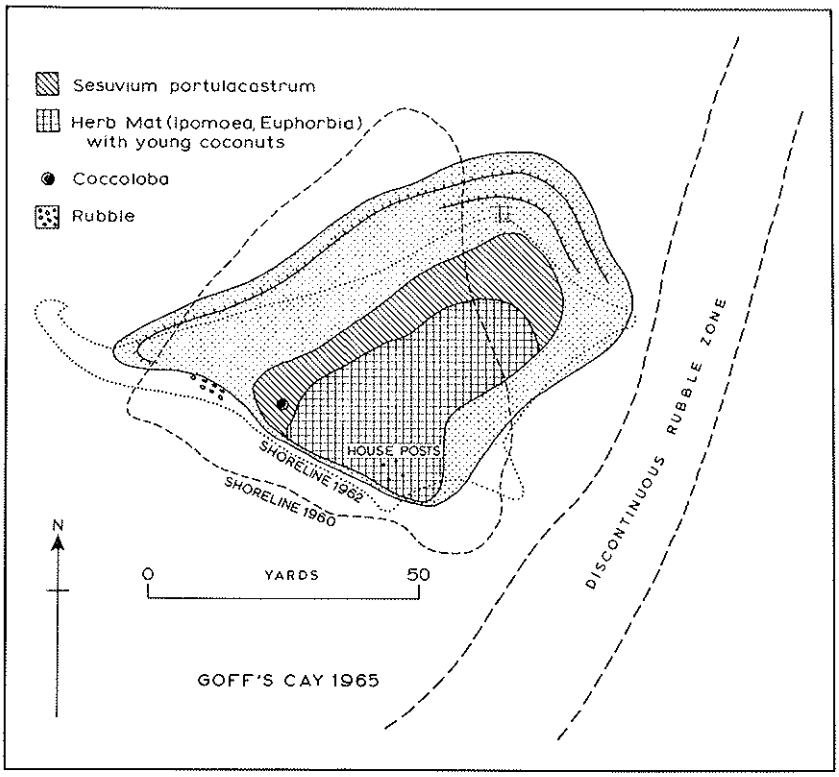
2 Status of coral reefs 1965



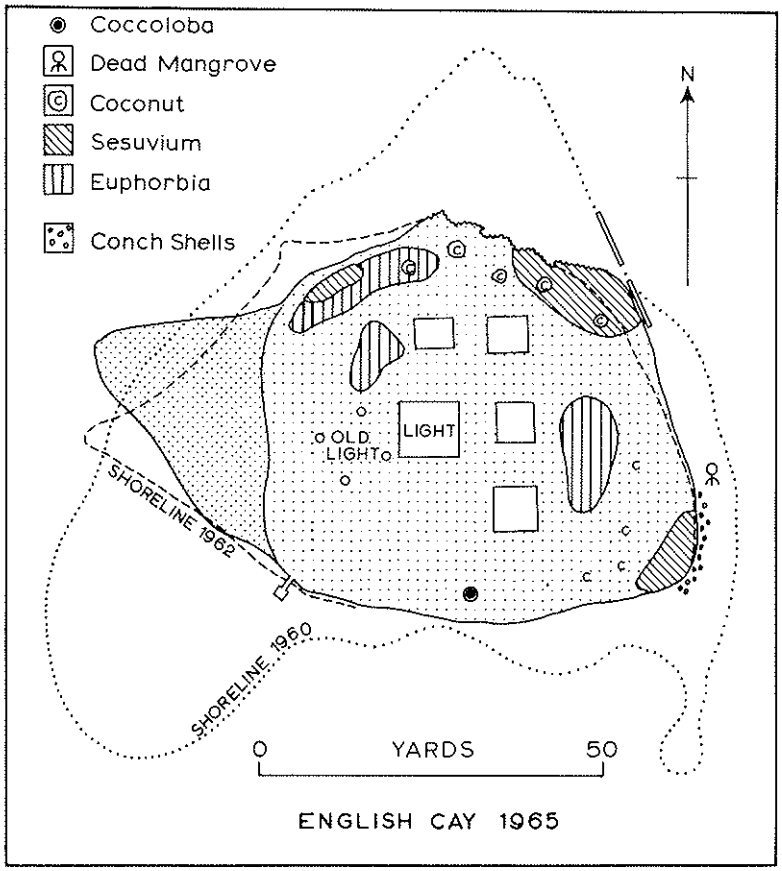
