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ASSESSMENT OF THE ECONOMIC IMPACTS OF HURRICANE GILBERT ON COASTAL AND MARINE RESOURCES IN JAMAICA

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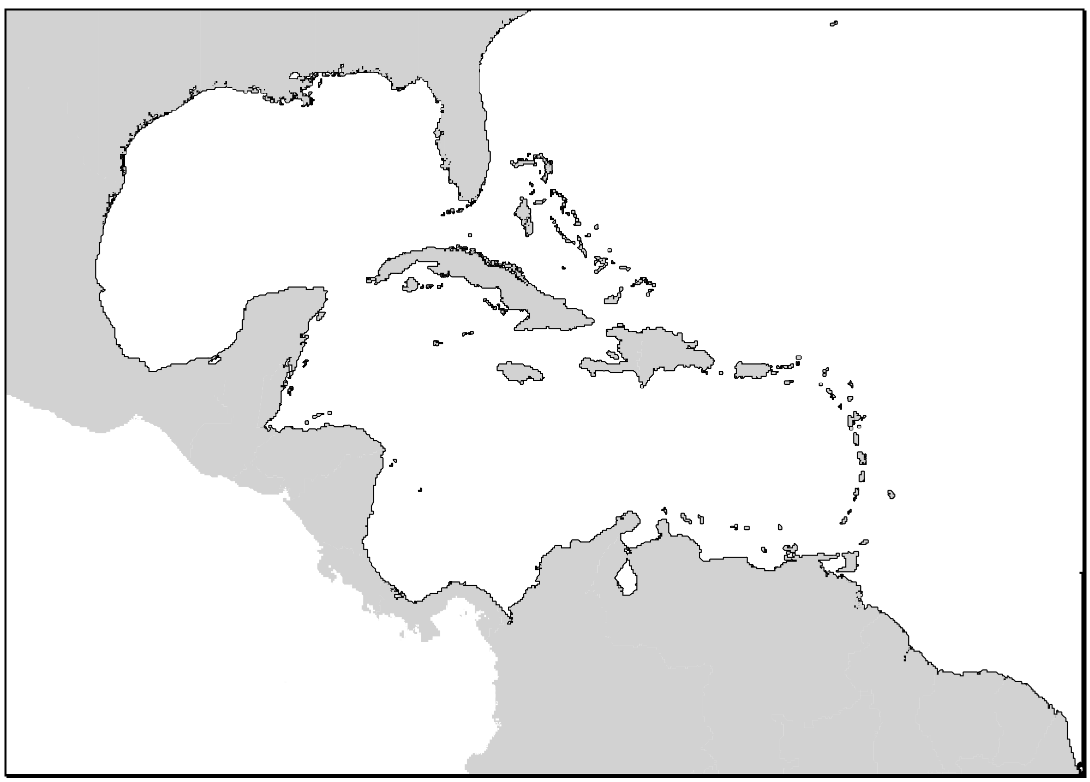

CEP Technical Report No.4

1989

TABLE OF CONTENTS

Page

APPENDICES

LIST OF FIGURES

LIST OF TABLES

SUMMARY

1. Hurricane impacts on beaches, coastal water quality, coral reefs, sea-grass beds, wetlands, coastal vegetation, fisheries and waterbirds are documented, following rapid survey.

2. Erosion of over 50% of beaches occurred, with damage worst on the east and north coasts.

3. Natural recovery of beaches is in progress.

4. Coastal water quality deteriorated, especially as a result of sediment-laden terrestrial run-off.

5. Recovery of water clarity occurred in about three weeks, except near river mouths, where high turbidity continues.

6. Coral reef damage was disastrous on the east and north coast.

7. The recovery of reefs since Hurricane Allen (1980) has been set back by Hurricane Gilbert.

8. There has been severe loss of all types of reef organisms, and some loss of reef fish.

9. Seagrass beds were damaged only superficially.

10. Mangroves were severely damaged, with loss of up to 60% of trees in some areas. Damage is worst on the east and north coasts.

11. Damage to mangroves was largely to upper parts of the trees, the ground and aquatic habitats were less affected.

12. Waterfowl and other wetland animals were little affected.

13. Natural recovery of mangrove areas is proceeding.

14. Coastal woodland and strand was severely damaged on the east and north coasts.

15. Considerable loss of fishing gear and fisheries infrastructure occurred, particularly on the east and north coasts.

16. Artisanal fishing was disrupted for three to four months following Hurricane Gilbert.

17. There is little evidence of damage to primary fisheries resources (scalefish, lobster, conch, etc.).

18. Oyster culture and artificial reef structures were damaged on the south coast.

19. Damage to seabirds and shorebirds appears to be minimal.

20. Available data is inadequate for accurate assessment of the economic impacts of Hurricane Gilbert on coastal and marine resources in Jamaica.

21. Immediate losses of coastal and marine resources are estimated at about US$200M.

22. Long-term losses can be expected to be much higher.

23. Most of the resources are expected to recover naturally, although the economic loss period may be several years in some cases.

24. Investment in recovery effort is recommended only for a few resources, such as beaches and fisheries.

25. Recovery of watershed forests should be aided in order to reduce adverse run-off effects on coastal waters.

26. The report highlights the need for further study of coastal and marine resource economics.

27. Key areas for research on marine resources and impacts of disasters are listed.

28. The report is supported by 10 appendices containing detailed information on impacts of Hurricane Gilbert.

29. The report is the first compilation of data and professional opinions on the effects of hurricanes on a wide range of coastal and marine resources in Jamaica.

30. The report is intended as a framework for more detailed analysis of the economic impacts of Hurricane Gilbert.

1. INTRODUCTION

2.1. Survey of Hurricane Damage

Hurricane Gilbert struck Jamaica on 12th September 1988, causing loss of life and considerable property damage. The Government and the scientific community acted quickly to establish several working groups to assess the damage in different sectors of the economy (Anon, 1988a), and to aid repair and recovery.

Although working groups were convened with responsibility for "Environment and Conservation" and for "Agriculture " (which presumably included fisheries), the Regional Co-ordinating Unit of the Caribbean Environment Programme, UNEP, felt that special attention should be paid to coastal and marine resources, because of their importance to the economy of this island state. It was decided that the assessment of the impacts of Hurricane Gilbert on, these resources should be undertaken in two phases: (a) a rapid survey to assess the scope of damage and identify the types of economic impact which resulted; and, if further funding were available, this would be followed up by (b) a longer-term study which would include a comprehensive economic analysis of damage, repair, recovery and the introduction of measures to reduce future losses.

This report is concerned with the first phase of this economic impact assessment, and attempts to provide a framework for the more detailed analyses which are to follow. Furthermore, after critically reviewing the existing information, the report outlines further research that will be necessary to accurately assess the effect's of Hurricane Gilbert on coastal and marine resources.

2.2. Terms of Reference

The Terms of Reference received on 16.11.88 stated that:

"Under the direct supervision of the Regional Co-ordinating Unit of the Caribbean Environment Programme, the consultant will prepare an ecological assessment in economic terms of the damage and impact of Hurricane Gilbert on the coastal and marine resources of Jamaica.

Specifically, he will:

- Make a rapid assessment of the extent to which coastal ecosystems and marine resources (beaches, coral reefs, fisheries, mangroves and seagrass beds) have been altered and/or damaged by Hurricane Gilbert.

- Assess the economic implications of these effects with a view to:
  - identifying priority areas for recovery effort,
  - reducing economic losses in future hurricane events,

- identifying key areas for marine resources research and management effort.

All available information on the effects of the hurricane with respect to coastal and marine resources will be assembled and collated by the consultant, including information resulting from interviews with government agencies and statutory bodies.

The consultancy is to be undertaken within one man-month."

2. METHODOLOGY

2.1. Resources to be Considered

The major natural resources of coastal and marine environments of Jamaica were identified by the consultant, in accordance with the Terms of Reference, and are shown in Table 1.

Table 1. Resources Considered in this Report

Resource	*Types of resource uses and values*
1. Beaches	Recreation & tourism; shorefront property
2. Coastal Waters	Water quality values (colour, clarity, cleanliness) in tourism and recreation (shipping, navigation & waste disposal uses not considered).
3. Coral Reefs	Coastal protection, fisheries, recreation, support for marine life and productivity (associated flora and fauna included).
4. Seagrass beds	Support to marine life and productivity (associated flora and fauna included).
5. Mangroves	Coastal protection, productivity, timber, charcoal, shellfish, support to marine life (associated flora and fauna included).
6. Littoral Woodland	Coastal protection, dune and shoreline stability, scenic quality.
7. Fisheries	Food production (scalefish, crabs, shrimp, conch, oysters, lobsters, turtles).
8. Seabirds	Food production, wildlife, recreation and education.

The report deals only superficially with man-made structures used in the exploitation and management of coastal and marine resources, such as beach and shoreline defences (groynes, seawalls), fisheries infrastructure (huts, gear stores, boats), and with buildings or facilities at resorts or recreation areas. The emphasis is placed on damage to the. primary resources themselves, as required by the Terms of Reference.

2.2. Data Sources and Data Collection

The information contained in this report comes from the following sources:

- Written submissions: Seven staff of the University of the West Indies, Mona, who have on-going research projects in different coastal environments were asked to record relevant observations and field measurements, or information that they had received. These submissions are reproduced in full as Appendices 1, 2, 4-6, 9 & 10.

- Natural Resources Conservation Department: Reports of surveys conducted by staff of NRCD, Ministry of Agriculture, and contained in the agency's files were kindly made available by the Director, Dr. Marcel Anderson. These included field observations made by A. Bailey, P. Campbell, E. Foster, L. Gardner, J. Miller, O. Morgan, J. Taylor, and L. Thompson, which are summarized in Appendix 7. Discussions were held with some of these observers to clarify points made in their reports. NRCD also has a set of photographs of damage to beaches and coastal infrastructure, part of which studied by the Consultant. *Contacts with staff from other agencies suggested that there was little information about damage to primary coastal resources in their files, so these were not consulted.*

- Surveys: Wetlands and related coastal areas were surveyed by the Author on 24, 28 & 29 November 8, 9 & 30 December 1988, and on 1 January 1989. Results of these surveys are summarized in Appendix 3. A photographic record of damage to wetlands was made on these occasions; some of this is reproduced in the Appendix. *The University of the West Indies Sub-Aqua Club was asked to survey the Marine Park at Ocho Rios. Due to prevailing poor sea conditions, only one preliminary dive could be completed in time for this report. Details of this survey, made by R. Robinson; M. Lindo; K. Roberts and G. Elliot, are given in Appendix 8.*

- Personal communications: Miscellaneous comments made to the author by a number of persons about different aspects of hurricane damage are included in this report. The author takes responsibility for the accuracy of these communications.