3 St. George's Cay 1965



4 Sergeant's Cay 1965

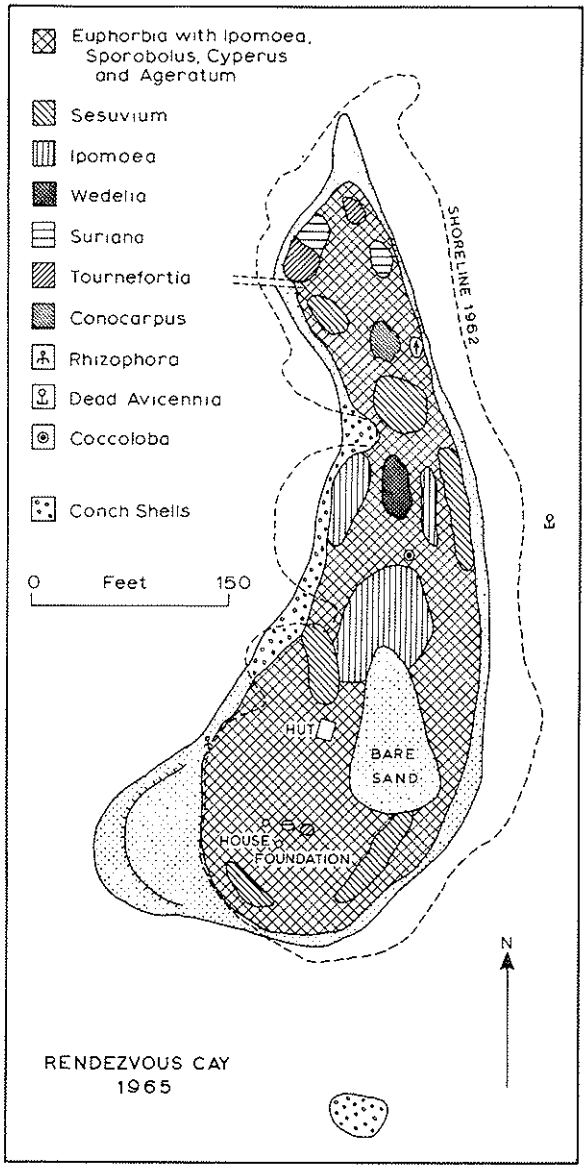


5 Goff's Cay 1965

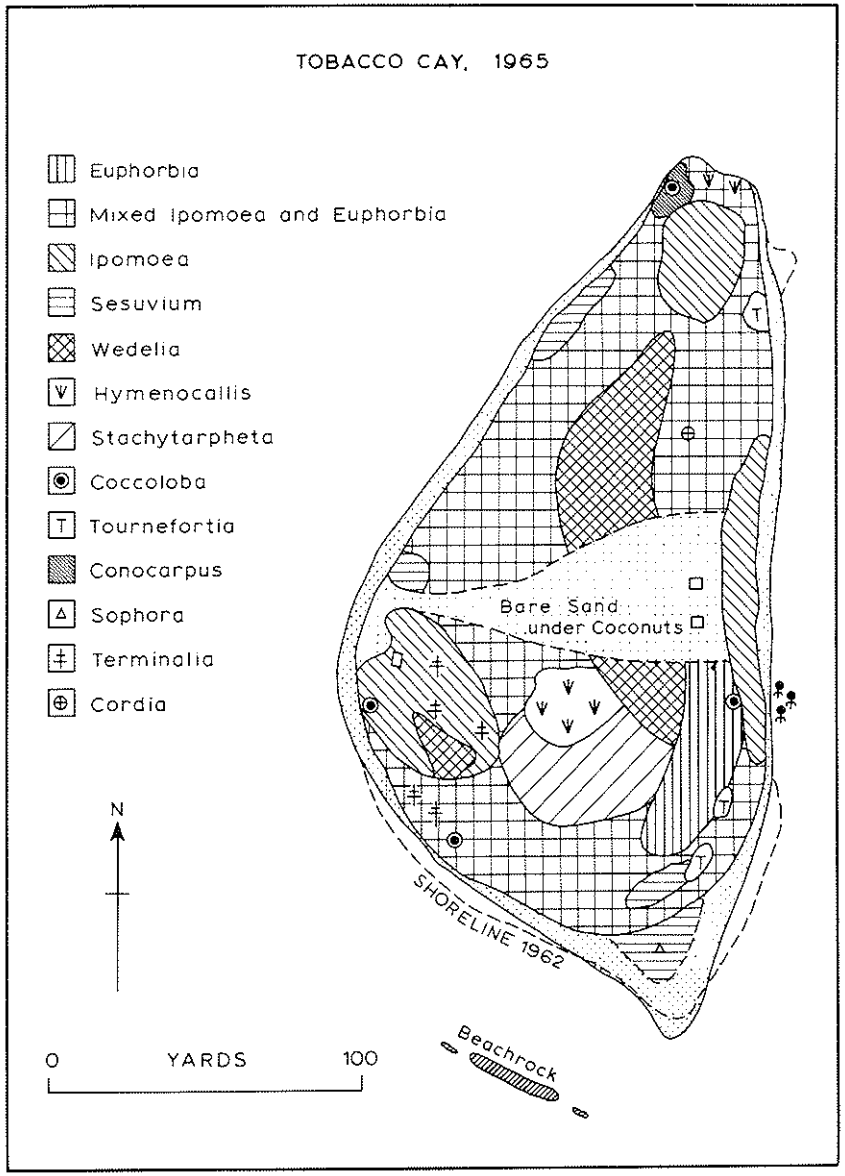


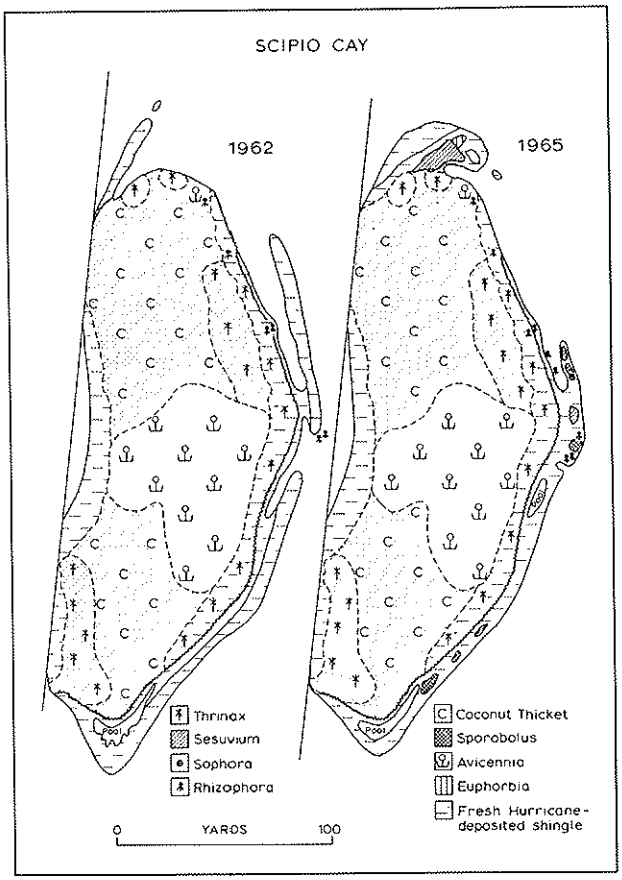
6 English Cay 1965

7 Rendezvous Cay 1965