The limitations of the data obtained from these sources are discussed in Section 4.

The time allocation and activity schedule for this project was as follows:

Day	Activity
1	*Project planning, definition of terms, identification of information sources.*
2 – 4	*Compilation of existing information and reports.*
5 – 12	*Field surveys (ground & aerial).*
13 – 22	*Sub-contracted time for work by co-operating specialists; interviews and discussions, visits to agencies.*
23 – 25	*Analysis of information; review with co-operating specialists.*
26 - 30	*Preparation of report.*

2.3 Ecological Assessment

There is no generally agreed set of criteria for assessing impacts of hurricanes upon natural systems; a wide range of terminology has been used in earlier reports on hurricane damage to coastal and marine ecosystems in the Caribbean region (Craighead & Gilbert, 1962; Alexander, 1968; Lugo & Snedaker, 1974; Zack, 1986).

The reports on file at the Natural Resources Conservation Department do not define criteria used for assessing damage, or the meaning of terms used, such as "severe" and "extensive". Furthermore, terminology was not standardized among the specialists making written submissions that appear as appendices.

Review of these reports, supported by field observations and study of available literature, suggested adoption of the terms listed in Table 2 for describing sectors of the coastal environment and the degree of damage:

Hurricane Gilbert, as with previous hurricanes, impacted on natural systems in several ways, including:

- Winds - abnormally high winds gusting to over 130 m.p.h.
- Waves - increased height and force of sea waves as a result of wind action, plus the related phenomena of battering and scouring by waterborne sand and debris.
- Storm surge - increased height of standing water level, resulting from changes in atmospheric pressure, which, coupled with wave action, produced damage at higher elevations on the shore and further inland.
- Precipitation - increased rainfall, leading to increased run-off with effects on salinity and sedimentation, plus flooding of low-lying areas.

Some data on winds and rainfall during Hurricane Gilbert are shown in Table 3.

The track of Hurricane Gilbert passed directly across Jamaica, so the level of intensity of these parameters and the location of their impact varied in relation to the geography of the coastline. Intensity and impact locations also differed from those of Hurricane Allen, which passed north of the island in 1980, particularly with respect to storm surge.

Table 2. Terminology Used in this Report

1. General terms:

Littoral	-the coastal area under tidal influence
Onshore	-the active shore zone (main part of beaches)
Nearshore/Inshore	-the area between low water level and reefs or barrier islands
Offshore	-the area seaward of reefs or barrier islands
Fastland	-dry land, terra *fima*, above high tide level, including cliffs and headlands

2. Categories of hurricane damage:

Slight	- < 10%
Moderate	- 10-50%
Severe	-> 50%

Severe damage, from the point of view of a population of organisms, can be described using the terminology of Highsmith et *al*, 1980, as:

Disastrous	- damage I such that the population can recover
Catastrophic	- damage virtually terminates the existence of the local population, such that its recovery is possible only if there is recruitment from outside the damaged area.

The parameters listed above may have acted singly or in concert on different coastal systems, or parts of systems, over several hours or at one period of peak intensity. The orientation and aspect of the different bays, headlands and other coastal features can be expected to have an influence on the severity of the impacts and the various biota in the natural systems will show differing susceptibility to the range of potential impacts.

Table 3. Some Meteorological Features of Hurricane Gilbert

Parameter	Date (Sept)	Time	Direction	Av. speed (kt)	Max. speed (kt)
Tropical storm force winds	12	0900	32 0	35	62
Hurricane force winds	12	1200	330	65	110
Hurricane eye	12	-			
Hurricane force winds	12	1500	-	67	114
Tropical storm force winds	13	0600		3 5	45
Rainfall September 12th 223.4 mm					

(Source: Meteorological Service, Norman Manley International Airport, November 1988)

However, while the specific causes and sequence of impacts on coastal and marine resources during Hurricane Gilbert could not be determined with any accuracy, levels of impact were determined as the percentage of physical damage (breakage, scouring, erosion, dislocation), and the nature of biological change (mortality, population decline, alteration of relative dominance of species).

In very few cases was there any accurate description of the resource components or resource-supporting natural systems (beaches, mangrove areas) prior to Hurricane Gilbert, so that precise measurement of the degree or extent of ecological impact was difficult. Furthermore, time constraints in the Terms of Reference have not allowed even the recognisable damage to be recorded in the detail which would have been possible with further funding and manpower. The ecological assessment is largely qualitative, therefore.

Alteration to the ecology of coastal and marine areas of Jamaica was recorded from days after the hurricane event during a period of only three months. Immediate effects, particularly on the marine fauna, were not observed, so the data gives evidence only of short-term effects. In making the assessment, however, an attempt has been made to view the damage and biological chances from the longer term perspective. As Woodley (Appendix 9) makes clear, hurricanes are one of the natural forcing, functions of Caribbean coastal ecosystems; so that modification of a system by an individual hurricane must be viewed against long-term structural development, successional change, adaptations and population dynamics in order to appreciate the significance of recorded ecological effects. In making the ecological assessment, possible long-term effects are noted, particularly the likely direction of ecosystem or population recovery, as are possible effects of pre-hurricane human impacts on the status of natural systems under stress from the hurricane.

To aid in the ecological assessment, library search was conducted for papers on the environmental effects of earlier hurricanes in Jamaica. -Effects on coral reefs were well covered, but there appeared to be very little relevant scientific literature on other ecosystems or resources. A list of the reports located is given in Appendix 11.

2.4 Economic Assessment

As indicated in Table 1, a range of resources of direct and indirect value was identified in coastal and marine environments of Jamaica. An attempt was made to consider the economic consequences of Hurricane Gilbert with respect to these resources under the following headings:

- Value of resources lost or damaged
- Loss of income resulting from the value of resources lost or damaged
- Costs of resource substitution
- Costs of resource recovery
- Costs of protecting resources from future events.

In order to make a valid assessment, the value of lost or damaged resources would need to be calculated for both short-term and long-term scenarios, based on their "capital" value or economic worth. This would be particularly important where indirect values are concerned, such as coastal protection from a reef or the fisheries support provided by mangrove nursery areas.

Loss of income is more directly measured, but should be considered on similar time scales. Losses may be borne privately, as in the case of hotel beachfront erosion, or publicly with the loss of a community bathing beach. There are difficulties involved with assessing loss of income from damage to common property resources, like reef fishing grounds, and in obtaining data from the artisanal user groups generating income through informal marketing procedures.

Costs may be involved with resource substitution, if a hotel must provide alternative facilities to guests because of damage to a beach, or fishermen must obtain alternative gear to that normally used on a reef which has been damaged. Resource substitution may be only temporary if natural or artificial recovery is anticipated. Where livelihood is normally dependent on multiple activities, the substitution process may be easier and costs lower.

The economics of resource recovery must be assessed in terms of the feasibility and desirability of taking action. Natural systems, including beaches, are likely to recover from hurricane-induced disturbance, given sufficient time. The costs of a "No-action" strategy (sustaining continued losses while the system recovers naturally) must be weighed against the costs of direct action (beach re-nourishment, mangrove re-planting) which may return the system to productive use more rapidly. Involved are the costs of supporting research and monitoring activities. Natural recovery might be aided by closing off the area from public use, such as prohibition of fishing on a damaged reef, but this introduces further socio-economic considerations.

Some of the damage to infrastructure designed to facilitate coastal resource use could be avoided by appropriate design, set-back or zoning regulations. Costs of redesign or relocation must be compared to the utility and realised gains from having structures remain in their pre-Hurricane Gilbert positions. Although of importance economically, damage to man-made structures was marainal to the Terms of Reference of this study.

Althouah little can be done to protect natural resources from hurricane damage, it is likely that the susceptibility of some systems, such as beaches, mangrove areas and seagrass beds, is increased when these areas have been modified previously by human activity. The costs of managing natural ecosystems in a healthy condition could be acceptable if damage is correspondingly reduced, in addition to other resulting benefits.

As a first step towards economic analysis of factors such as those discussed above, an attempt was made to locate relevant information on the value of the individual coastal and marine resources of Jamaica; the extent of current resource use; the dependence for employment or income; and the rates or likelihood/indications of natural recovery taking place. This information was assessed for its accuracy, completeness and availability. A framework for further, more detailed economic analysis was then prepared.

3. IDENTIFICATION OF IMPACTS

3.1 Beaches

Information on impacts of the hurricane on teaches and associated onshore features is contained in Appendices 1, 4, 6 and 7; and shows wave and storm surge effects of varying intensity on different areas of the coast.

Of the 56 beaches surveyed by NRCD (Appendix 7, Fig. A7.1), 57% were found to be eroded. Sand lost from the beach face was either transported out of the site or, more frequently, piled up at the back of the beach forming a storm berm. In several cases (Roxburgh, Pear Tree Bottom), coral debris was deposited on top of the beach sand, while in others it was spread inland beyond the limits of the beach (Fig. A3.11). The deposition of plant debris (seagrass blades, seaweed, fragments of littoral vegetation or driftwood) was reported commonly. The distance to which storm surge had carried sand, coral or plant debris varied with the degree of exposure of the beach and the topography of the backbeach areas. As these factors were not recorded along with observations on the degree of erosion, it is difficult to draw conclusions about the height of storm surge at any point.

The reports suggests that damage to beaches was most severe at the eastern end of the island, from Rozelle round to Manchioneal, and along the north-western and north-central coasts. The south coast suffered less damage. One observer thought that storm surge reached about 4 ft on the east and parts of the north coast, but only 3 ft. or less on the south and most of the north coast (J. Lethbridge, personal communication). The approach of the hurricane from the east over the sea could be expected to localize highest storm surge effects in the east coast sector, but be less marked as the track continued over land. Dominant wind directions (Table 3) would focus wave and surge effects on the north and east coasts at different stages of the hurricane's passage, leading to greater damage in those areas.

Some net movement of beach sediments to westward is suggested by reports of beach accretion at Burnwood and Club Paradise (Appendix 7), and by the shape of some Post-hurricane beach profiles examined between Ocho Rios and Wyndham Rose Hall.

By the time of the NRCD surveys (Appendix 7), debris had been cleared from many of the privately managed hotel beaches. During the following two months, several of the beaches showed signs that they had begun to prograde and re-establish pre-hurricane profiles; as at Mammee Bay, St. Ann (Fig. A3.3), and the Trelawny Beach Hotel (personal communication, unidentified member of staff). Rebuilding of beaches was aided in some cases by mechanical shifting of the sand that had been piled up on the backbeach.

It will be difficult to determine the speed with which beach profiles are restored, as the existing air photo coverage has not been obtained recently enough to determine profiles immediately preceding Hurricane Gilbert. However, it is apparent that natural re-nourishment is taking place very rapidly in some areas.

Jones (Appendix 6) gives further information on beach erosion and modification, which generally confirms the NRCD statements. She has shown also how beach tar pollution levels on beaches changed as a result of the hurricane. In the majority of cases there was transport of tar balls to backbeach areas, but some beaches we're swept clean of oil residues.

3.2 Coastal Water Quality

Coastal water quality is considered broadly, to include alteration to the normal colour and clarity, changes in salinity and suspended particle content; the latter related to increased sedimentation in coastal water bodies.

A deterioration in water quality in coastal areas all round Jamaica, due to increased amounts of suspended particles (sand, organic matter), is likely during and immediately following Hurricane Gilbert. It appears, however, that clear water conditions were reestablished quite quickly, as high turbidity was not recorded along the open coast by any of the contributors to this report in the weeks following the storm. Woodley (Appendix 9) provides the only detailed information, showing that at Discovery Bay it took about two weeks for underwater visibility to return to normal.

The NRCD report (Appendix 7) notes increases in silt deposits in rivers following Hurricane Gilbert, especially in the Morant and Plantain Garden Rivers, and a plume of turbid water at Rio Bueno. Increased terrestrial run-off, following heavy rains associated with the hurricane, must have contributed substantially to increases in turbidity and sedimentation in marine environments near the mouths of major rivers. This is a frequent occurrence after storms at Rio Bueno, Great River and other locations, but its ecological effects are poorly documented. Damage to watersheds, due to loss of forest cover and subsequent erosion, may prove to be of great importance to water quality and sedimentation in coastal environments of the next few years, because of the long-term nature of recovery of those upland environments.

At the end of November 1988, the Port Authority contracted with the Royal Navy Hydrographic Survey Ships HMS Beagle and Fawn to survey Kingston Harbour, to see if storm run-off following the Hurricane had caused silting of the ship channel (Anon, 1988 b). It was feared that any appreciable amount of silting, including tree debris and garbage, might cause obstructions to shipping. However, sonar traces showed no appreciable silting since the previous survey conducted in about 1987 (Capt. P. Prawl, personal communication,). If a high sediment load had been brought to the Harbour from the Rio Cobre and other drainage channels, it is more likely that it would have been deposited in Hunt's Bay.

Salinity in Kingston Harbour was reduced after Hurricane Gilbert and remained lower than normal for several days, as noted by Alleng (Appendix 2).

3.3 Coral Reefs

The best set of data on the ecological impacts of Hurricane Gilbert comes from the Discovery Bay Marine Laboratory; as researchers there have long-studied monitoring stations on the reefs and had documented the effects of the previous hurricane (Hurricane Allen, 1980).

Woodley (Appendix 9) reports that damage to the reefs in the Discovery Bay area was severe. The level of damage was lower than that caused by Hurricane Allen, however, because the reef had not recovered to its pre-Allen structure and complexity by the time Gilbert struck. The types of damage were similar, and included breakage and smashing of branching and massive corals, scouring and abrasion by water-borne debris and redistribution of the debris, plus overthrow and breaking of sea-fans and other reef organisms. Some degree of disturbance to fish territories and behaviour was noted. The aeneral effect of Hurricane Gilbert has been to return the reefs to their immediate post-Allen condition.

The effects of the Hurricane are likely to be felt in a loss of productivity, particularly fisheries production due to habitat damage. The base structure of the reef has not been disturbed to the same extent as the cover of living organisms, so structural values, such as coastal protection, should not be reduced.

As during the period following Hurricane Allen, reef recovery at Discovery Bay was evident in a few weeks and is expected to continue. Recovery can be expected to be a long-term process; pre-Allen ecology and productivity level had not been re-established by the time of Hurricane Gilbert (a period of 8 years). Furthermore, the reefs at

Discovery Bay must recover without any reduction in current fishing pressure or other stressors.

Other data for north coast reefs comes from a preliminary survey of the marine park at Ocho Rios. Robinson et al (Appendix 8) report breakage of corals close to the reef crest, plus the re-distribution of reef debris in the back-reef areas and scouring of algal cover.

Increased quantities of reef rock debris were observed in the back-reef zone at Pear Tree Bottom and debris from the "Allen Islands" at Discovery Bay (thrown up in 1980) had been pushed over and re-distributed in the lagoon by Hurricane Gilbert, reducing the height of these islands.

In addition to this, damage to the reef crest zone was observed at Orange..Bay (Ralph Robinson, personal communication), and included gouging on the windward side of coral buttresses, blockage of channels and burial of previously familiar topographic features. In places it appeared that more than a metre of sand had been deposited over entrances to channels and a sand bar had appeared in the back reef area, with dark coloured sand of possible riverine origin.

No data was obtained from the south coast reef areas.

3.4 Seagrass Beds

Very little information is available on the extent of damage to seagrass beds around Jamaica.

Aiken (Appendix 1) reports only moderate disturbance of seagrass beds, including erosion of the edges of pre-existing "blow-outs". The observation of remaining short stumps of seagrasses in the Discovery Bay area suggest that blade fracture had occurred. There was some evidence of reductions in fish populations; but these are likely to have been temporary.

The following observations by the Author support Aiken's conclusions:

(24.11.88) Hellshire:

Quantities of Thalassia debris on Half Moon and Great Salt Pond (east side) Beaches was not unusually high (compared with Witter, 1983; Bacon & Head, 1985; Head & Hendry, 1986). However, on Salt Pond Beach, several relatively freshly-cast up shells of the bottom-dwelling bivalve, Atrina seminuda, were found, suaaestina that benthic sediments had been severely disturbed by hurricane swells.

(29.11.88) Beach adjacent to Wyndham Rose Hall Hotel, St. James:

Slightly increased quantities of seagrass debris on the beach. In two samples examined, Thalassia blade material was 72% and 68% (wet weight) respectively. This indicated little disturbance to the sub-sediment rhizomes and, thus, only superficial damage to the seagrass beds.

(08.12.88) Llandovery:

As shown in Figure A3.6., quantities of seagrass debris were thrown among mangrove prop roots. Quantities appeared to be larger than normal and contained on estimate >80% blade material. Damaae at this site appears to be confined to the above-ground portions of the plants also.

Beach debris levels are difficult to interpret at some sites in the absence of previous quantification, but, coupled with the small amount of visual evidence of erosion in the beds themselves, it appears that hurricane damage to seagrass ecosystems has not been serious. Re-growth of blades from undisturbed rhizomes can be expected.

3.5 Mangroves and other Wetlands

Wetlands were studied at 25 sites (Fia. A3.1.). In contrast to the situation in coral reefs, mangroves were more seriously damaged by Hurricane Gilbert than appears to have been the case during Hurricane Allen.

Due to the lack of previous damage, some areas contained well developed, mature trees, such as Crater Lake and Florida Lands on the north coast. Wind damage by Hurricane Gilbert to these forests was severe, with the loss of a high percentage of the tall trees. Lugo and Snedaker (1974) suggest that, in the Caribbean islands, mangrove forest structure and maximum biomass is limited by hurricanes. Mangroves reach maturity in 20-25 years so that, with a hurricane frequency of about 20 years, full maturity is rarely attained before the forest is damaged. The sizes of red and black mangrove trees in some north coast sites (see Appendix 3) suggest that these forests had not been exposed to hurricane force winds for a considerable time period, certainly more than 25 years. Following Woodley's argument (Appendix 9) it appears that, whereas north coast reefs had already been damaged by Hurricane Allen when Hurricane Gilbert struck, the mangrove forests were still in their "pre-Allen state" and damage was correspondingly greater.

The situation on the south coast is less clear, but several factors may be involved in the lower levels of damage recorded. Wind forces appear to have been lower; much of the coastal mangrove is growing under edaphic conditions that do not permit full tree development; and some pre-Gilbert storm damage is evident.

In some cases, damage to coastal wetland vegetation was due to wave action or transported debris, but the main damage was caused by the wind. Hurricane and gale force winds acting over a long period of time caused defoliation, branch and trunk damage and felling of mangrove trees. Defoliation was the most widespread effect. Damage was recorded to all genera of mangroves, Rhizol2hora. Avicennia, Laguncularia and Conocarpus, but was highly variable between sites. The north coast was generally more seriously affected than the south coast, with the exception of the Great Morass in St. Thomas at the southeastern tip of the island. A gradient in level of damage was found along the south coast, with areas west of Kingston successively less affected. On the north coast, no such gradient was detectable.

As mentioned, the best developed mangrove forests on the north coast suffered the greatest damage (Fig. A3.7, 11 & 12). Tall red mangrove (Rhizophora) suffered defoliation (Fig. A3.10) or toppled after breaking above the buttress roots (Fig. A3.8), while mature black mangrove (Avicennia) was uprooted at several sites (Fig A3.13). There was loss of up to 60% of the trees in some forest stands, although such damage was patchy, and defoliation/branch breakage between 75 and 100% in other stands, such as the Great Morass in St. Thomas and Florida Lands, Trelawny. Defoliation tended to be of the upper parts of the canopy and lower strata appeared virtually unchanged in most mangrove areas. Furthermore, very few Rhizophora were found uprooted in any of the north or south coast swamps examined; so, although the arboreal environments were damaged, prop roots and their associated biota remained in tact.

Other fauna associated with mangrove areas did not appear to be reduced following the hurricane; waterbird populations at several north coast sites, where records had been kept over the last few years, showed no obvious sign of depletion. Even where regular roosting areas had been severely damaged, as at Florida Lands (Fig. A3.12 & 13), pelicans and herons still used the damaged trees. Cattle egrets similarly continued their use of a damaged mangrove tree roost at Pear Tree Bottom (Fig. A3.8).

Although severe, damage does not appear to have been catastrophic in any of the mangrove areas examined. There may be some delayed mortality in defoliated trees, although most are expected to recover. Even where a high percentage of the larger trees have been lost, younger trees and saplings are present and the ecosystems can be expected to recover. Red mangrove stands studied at Crater Lake and Falmouth showed dense seedling cover; and growth of these is likely to be enhanced by thinning of the leaf canopy. Although the damaged black mangrove stand at Saltmarsh (Fig. A3.15) had minimal numbers of seedlings, there were abundant saplings and some regrowth from coppiced adult trees. Species composition in the Crater Lake forest may change during regrowth, as there is a preponderance of white mangrove seedlings on the floor of what was previously a red mangrove-dominated forest, and it is possible that some black mangrove areas will not be able to recover fully if drying out of the swamps takes place due to loss of tree cover. Otherwise, recovery is likely in mangrove forests throughout the island.