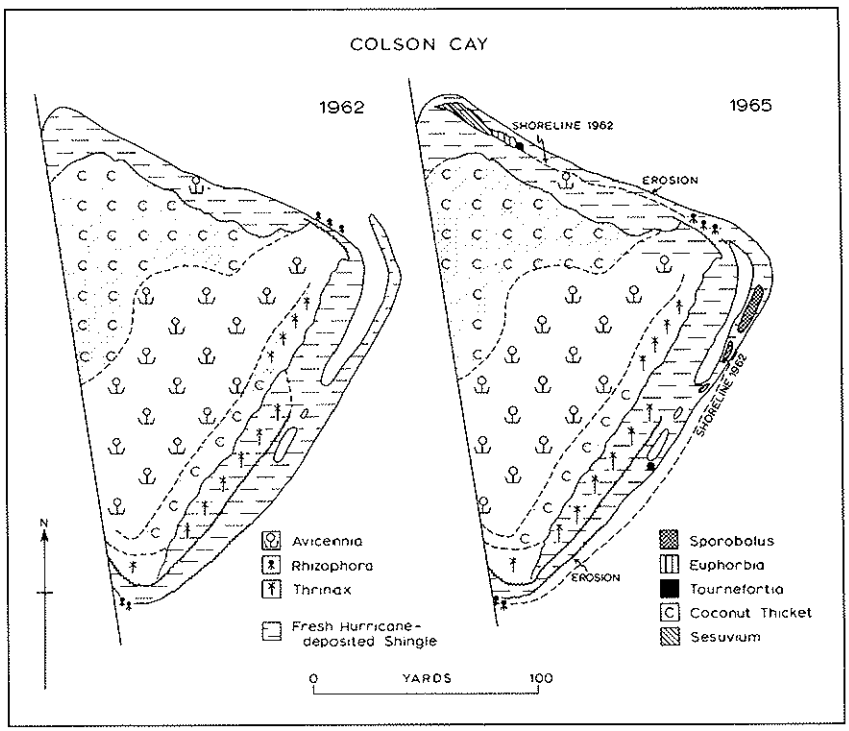
8 Tobacco Cay 1965

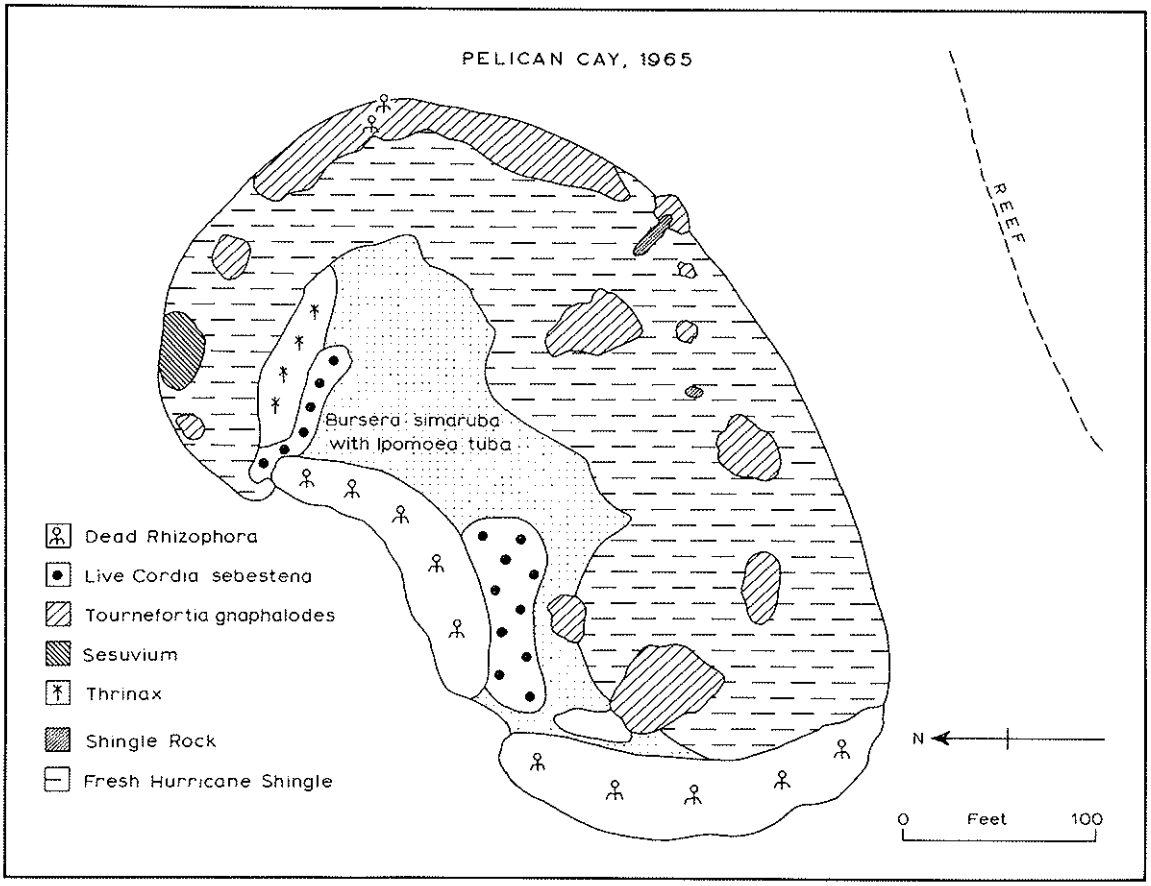




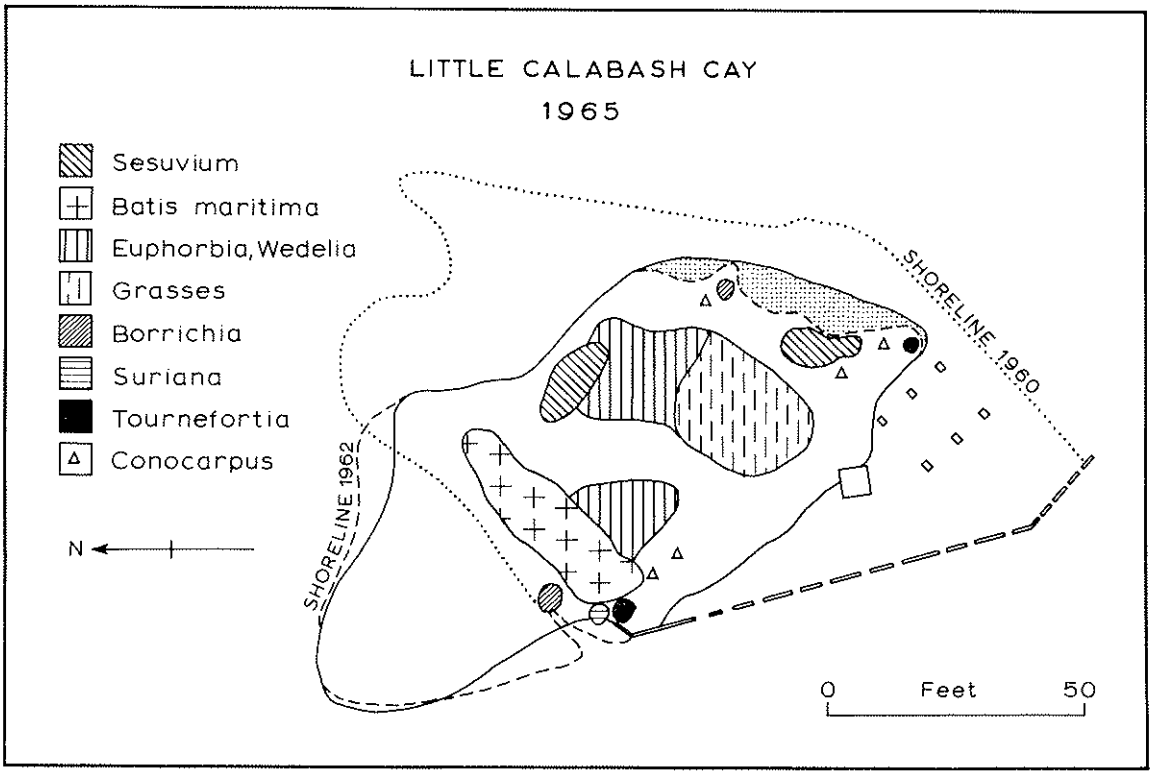