It should be noted that, in several areas of the coast where human impacts had been severe before Hurricane Gilbert, interpretation of the relative importance of human and hurricane-induced damage was difficult. This was particularly true for Hellshire (Fig.A3.2) and Half Moon Bay, Falmouth, where charcoal burning had been in progress at least since 1987.

3.6 Littoral Woodland and Strand Vegetation

Littoral woodland forms a fringe of trees and shrubs in back beach and shore environments; it includes such species as the button mangrove, Conocarpus, erectus (see section 3.5), seaside grape, Coccoloba uvifera, seaside mahoe, Thespesia populnae, and West Indian almond, Terminalia catappa. The community of herbs and shrubs that spreads seawards across dunes and beaches is referred to as the strand vegetation; it includes such species as the beach morning glory, Ipomoea pes-caprae brasiliensis, seaside bean, Canavalia maritima, and the grass Sporobolus virginicus.

Scattered records of damage to shore vegetation are given by Bacon (Appendix 3) and the NRCD (Appendix 7). These range from erosion at the roots or branch fracture in seaside trees, as at Couples Hotel and Ocho Rios, and extensive uprooting, as at Eden II and Pear Tree Bottom (Fig. A3.7), to complete destruction of the littoral fringe trees, as at Priory and Bengal-Queen's Highway. There was some damage along almost the whole of the island's eastern and northern coastline.

Although no specific information was obtained, wherever beach erosion was recorded it is likely that some of the strand vegetation was lost or damaged. Recovery of this vegetation will be important in sand restabilisation at the upper level of beaches.

3.7 Fishery Resources

Damage to the fishery resources is discussed at length by Aiken (Appendix 1). Fishermen and the Government Fisheries Division suffered heavy losses in terms of equipment (boats, fish pots) and infrastructure (buildings, shellfish culture rafts, artificial reefs). However, the nature and extent of damage to the **primary** resources (scalefish, lobster, conch, etc.) was less conspicuous. Aiken (Appendix 1) and Woodley (Appendix 9) describe perturbation of coral reef environments, and include some qualitative observations of the effects of the hurricane on fish populations. Whether significant reduction in reef fish population size or alteration in species composition took place, how long these effects will last, what recovery in fish populations can be expected, and how soon, cannot be stated with any accuracy. Unfortunately, baseline data against which to assess changes does not exist with the necessary degree of detail (as it does for coral reefs at Discovery Bay - Woodley, Appendix 9).

Furthermore, no study appears to have been carried out on the effects of Hurricane Allen on coral reef fishery resources, or of the pattern of post-Allen recovery. This might have given an indication of what the long-term effects of Hurricane Gilbert are likely to be on this sector of the economy.

It is surmised that there was little direct mortality to fish, crustaceans or mollusks as a result of Hurricane Gilbert; but that the resources may decline as a result of damage to feeding and breeding habitats, particularly on the coral reefs. Damage to seagrass beds does not appear to have been serious, and **aquatic** habitats of mangrove areas appear to have been less affected than arboreal (trunk and canopy) habitats. Prop root habitats in red mangrove areas, which are important for feeding and as juvenile fish habitat, were little disrupted by the storm. Furthermore, flat tree-oyster populations at Saltmarsh and natural populations of mangrove cup-oysters near the Bowden oyster culture site show no signs of mortality or dislodgement as .a result of the hurricane.

Although Aiken (Appendix 1) notes that the hurricane occurred during the nesting season for sea turtles, it struck well after the normal peak nesting time (Bacon**,** et al, 1984), so direct damage to eggs and hatchlings is unlikely. What may be of significance is the degree of recovery from erosion of beaches that might be required for next season's sea turtle nesting.

Although the losses of gear and earnings by fishermen are to be regretted, long-term effects of Hurricane Gilbert on coastal fish and invertebrate habitat may be the most important issue facing the fishing industry. The lack of data is unfortunate.

3.8 Seabirds and Shorebirds

About 40 species of water birds (terns, pelicans, herons, plovers, sandpipers, ducks, etc.) feed, roost or nest in coastal habitats around Jamaica, including the offshore cays. The majority of these are resident but others occur seasonally during migratory passage through Jamaica; and populations of resident species may be supplemented by passage migrants. Although there is considerable information on the status of seabirds and shorebirds (i.e. how common they are, whether they nest), less is known about their degree of dependence on particular locations for feeding or breeding. Consequently, it is difficult to relate hurricane damage at a particular site to expected disturbance of the bird populations. Furthermore, wading birds, such as herons and egrets, regularly move between feeding habitats to accommodate to fluctuating water levels and food availability (diurnal, tidal and seasonal changes); so that hurricane damage to one part of their habitat will more likely lead to greater use of another part, rather than population disruption. Where regularly used roosting or nesting sites have been damaged, effects on present and future populations might be expected, but only if alternative sites are unavailable.

Haynes-Sutton (1988) predicted that Hurricane Gilbert had caused severe damage to bird populations in Jamaica, although providing no evidence that this was so. She was particularly concerned with loss of endemic species as a result of damage to terrestrial forests. No endemic seabirds or shorebirds are found in Jamaica, so that aspect of the potential problem is not relevant to coastal and marine resources. Clark (1988) reported the destruction of some waterbirds in Mexico as a direct result of Hurricane Gilbert, but no reports have been received of adult bird mortality in Jamaica.

The only evidence of direct damage is a report that a nesting/roosting area on Refuge Cay, in Kingston Harbour, was severely damaged when pelicans were in process of nesting. Some loss of eggs and young birds took place. However, the pelican colony moved approximately 150m westward to another mangrove stand at Gallows Point and, three weeks later, were sitting on new egg clutches (I. Goodbody, personal communication).

Loss of eggs or young at the economically important tern nesting sites on the Morant Cays is not expected as the hurricane struck outside the main nestinc, period (mid-April to June; Haynes, 1986). The level of damage to nesting habitat on the Cays is not known, as reports of wave or storm surge levels there are not available.

Hurricane Gilbert also struck prior to the main autumn passage period of migrant birds.

Some damage to roosting sites was also recorded (Appendix 3). At Pear Tree Bottom, an egret and heron colony was not displaced by severe damage to roost trees (Fig. A3.8), but simply adjusted to use of the remaining mangroves. Pelicans, herons, egrets and other birds around Falmouth showed roost site fixation, despite considerable damage in that area.

Miscellaneous observations suggest that seabirds and shorebirds have been little affected by the hurricane. Waterfowl counts by the author in wetlands at Hellshire, Florida Lands, Salt-marsh and Wyndham Rose Hall showed no significant change from pre-hurricane levels. In the last site, where vegetation was damaged and seawater introduced into the swamp (Greenaway, Appendix 5), grebes, moorhens, ducks and waders were present in expected numbers a few weeks after Gilbert.

Apart from damage to beaches, which ma have caused some disturbance to feeding by shorebirds such as plovers and sandpipers, feeding habitats of waterbirds appear to have been little altered by Hurricane Gilbert. In mangrove areas, damage at ground level appears to have been much less than to upper tree levels. Accumulation of litter and debris and some flooding of low lying areas may temporarily restrict feeding at those sites, but the effect on waterbird populations is likely to be minor.

4. FRAMEWORK FOR ECONOMIC ASSESSMENT OF THE IMPACTS

Preamble: It must be stated clearly that a meaningful economic assessment of the impacts of Hurricane Gilbert on coastal and marine resources in Jamaica cannot be made from the existing data.

Apart from the time constraints placed on this study by the Terms of Reference, the pre-hurricane economic status of the resources was quantified only for some aspects of the fisheries; the ecological database was such that the scale of impact could be identified only in a few cases; very little natural resource economics research has been done in Jamaica; and no coastal or marine resource economist was working in Jamaica to determine the significance of the changes which had taken place.

Nonetheless, because of the importance of these resources to the economy of Jamaica, an attempt is made to provide a framework within which an economic analysis can take place. Previously available data is reviewed and the limitations of the collected data discussed. Despite a long history of coastal and marine research at the University of the West Indies and other institutions, the inventory and assessment of beaches, reefs, mangroves, etc., in terms of their resource value to the nation, are in their infancy. Until steps are taken to address these aspects of resource management, the full impacts of hurricanes and other "disasters" will not be properly understood.

4.1 Economic Worth (Market & Non-market) of the Resources

4.1.1. Beaches

Although the Jamaica Country Environmental Profile (GOJ, 1987) notes the importance of beaches to the tourism sector, no attempt is made to quantify their value. No estimate of the value of the total national
beach resource appears to be available.

As one of the primary resources of the tourism sector, the value of beaches could be estimated in relation to the value of that sector, as follows:

Gross foreign exchange earnings in the tourism sector were US$595M in 1987 (PIJ, 19$8) and US$530M in 1988 (Green, 1989). The tourism sector is supported primarily by three environmental resources - sand, sun and sea. Therefore, a value that could be placed on the beaches is one third of the value of sector earnings; that is approximately US$200M.

An alternative approach would be to examine property values for coastal real estate. Morris (1989) gives beachfront property values at Negril of J$1.4M per acre. With a linear beach front length (per acre) of 69.6 yds and a total beach length of 7 miles, the value of Negril Beach could be estimated at J$247M, or J$35M per mile. (This converts to approximately US$6.5M per mile of beach).

The above estimate probably gives an inflated value if applied island-wide, as Negril is a tourism development pole. Nonetheless it does suggest the possible order of magnitude for resource value.

In addition to tourism, beaches are important as public recreation areas, although there is very little data on the extent of use. Unpublished records for Half Moon Bay, Hellshire, on one public holiday in 1986, show about 15,000 people using the beach. Numbers at other sites may be similar. In the few cases where privately owned beaches are used by the public, ticket sales could be used to calculate what people are prepared to spend annually for use of beaches. An example would be the very popular Puerto Seco Beach, Discovery Bay, which Kaiser Bauxite maintains for the benefit of the public.

Further to this, several "fishing beaches" are important for boat mooring and fish marketing, while some support resident fishing communities. These beaches, thus, make an additional indirect contribution to the economy.

4.1.2. Coastal Water Quality

Calculation of the economic worth of high quality sea water around Jamaica could be based on benefits to the tourism sector, as above. Possible decline in fisheries, reef and sea-grass production, due to reduction in that quality (by increases in turbidity, etc.) should be quantifiable; although several other variables would need to be taken into account. The dependence of coral reefs, and to a lesser extent seagrass beds, on clear, silt-free, saline water **is well established in the literature.**

4.1.3. Coral Reefs

Unlike the fastland zone, real estate values do not exist for coastal ecosystems, so analysis of economic worth must be based on a different set of criteria.

As coral reefs protect beaches and are one of the major sources of beach sand particles, their value must be at least as great as that of the beaches. Added to this is their direct value for recreational diving and other forms of visitor use; although no separate calculation was available for this facet of the tourist industry.

Aiken (Appendix 1) states that the major part of fishing activity takes place on or near coral reefs. The reefs support most of the 12,000 registered fishermen and the 38,000 associated vendors, and support a harvest of approximately 7,000 tonnes annum^{-1}. As a primary resource for the fishing industry, a value could be assigned to reefs in accordance with the industry's contribution to the economy.

In addition, reefs are sources for minor products, such as black coral, shells and coral rock specimens used in the jewelry and souvenir trades. No figures were available on this trade (much of which is illegal).

The total economic worth of Jamaica's reefs in probably in excess of US$500M yr^{-1}, when all these factors, plus coast protection and wildlife support, are taken into account.

4.1.4. Seagrass beds

No data.

4.1.5. Mangroves (and other wetlands)

No estimate is available for the value of mangrove ecosystems in Jamaica. The exact hectarage is not quantified, but is approximately 5,500 ha in scattered stands along 10-15% of the coast.

Browder (1976) estimated a value for mangrove areas in Florida equivalent to US$13,000 ha^{-1} yr^{-1}. If this figure is accepted as a guide, the value of the national mangrove resource is in the order of US$71.5M yr.

Mangrove ecosystem values lie in their role in coastal protection, fisheries support, support of other aquatic and terrestrial biota, production of directly marketable products such as timber, charcoal, crabs and shellfish, plus actual and potential tourism, recreational and educational uses.

Mangroves at Bowden, and possibly other sites, indirectly support a commercially viable oyster culture industry.

4.1.6. Littoral Woodland and Strand

Littoral woodlands and strand vegetation have largely unrecognised scenic and coastal stabilisation properties, related to real estate values, tourism and recreation. They make a minor contribution to organic matter production in coastal environments and provide wildlife habitat. No estimates of these indirect contributions to the economy are available.

4.1.7. Fishery Resources

Fishery resource values are well documented and data is available on harvest sizes and rates, direct and indirect employment in the industry and market prices. Some economic aspects of the fishing industry are reviewed by Aiken (Appendix 1), and have been referred to above (section 4.1.3).

4.1.8. Seabirds and Shorebirds

Direct utilization of seabirds and shorebirds is largely in the form of egg collecting Haynes (1986) reports that over 600,000 eggs were collected annually from the Pedro and Morant Cays in the 1920's. Numbers had declined to about 100,000 by 1975 and harvesting continues at the present time; although no market values are suggested.

Indirect value of birds and other wildlife in recreation and education is not quantified, but is thought to be minimal at the present time.

4.2 Estimation of Economic Losses Resulting from Hurricane Gilbert

4.2.1. Beaches and -Water Quality

Based on a possible value to the tourism sector of US$200M per year, or US$16M per month, total loss of beach use for three months following Hurricane Gilbert could be set at US$48M.

However, NRCD (Appendix 7) recorded damage to only about 57% of the beaches studied; although this was not necessarily severe enough to halt beach utilization completely.

Losses of earnings as a direct result of erosion and accumulation of debris were probably small.

The scale of tourist cancellations due directly to loss of beach use following Hurricane Gilbert is not known; nor are the costs to hoteliers resulting from provision of alternative activities for their guests. It is noted, however, that in most cases recreational beaches were cleared of debris and made usable within a few days of the hurricane. This involved some cost, of course.

Reduced amounts of bathing and water sports as a result of poor water quality, possibly followed a similar trend. Water clarity was re-established relatively rapidly after Hurricane Gilbert (see Woodley, Appendix 9).

Jamaica Tourist Board data (Green, 1989) suggest that there was a 19% drop in visitor arrivals "resulting from Hurricane Gilbert" in the last four months of 1988 compared with the period September to December 1987. Loss of earnings from the 79,000 fewer visitors can be calculated from Green's article as approximately USS33M.

Losses of beach extent and sand supply are expected to be short-lived in most cases. Beach quality should recover in most areas, as it has done already in some locations. The **NRCD** report (Appendix 7) describes some sites showing net accretion of sand, including the "re-appearance" of a beach that had been eroded on a previous occasion.

NRCD, 1988 & Appendix 7 reports the costs of repair to damaged beach facilities and infrastructure, and associated damage in the coastal zone, at between J$40-50M.

4.2.2. Coral Reefs and Seagrass Beds

Disastrous hurricane damage was apparently confined to the east and north coast reefs (no data available for the south coast). Damage was not uniform and loss of functional values was not total. That is, losses were apparent in reef fisheries, biological support and possibly the attractiveness of reefs to recreational divers, but not to their physical structure in relation to coastal protection or beach nourishment. The end result of the direct action of Hurricane Gilbert is comparable with that of Hurricane Allen (Woodley, et al, 1981 and Appendix 9).

The resource value of Jamaica's reefs has probably been reduced by less than half, but only in some areas of the coast and only in certain reef zones at each damaged location. Based on a possible resource value of about US$500M per annum, losses due to hurricane damage on reefs were probably less than US$100M.

If, as Woodley (Appendix 9) points out, hurricane effects are a normal aspect of reef ecology in Jamaica, the "damage" should perhaps not be considered as a "loss". As successional recovery processes take place with the re-setting of the "reef clock", there is the probability of much higher biological productivity than would be found on a mature, stable reef. From the economic point of view, damage must be considered in the short term; direct loss from lowered fish yields and reduced recreational use are the only quantifiable parameters, if data becomes available.

The extent of damage to the Ocho Rios Marine Park could not be assessed fully, and the Montego Bay Marine Park was not investigated, but damage was probably not severe enough for tour guides to be prevented from using these parks.

There is no data to use for estimating economic losses from the moderate amount of damage recorded in seagrass beds.

4.2.3. Mangroves and other Coastal Vegetation

Direct losses of mangrove timber, as at Crater Lake and Falmouth (Appendix 3) are quantifiable on a site by site basis. Very little mangrove timber is actually harvested, except for small stakes at the subsistence level, so no market price is available.

In most cases fallen timber has not been lost entirely, as it could still be harvested and used for charcoal production. From this point of view, resource availability has increased temporarily, even though the standing crop of future charcoal trees has been reduced. The econornics of the mangrove charcoal industry in Jamaica are incompletely documented, however.

From estimates of economic worth of mangroves of approximately US$70M yr^{-1} and probable damage levels to mangrove stocks of 20 % island wide, total losses in resource value may be between US$10-15M.

As with reef, damage was not catastrophic for any of the mangrove stands, and recovery can be expected. Field observations suggest that re-growth of mangrove forests is taking place rapidly. Resource recovery and re-establishment of functional values can be expected in most areas. However, where seedling supply is sparse, as in the Avicennia stands at Saltmarsh, or mature forest was damaged, as a Crater Lake, the wetland may develop differently during the recovery process.

Aquatic habitats in mangrove environments do not appear to have been damaged to any degree, so losses in terms of fisheries and wildlife have probably been minor.

Some damage has been recorded in wetland parks which might have more direct commercial implications. Repairs to the Royal Palm Park in Negril are being effected at some cost to the Petroleum Corporation of Jamaica. The proposed Hellshire Recreational Park has been damaged severely and this may have implications for future development of recreational and educational use. Damage to the Canoe Valley wetland park area consisted largely in fallen trees, the cost of removal of which was estimated by NRCD (1988) at J$5,000.

4.2.4. Fishery Resources

The Ministry of Agriculture has estimated total island wide losses to the fishing industry at approximately J$25M (including fishing beach, trap, boat and infrastructure losses). Fishermen probably were prevented from fishing for up to 10 days after Hurricane Gilbert, with corresponding loss of earnings to themselves and associated vendors. Aiken

(Appendix 1) reports that levels of fishing were still depressed two months after the hurricane.

Losses, immediately and in the future, through damage to fishery habitat and/or juvenile stocks cannot be assessed with the current data.

4.2.5. Seabirds and Shorebirds

There is no evidence of losses resulting from the Hurricane, in terms of exploitable bird resources or recreational/educational use of birds or other wildlife. Some habitat damage is recorded or likely, but its effects cannot be quantified at present.

4.3 Economics of Resource Recovery and Damage Prevention

As indicated above, most resources or parts of resources that have been damaged in coastal and marine environments in Jamaica are expected to recover naturally. Apart from there being little that can be done to aid this recovery process, the no-action strategy appears to make economic sense in most cases.

Intensively used and privately owned beaches have been cleared of debris and, in some cases, washed up sand has been replaced by mechanical means. In the absence of detailed documentation on coastal sand dynamics around Jamaica it is virtually impossible to suggest engineering options that might speed natural beach recovery processes.

The re-planting of coastal vegetation, particularly on dunes, may aid sand stabilisation; but investment in this should not be contemplated until the speed of natural re-growth has been studied at critical sites.

In several areas, sand which had been piled upat the back of beaches by the hurricane was removed for construction purposes. It has been suggested (M. Hendry, personal communication) that such "sand stealing" delays the process of beach recovery. If this is so, it should be prevented in order to retain the sand supply for post-storm recovery. In order to stop people removing this readily accessible source of sand, alternative sources need to be identified and made available to the construction industry.

Set-back of buildings and other infrastructure behind beaches is recommended as a means of reducing damage from storms (as well as removing stress from the beach face), but will not aid in prevention of damage to the beaches themselves. Design of beach developments should acknowledge the dynamic nature of beaches and the probability of erosion and other types of storm damage. Aiding the natural recovery of damaged reefs does not seem to be a feasible option. There is no evidence that reducing the fishing pressure on damaged reefs would aid their recovery, but this should be investigated. Prevention of future damage is almost certainly unrealistic.

The Natural Resources Conservation Department (NRCD, 1988) recommend investment in a programme of seagrass re-planting as an aid to hurricane recovery. Although this may be valuable, it should be preceded by a detailed investigation of the current status of the seagrass beds in different areas of the coast, and a re-assessment of earlier seagrass re-planting schemes. Some of the more severely damaged mangrove stands should be monitored for the degree of recovery, and the need for a re-planting scheme assessed. Like the proposed seagrass re-planting, this could be very costly and require a large amount of manpower.

It is thought that little can be done to prevent damage by future hurricanes to either sea-grass beds or wetlands. It is suggested that, had the mangrove timber crop at sites like Crater Lake and Florida Lands been harvested as soon as the trees were large enough to be usable, damage and timber losses could have been avoided.