9 Scipio Cay 1962 and 1965

10 Colson Cay 1962 and 1965

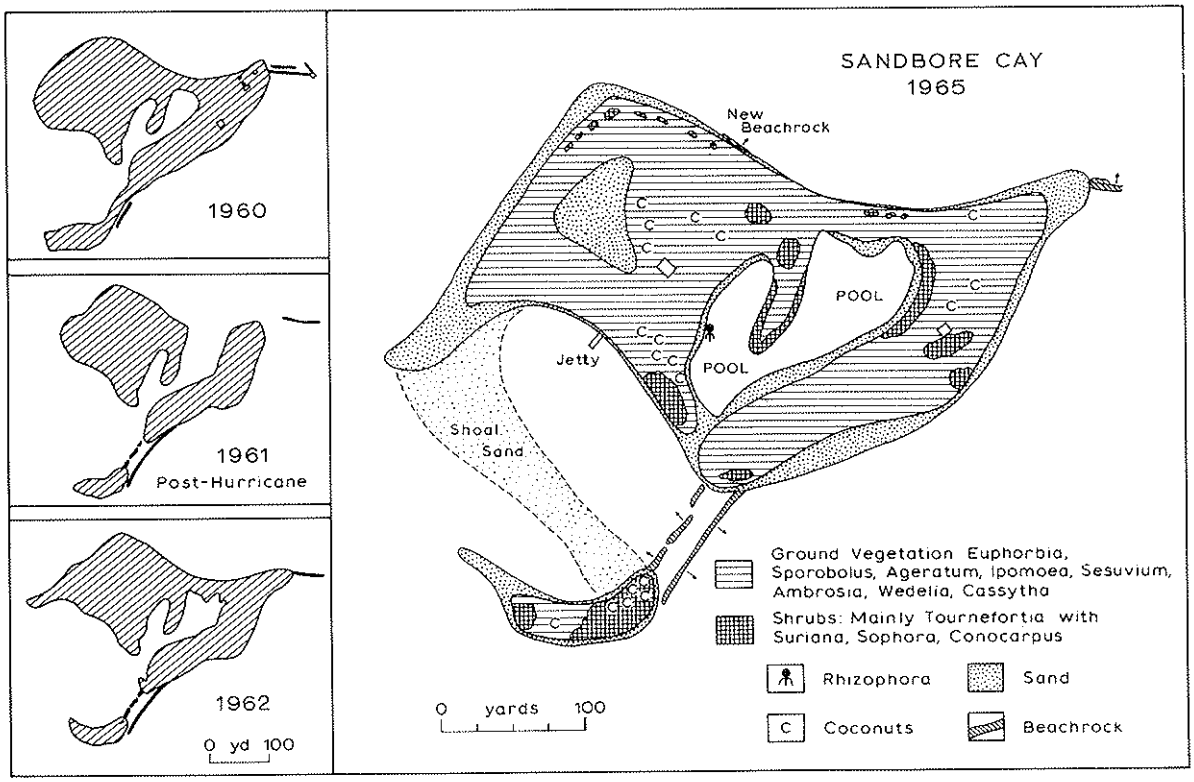