The littoral woodland vegetation is likely to recover from damage very slowly if at all, as the plants have to grow under poor edaphic conditions. Re-planting may be advantageous in many areas of the coast to provide wind-break and scenic attraction. The production of seedlings and planting costs should be estimated.

With the fishing industry, there is little evidence of primary resource damage, so recovery is not a problem. The major costs will be involved with repair and rebuilding of supporting infrastructure. It is noted that national contingency plans for hurricane disaster did not include gear replacement for fishermen, so fishing was disrupted for an unacceptable period of time. The economics of such a facility should be investigated, in the light of the considerable losses sustained by the industry.

Economic assessment of an assisted recovery process must anticipate the expected level and speed of natural recovery. Some further expenditure on baseline ecological research would be worthwhile.

5. DISCUSSION

5.1 Utility of the Assessment

In seeking to make an assessment of the economic impacts of Hurricane Gilbert, two major problems have been identified: (a) the absence of a detailed inventory of the country's coastal and marine resources, and (b) the shortage of information on the value and current utilization of these resources. The types of resource damage have been described and the sectors of the economy experiencing losses identified, but there is an obvious problem evaluating the losses in the absence of detailed biological information on the extent of stock damage and potential recovery.

The expected variations in the pattern of resource recovery introduced the further difficulty of assigning a loss period for economic assessment. Losses of satisfaction to tourists and residents from beach erosion were considered for a three to four month period, due to the apparent rapid recovery of the resource. Resource costs to the fishery could be assessed for a similar period, by comparing expected catch with actual catch in the months following the hurricane; but, if coral reef habitats are going to take more than eight years to recover, the loss period may need to be greatly extended.

With the exception of hotel beaches and other resources in the tourism sector for which official data on hurricane costs are beginning to emerge, the major part of the coastal and marine resources under consideration is utilized directly or indirectly at the subsistence level. This is a further reason why market data are sparse and difficult to obtain. This suggests, with the exception noted above, that the costs of hurricane damage were greater in the subsistence section of the economy.

By identifying gaps in the database, both for the resources and resource utilization, the study provides a framework for further research and analysis. Although unable to provide satisfactory hard data, it suggests also what the long-term effects of the hurricane might be and, thus, identifies priority areas for aiding recovery. These suggestions are listed below:

5.2 Priority Areas for Recovery Effort

Natural recovery is expected in almost all areas of the natural environment subjected to hurricane impact, but the likely long-term nature of the recovery must be recognised. With some systems, like coral reefs, the desirability and feasibility of aiding recovery are questionable, particularly when the scale of the damage and the lack of suitable techniques are considered. In others, such as mangroves where replanting techniques are well researched, investment in recovery may not be justifiable until more is known about the level of economic dependence on mangrove resources. Priority areas for recovery effort should be those where (a) further natural resource loss or (b) secondary negative environmental impacts may occur if action is not taken. Until further study of the effects of Hurricane Gilbert has been carried out, the following areas are identified:

(i) Watershed Management

Evidence presented by NRCD (Appendix 7) suggests increased freshwater run-off and sediment loading as a result of hurricane damage to upland forested areas. Replanting of damaged forest and prevention of soil erosion is required urgently to guard against deterioration of inshore water quality, and the negative ecological and aesthetic effects of this on the coast.

(ii) Repair to Fisheries Infrastructure and Coastal Defenses

As identified by Aiken (Appendix 1) and NRCD (Appendix 7), damage to beaches and fishing equipment has caused identifiable losses to an important sector of the economy; and the effort needed for recovery of the industry can be quantified. Secondly, there is need for repair of coastal defenses, in order that roads, coastal property and facilities can be used again.

(iii) Repair to Public Beaches

Repair to private beaches and other facilities in the tourism sector is well underway and that sector is likely to receive attention because of its direct importance to the economy.

There is a danger that beaches used by residents will not be given the attention merited by their heavy use and t hat further deterioration may result.

(iv) Replanting of Littoral Woodland

Littoral woodland almost certainly requires replanting, as its natural recovery rate is likely to be slow. The aesthetic, wind screening and sand stabilising properties of this vegetation make replanting an economic proposition. Seafront property owners could be encouraged to replant, but some public effort will be required in selected shoreline areas.

5.3 Key Areas for Marine Resources Research and Management Effort

The areas for research and management effort all relate to the effects of the hurricane; particularly for improving the data base on resources, their use and levels of damage, but also for a better understanding of the long-term effects of disasters on coastal and marine resources. An order of priority is suggested.

(i) The preparation of an accurate, detailed **inventory** of the coastal and marine resources of Jamaica (beaches, mangroves, seagrasses, coral reefs, seabirds, etc.).

(ii) An in-depth study of **resource economics**, to include: available stocks, types and quantification of resource use, dependence for employment directly and indirectly, markets, etc.

(iii) Monitoring **run-off and sediment loads** from all major rivers and analysing the effects on coastal ecosystems. This should be supported by development of a strategy for watershed management, with an emphasis on protecting the marine environment.

(iv) A study of the rate of recovery of the **artisanal fishery** in locations where gear and infrastructure were damaged. This has as its objective the production of a contingency/recovery plan for the fishing industry for use in future disasters.

(v) A study of the re-establishment of commercial **fish populations** on selected coral reef fishing grounds, where damage is recorded.

(vi) Comparison of long-term **beach profiles** (from air photos) with present profiles, in an attempt to monitor the rate and direction of recovery.

(vii) A detailed study of the island **sand budget** (patterns of supply, long-shore drift, storage and loss); in order to understand the beach erosion and recovery process and to identify sources of sand which might be available to the construction industry. The latter as an aid to control of illegal sand removal, which might be important to beach recovery.

(viii) Study of regeneration rates and extent in different **mangrove** communities. This will aid in accurate estimation of eventual damage/losses from hurricane damage, but also identify locations where aided recovery may be required.

(ix) An investigation of the mangrove **charcoal economy**; with a view to management (ensuring adequate stocks, controlling recovery of hurricane damaged or cut over plots to ensure regeneration of the most suitable species, etc.).

(x) Investigation of **seabird nesting** habitat on the Morant and Pedro Cays to see if aided recovery from hurricane damage is required. This study to support on-going research on techniques for the regulation of egg harvesting.

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7. REFERENCES

ANON 1988 a. Scientists to study and report on Hurricane Gilbert damage. Jamaica Record, 7.11.88; p. 3A.

ANON 1988 b. Royal Navy tests Harbour's depth. Daily G,leaner, 29:11.88; p. 33.

Alexander, T.R. 1968. Effect of Hurricane Betsy on the southeastern Everglades. Quarterly J. Florida Academy of Sciences, 30 (1); 10 - 24.

Browder, J.A. 1976. An estimate of the value of manaroves to the economy based on net primary productivity. Unpublished report, National Marine Fisheries Service, Miami; 3 pages.

Craighead, F.C. & Gilbert, V.C. 1962. The effects of Hurricane Donna on the vegetation of southern Florida. Quarterly J. Florida Academy of Sciences, 25 (1); 1 -28.

Bacon, P.R., Berry, F.D., et al., 1984. Proceedings of the Western Atlantic Turtle Symposium, San Jose, Costa Rica, July 1983; 3) vols, 1138 pages.

Bacon, P. & Head, S. 1985. Formation of a Caribbean Coastal Management Unit. Coastzone '85, 1; 280-299.

Clark, J 1988. Hurricane Gilbert Assails Caribbe an. ICBP Pan American Bulletin, 3 (2); 2.

G.O.J. 1987. Jamaica Country Environmental Profile. Government of Jamaica, Ministry of Agriculture, Natural Resources Conservation Division, and Ralph M. Field Ass. Inc., on behalf of International Institute for Environment and Development; 362 pages.

Green, A. 1989. Tourist arrivals fell two per cent in 1988. Financial Gleaner, 27.01.89; p. I & 13.

Haynes, A.M. 1986. Preliminary report on status and conservation of booby terns at Morant Cays, Jamaica, 1982 - 1985. Natural Resources Conservation Department; 19 pages.

Haynes-Sutton, A. 1988. Hurricane Gilbert strikes Jamaica's unique birdlife. World Birdwatch, 10 (3-4); 1 & 11.

Highsmith, R.C., Riggs, A.C. & DAntonio, C.M. 1980. Survival of hurricane-generated coral fragments and a disturbance model of reef calcification/growth rates. Oecologia (Berlin), 46; 322-329.

Lugo, A.E. & Snedaker, S.C. 1974. The ecology of mangroves. Annual Review of Ecology and Systematics; 39-64.

Meteorological Service 1988. Letter to G. Alleng, University of the West Indies, dated 09.11.88, from the Meteorological Service, Norman Manley International Airport, plus attachments; 3 pages.

Morris, M. 1989. Can Negril be saved from destruction through greed? Sunday Gleaner, 15.01.89; p. 11.

P.I.J. 1988. Economic and Social Survey; Jamaica 1987. Planning Institute of Jamaica; 1-24.7.

Woodley, J.D. et al., 1981. Hurricane Allen's impact on Jamaican coral reefs. Science, 214; 749-755.

Zack, A. 1986. Hydrology of wetlands in the West Indies. Draft paper to the Caribbean Island Wetlands Workshop, October 28 - 29, 1986, Rio Piedras, Puerto Rico.

APPENDICES

Appendix 1

HURRICANE GILBERT AND ITS EFFECT ON FISHERY RESOURCES

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General

The fishery resources of Jamaica have been considerably affected by the passage of one of the most powerful hurricanes in this century, Hurricane Gilbert. To best appreciate the effects of this hurricane on fishery resources, it is perhaps useful to examine briefly where fishing activity takes place and the organisation of the fishery.

Approximately 12,000 fishermen, who are full-time registered commercial fishermen, harvest reef fish, pelagic fish, lobsters and conch resources from the island shelf, principally along, the edges where coral reef development is greatest. Principal fishing gears used are fish traps, called Z-type Antillean traps, which have a long history in the fishery. These traps take approximately 45% of all landings and the remainder of the catch derives from hook and line, gill and seine nets and spearing.

The traps are set from some 4,000 canoes which operate out on the island shelf. Traps are set singly, on or near coral aggregations, generally in waters ranging from -25 to -50 m depth. The distances from the mainland at which traps are set are governed by the location of the shelf edge. As shown in Figure A1.l, this shelf edge where coral development is greatest is on average 2 km from shore along the north coast but approaches a maximum of 20 km on the south coast. Some 30% of the total number of fishermen operate on the north, with 70% on the south coast.

Of considerable significance is the high number of spearfishermen, especially on the north coast where reefs are in closer proximity to the shore. These spearfishermen, who take fish and crustaceans of all sizes, along with the collection of coral by curio vendors, have contributed to the severe decline in reef fish on the north coast. There has been a considerable increase in the numbers of spearfishermen, especially since 1978, due to the relatively low capital outlay involved and the downturn in the economy.

Figure A1.1   Fishing areas of Jamaica and 200m isobath

The Status of Fishery Resources before Hurricane Gilbert

The fishery resources of Jamaica (including scalefish & lobsters) derive primarily from reef environments and certainly around the island shelf are overfished and badly in need of corrective management measures. Catch levels for the 20 year period 1968-1988 have remained at approximately 7,000 tonnes annum^{-1} from the island shelf. This is despite almost a doubling in effective fishing, effort during this period (Aiken & Haughton, 1987a; O'Callaghan, et al, 1988).

Fishing intensity has been shown by several researchers (Aiken & Haughton, 1987a, 1987b) to have reached levels which brought about maximum yield from the island shelf fishery as long ago as 1975/76. Since that time, the fishery has entered the overexploitation stage, typified by declining catch rates as fishing intensity increases.

Overfishing of reef fishes has brought about alteration of the fish community structure itself, where, for instance, there has been a significant decline in the abundance of predatory fishes, such as snappers (Lutjanidae), groupers (Serranidae) and others which have the highest commercial value. Simultaneously, catches have become dominated by less valuable species of fish, such as parrotfishes (Scaridae), surgeonfishes (Acanthuridae) and squirrel-fishes (Holocentridae) (Aiken & Haughton, 1987a).

The economics of the fishery has been altered negatively, therefore, and in real terms the value of the catch is steadily declining. In some areas, where due to overfishing even the herbivorous reef fish have been largely removed, algal growth has increased. An over-abundance of marine algae can smother corals and, through wmplex dynamic interactions, reduce the ability of the reef to support normal levels of reef fish (O'Callagan, et al, 1988).

Reef Structure and Fishery Resources

Jamaican reef profiles or sections, as described by Goreau (19-59), Goreau and Goreau (1973) and others, are typified by a clearly separated fore-reef and back-reef separated by a reef flat and surf zone. Behind the last two zones are the rear zone (just behind the emergent reef flat) and the lagoon zone. The areas routinely fished by traps are all in the fore-reef zone from approximately 20 to 25 m down to a depth of 50 m. Most adults and sub-adults of some 180 reef fish species and 4 species of lobster come from this fore-reef zone, while the smaller juveniles generally inhabit the shallows.

Hurricane Gilbert Damage to Reefs

By way of introduction, the island can be divided into two zones to summarise the hurricane damage, viz. a northern zone from Portland in the east to Hanover in the west, and a southern zone from St. Thomas in the east to Westmoreland in the west.

The phenomena which affected fishery resources were as follows: (a) storm surge, (b) wave action, (c) wind velocity, and (d) terrestrial run-off from storm precipitation.

(a) Storm Surge

Sea levels along the north coast generally rose less than on the south. Information suggests that highest levels were recorded along the eastern section of the island, such as in Portland. In this parish, much damage was done to coral reefs down to a depth of approximately -20 in. The fore-reef all along this coastline was severely damaged by waves accompanying storm surge. Storm surge, produced by the effect of high winds literally piling up water in front of them, pushed seawater ashore into areas often well above the reach of waves.

On many low-lying beaches there was considerable damage to boats (see fishing infrastructure, below) due to these being swept ashore and broken up by waves and/or collision with immobile terrestrial objects.

Again, southern beaches had reportedly less storm surge and those visited in St. Thomas, Kingston, St. Catherine and Westmoreland showed evidence of a surge of approximately +1.5-2.0 m a.s.l. (above sea level). On the north coast surge level was somewhat higher, apparently reaching about + 2.0 m along the northeast section.

(b) Wave Action

Wave action was apparently most severe on the northeastern section of Jamaica, where wind velocity was highest and the coast most exposed. Fishing beaches reporting heaviest damage were found in Portland, St. Mary and St. Ann. Lesser damage was reported also from Trelawny, St. James and Hanover. Considerable damage was said to have been done to mangroves in Trelawny, such as those near Falmouth. The most obvious effect was considerable defoliation of all mangrove trees, breakages of stems and prop roots, particularly in Rhizophora mangle, the red mangrove, at the water's edge.

Fishery Resource Nursery Areas

Most fishery resources (scalefish, crustaceans, etc.) have clearly defined nursery areas (Ross, 1982), which may be summarized as shallow reef areas (-10 m) and inshore areas of mixed coral, reef rubble and algae. Shallow Thalassia (Turtle grass) beds, mangrove areas and some deeper reef areas are important as nursery grounds also.

Hurricane Gilbert's effects were probably greatest in just these areas which, due to their shallowness, were those in which wave action and storm surge were greatest. Examination of several typical nursery grounds on the north coast near Discovery Bay showed, however, that only moderate disturbances had been done to Thalassia beds, even on exposed shorelines. This, perhaps, is a considerable tribute to the wave-energy dispersing effects of the many blades of this marine phanerogam. Undoubtedly, however, there must have been somewhat more damage to nursery areas along the northeast coastline.

Visible effects in these areas were increased size of Thalassia "blow-outs" (eroded edges of large seagrass beds), back reef rubble deposited on top of Thalassia, killing most plants, and short stumps of these seagrasses where previously full grown plants flourished. Significantly reduced abundance of juvenile fishes was quite apparent to observers in all areas examined (Rocky Point, St. Thomas; Discovery Bay; Ocho Rios and Falmouth). Previously, numbers were greater by approximately 50%.

Fishermen's Beaches

In all, it has been officially estimated that Hurricane Gilbert caused approximately J$25M in damage to fishing beaches and Fisheries Division infrastructure, which includes outstation roof loss/damage, fuel pump damage, etc., (R. MooYoung, personal communication). Generally, most damage occurred on fishing beaches on the northeast coast, particularly Manchioneal and Buff Bay in Portland, as these areas were completely exposed. Reports from the Fisheries Division suggest that there was rather less damage on the south coast and that those fishing beaches with gear sheds (with aluminium roofing) suffered some darmage. However, much of this damage on the south coast has already been repaired by persons working on those beaches. Beaches on the south coast reporting much gear shed roof damage include Rae Town, Greenwich Town and Old Harbour Bay. These three beaches have many gear sheds provided for the fishermen.

On the north coast, the beaches at Manchioneal and Buff Bay were among ones with particularly severe damage. At the former, the outstation and its pump were for a time completely inundated by the sea and left buried in sand, beach rubble and boulders thrown up by particularly severe storm surge and accompanying waves. At this beach the fuel pump may have to be completely replaced and major structural repairs are needed to the outstation building. This entire township it should be noted is only 20m from the shoreline and located almost at sea level; it was especially battered by the sea. Buff Bay in western Portland also suffered particularly heavy damage due to the entire beach being covered by many large boulders thrown up by the storm surge and waves. Additionally, two groynes constructed to enhance sand entrapment on this exposed beach were completely destroyed by wave action. The complete coverage by boulders at the time of writing (November 1988) prevents proper usage of this beach by fishermen as well as the public.

While not strictly part of this report, it should be noted that almost 90% of all traps were lost and some 200 boats damaged islandwide. This results in considerable alteration in fishing patterns following the storm. As replacement of traps is necessarily slow, as they are built by artisans, the trap fishery is still depressed at present.

Discovery Bay Reef Damage and Fishery Effects

Discovery Bay reefs are well described in the literature and are known to support (barely) a number of fishermen who operate out of two small sites, Top Beach and Old Folly. There are two major fishing areas, the east fore-reef and west fore-reef. The former is the eastern limb of the Bay, which is dominated by a broad, flat, relatively coral-free slope running into approximately 30m where there is the "drop offs" fringed with coral. This area is convex shaped and in Hurricane Allen (1980) the shape helped focus the waves and the highest breakers were said to have been seen there (O'Callaghan et al, 1981). The west fore-reef encompasses all the reef in front of the Discovery Bay Marine Laboratory. The reef is a series of well developed systems of spurs and grooves which run alternately seaward and may be summarized as being divided by depth into the following zone:

(1) Reef crest (0 to 2 m)
(2) Shallow fore-reef/Acropora palmata zone (-2 to -10 in)
(3) Acropora cervicornis zone (-10 to -20 m)
(4) Fore-reef (-20 to -50 in)
(5) First drop off (> -50 m)

The fishermen report that many traps were swept into deeper water by strong currents during the hurricane and that fish catches were depressed afterwards for several weeks. Of major importance is the loss of 50%, of all traps.

Diving in Discovery Bay showed that, as in the 1980 Hurricane Allen, there was considerable damage to A. cervicornis (elkhorn coral) on the fore-reef, resulting in many of the "fingers" being broken off and scattered on the sea floor in broken masses. In November, these broken dead pieces were being colonised b various algae and were slowly becoming cemented y into the reef floor.

Offshore Fishing Reefs

(a) Morant Cays

Hurricane Gilbert slightly damaged the wooden huts proved by the Ministry of Agriculture as accommodation for fishermen on the Morant Cays on the eastern limb of the Morant Bank, though not severely. All of these huts had zinc roofs and nearly all were damaged to some degree. Due to the greater distance than Kingston from the eye of the storm, there was not a great deal of storm surge and, thus, its effects were rather less (Morant Cays are some 100 kin southeast of Kingston). Reports were received from fishermen of some coral and coral rubble being thrown up on the beaches on these cays, suggesting that there was some damage to shallow water corals. This may affect the survival of juvenile fish and lobsters in that area.

As the hurricane occurred during the marine turtle egg-laying period, it may be assumed that turtle nesting beaches, which are found especially on the smaller uninhabited cays, may have been severely eroded by the storm surge.

(b) Pedro Cays

Much the same events occurred on the Pedro Cays, some 200 km to the southwest of Kingston, where wind caused slight damage to the reefing of fishermen's huts. Storm surge caused some damage to shallow water coral on the exposed east sides of the cays.

Kingston Fishing Port

The very high winds accompanying the passage of Hurricane Gilbert wreaked havoc with the Kingston Fisheries Terminal at East Bustamante Port. All the facility was covered with aluminium roofing and considerable damage was done to the ice factory, the canteen and the covered market hall. The value of the damage to the fishing port is estimated at about J$500,000.

Additionally, two fishing vessels moored at the port were badly damaged by the storm and sank, but were refloated later.