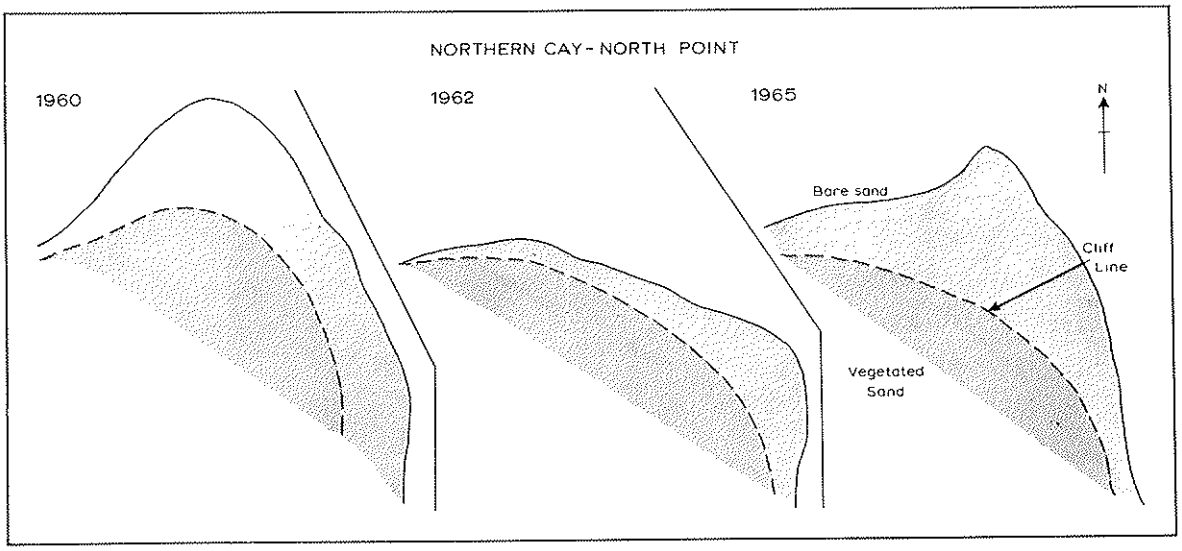
11 Pelican Cay 1965



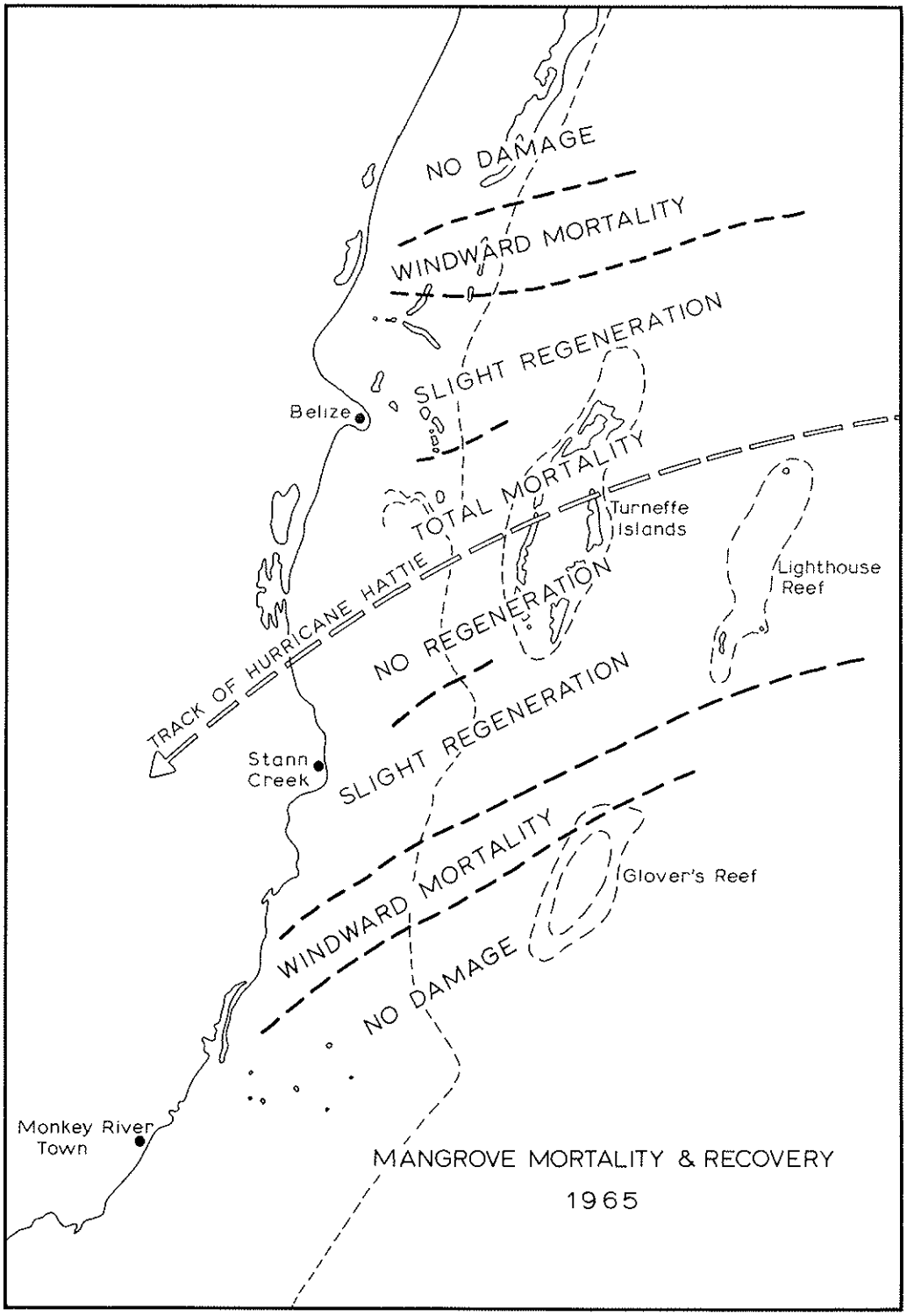
12 Little Calabash Cay 1965



13 Sandbore Cay 1965



14 Northern Cay north point 1960, 1962, 1965



15 Mangrove mortality and recovery 1965