Oysterculture

The island has developed, since 1980 particularly, an oysterculture industry based on the raft mariculture of the mangrove oyster, Crassostrea rhizophorae. In St. Thomas, Port Morant's inner bay called Bowden was the major site of oysterculture due to its larger natural oyster population and its easy access, as well as its relatively sheltered nature from waves and winds.

The grow-out or culture technology has been based since the inception of the project on the use of artificial cultch surfaces, namely cut squares of vehicle types spaced about 10 cm. apart and hung on monofilament lines suspended from large tethered rafts made of bamboo and empty 44 gallon oil drums.

Before the hurricane struck, Bowden Bay supported approximately 80 rafts, moored throughout its reaches. During the hurricane, damage was caused by storm surge and wave action. Storm surge from the open southern end of the bay piled many rafts into each other and generally there was a movement northwards by the rafts. Many sunk and were smashed by high waves. Generally, a 50% loss of all rafts was estimated, in addition to the loss of the roof of the oysterculture office and workshed building. This loss has been estimated at about J$75,000 (see footnote).

Oysterculture rafts in Port Antonio Harbour were damaged also by wave action and storm surge, according to reports recieved. However, it is not known what losses were incurred as this was a private facility. Oyster culture losses at Green Island, Hanover, are unknown at this time, but were probably small as the activities are a small fraction of what occurs at Bowden.

Artificial Reefs

There were four artificial reefs in Jamaican coastal waters. The first and largest was at Jackson's Bay, Clarendon, and the other three at Pigeon Island, St. Catherine, Rackham's Cay and South Cay, Port Royal Cays. These reefs were constructed of motor vehicle tyres specially weighted with concrete and tied into bundles of three to six tyres. Most of these reefs were constructed in the mid 1970's and one in 1986 by the Fisheries Division, Ministry of Agriculture, and were especially located in relatively shallow seagrass-covered embayments which are much like lagoon environments. These reef sites, except Rackham's Cay, generally had coarse calcareous sand floors with extensive turtle grass beds, scattered coral heads and small patch reefs. The average depth for most sites was a proximately 10 m.

Editor's Note: *Little damage appears to have been done to the natural oyster beds in Bowden Bay, which are important as the main source of juveniles for the culture project.*

Jackson's Bay artificial reef contained the highest number of tyres, over 3,000 (Haughton & Aiken, in press) and others had lesser numbers. Several of the reefs were damaged by Hurricane Allen in 1980 and the South Cay reef almost completely destroyed by having many of its tyre bundles (modules) swept into deeper water by wave action at that time. In 1986, between January and July, another reef of about 1,000 tyres set in 6 tyre modules was constructed at -25 to -30 m at South Cay. This reef is of unknown status as no reports or dives on it have been made. However, the depth at which it is located would suggest that it would be undamaged as wave damage did not generally affect the reefs below -20 m.

Reports suggest that there has been again some damage to the Jackson's Bay artificial reef from Hurricane Gilbert. The effects of the damage are to reduce the carrying capacity of the reef. The reefs at Pigeon Island and Rackham's Cay are extremely small and probably contribute very little to fish enhancement as a result.

The monetary damage cannot be properly estimated at this time, but it would take approximately 5 trips of the M.V. Dolphin (72 foot, double rigged Gulf shrimp trawler design) fully loaded with 500 tyres per trip to replace a reef. If it is assumed that 500 tyres cost J$5 each to be prepared and each trip costs J$2,000 in full, this total would be approximately J$13,000.

Socio-economic Effects

Generally the hurricane created problems, through physical damage to the infrastructure and especially submerged fishing gear. Earning losses occurred also, especially among trap fishermen due to these persons being unable to land catches for one week due to almost complete loss islandwide of fish traps and damage to boats. Though it is not possible to give a precise figure for these losses, it is known that at least 7-10 days passed before actual fishing resumed islandwide, and then at levels considerably below normal. Even at the time of writing, 2 months after the hurricane, levels of fishing are still depressed due to a shortage of mainly imported meshwire to replace lost traps.

Furthermore, if we accept that approximately three vendors are supported by each fisherman (Aiken & Haughton, 1986b), with 12,000 commercial fishermen in Jamaica approximately 38,000 vendors were affected and suffered earning losses for several days.

Summary

Hurricane Gilbert's direct hit on the island affected the fishing industry to a considerable extent. There was almost a complete loss of active fish traps at sea, with approximately 5% of all boats being damaged. Fishing beaches were considerably affected islandwide, but damage was greatest along the northeast coastline, especially from Portland to St. Mary. Storm surge caused significant reef damage down to approximately -20 m, especially among the ramose (branching) corals. Most severe trap and. boat losses came from this section of the island. Nursery areas were affected by erosion and reduction in blade length. Also noticeable were reductions in juvenile fish numbers in nursery areas. The long term effects of this damage, coupled with severe overfishing, cannot be predicted precisely at this time, but are likely to be considerable.

Damage to the oysterculture industry was severe also, with an estimated 50% loss of grow-out (production) rafts with oysters, put at approximately J$75,000. The artificial reef at Jackson's Bay was affected by storm surge and tyre modules were swept ashore. Replacement costs would be about J$13,000. Deeper artificial reefs suffered less damage. Fishermen suffered significant earning losses, especially trap or fish pot users who experienced approximately 90% losses. Total islandwide fishing beach, trap, boat and fisheries infrastructure losses have been put at approximately J$25M by the Ministry of Agriculture.

The effects on fishery resources have been considerable, in the opinion of this author, especially in the northeast of the island. Other complex ecosystem interactions between fishes and the damaged reefs are more subtle and more long-term and these effects will only become apparent with time. Short- and medium-term effects may be much in keeping with observations made after Hurricane Allen in 1980, when abnormally great quantities of various macroalgae grew on the reefs smothering some corals already weakened by storm damage. Further monitoring of the fishery effects of Hurricane Gilbert during 1989 is recommended.

Reference

Aiken, K.A. & Haughton, M.O. 1987a. Status of the Jamaican reef fishery and proposals for its management. Proc. 38th Ann. Gulf & Caribb. Fish. Inst. Nov. 1985. Martinique, University of Miami Press; 469-484.

Aiken, K.A. & Haughton, M.O. 1987b. A Management Plan for the Jamaican Fishery. Report to the Ministry of Agriculture Science & Technology; 42 pages.

Goreau, T.F. 1959. The Ecology of Jamaican Coral Reefs: 1. Species composition and zonation. Ecology, 40; 67 -90.

Goreau, T.F. & Goreau, N.I. 1973. Coral Reef Project - papers in memory of Dt. T.F. Goreau, 17. The ecology of Jamaican coral reefs. 11. Geomorphology, zonation and sedimentary phases. Bull. Mar. Sci. 23 (2); 399 - 464.

O'Callaghan, PA., Woodley, J.D., Aiken, K.A. & Haughton, M.O. 1988. Marine Park Development in Jamaica. Report to the OAS Tourism Development Plurinational Project, Montego Bay, Jamaica; 205 pages.

Ross, F.E. 1982. Distribution, Abundance and Development of Young Jamaican Reef Fishes Pt. 3(2) Fish nursery grounds. Scientific Report ODA/UWI Fish. Ecol. Res. Project, 1974 1979, Zoology Department, University of the West Indies, Mona; 121 pages.

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Appendix 2

HURRICANE DAMAGE AT PORT ROYAL

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Damage to the mangrove areas of Port Royal was widespread, with approximately 30% of trees being severely damaged or destroyed. The fringe areas of the mangrove experienced the heaviest toll, especially on the Kingston Harbour side, i.e. the northern and northwestern areas of the swamp. The main damage was to red mangrove (Rhizophora mangle) but large trees of red, black (Avicennia germinans) and white (Laguncularia racemosa) mangrove were all damaged. A large number of the black mangrove trees were uprooted and the area experiencing, heaviest damage was Refuge Cay, which was also an important rookery for a number of birds. A photographic record was obtained.

Defoliation of mangrove trees tended to be high; at one sampling station in the fringe mangrove area litter fall was estimated at greater than 149 g m^{-2} day^{-1} (dry weight). (It is not known how effective litter sampling traps were during the hurricane, as some leaf material may have been blown out of the traps. The measurement is an approximation, therefore).*

Data received from the Meteorological Office, Norman Manley Airport, indicated that 223.4 mm of rain fell on September 12th. Freshwater inputs to Kingston Harbour lowered the salinity for several days after the Hurricane. Surface water samples showed the following:

Date	Salinity o/oo	Sampling station
14 Sept.	14	Port Royal Marine Lab.
17 Sept.	22	Port Royal Marine Lab.
17 Sept.	18	Port Royal mangroves
17 Sept.	18	Plumb Point Lagoon

Received: 9 December 1988

* **Editor's note:** *Unpublished data from Falmouth Rhizophora forest give a maximum litter fall of 6 g m^{-2} day^{-1}.*

Appendix 3

SURVEY AND ASSESSMENT OF HURRICANE DAMAGE TO WETLANDS

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The following is a catalogue of observations on wetlands in several parts of the coast of Jamaica (Figure A3. 1), made during on-the-ground and air surveys in November and December 1988 and January 1989. Reference should be made also to data on wetlands which appears in other Appendix reports. Notes are included also on the associated littoral woodland vegetation, where appropriate.

A. SOUTH COAST

(1) Great Morass, St. Thomas

(28.11.88) Extreme defoliation observed, over 75% of mangrove area, with severe breakage to upper branches and about 30% trunks. This was confirmed by John Lethbridge (personal communication), who noted also evidence from the air of rain flooding and run-off induced erosion effects around the Morass.

(2) Palisadoes

(24.11.88) Low level of damage to Palisadoes mangroves and littoral woodland (near airport); breakage of upper branches and some defoliation. Large trees lost tops and upper branches, but uprooting not observed. Trunks of Rhizophora (red mangrove) up to 15 cms d.b.h. (diameter at breast height) shattered at between 4-5 m above ground. Estimate 50% of mangrove fringe showing some damage.

The presence of a thick ground cover of propagules and germinated seedlings should lead to rapid regeneration of the mangrove area. Mangrove trees in this area have little direct economic value, except minor cutting for charcoal and poles. Increase in fallen timber expected to provide increased supplies of wood for the charcoal industry.

(3) Kingston Harbour/Port Royal

(09.12.88) Air survey: Considerable damage evident around Dawkin's Pond, but this is probably due to cutting and clearance rather than the hurricane.

At Port Royal hurricane damage is most severe on the northern (harbour) side, with 10- 20% breakage. 10% of trees down, largely Rhizophora, with about 30% defoliation.

(4) Hellshire

(24.11.88) Rhizophora all round the Great Salt Pond (D'Aguilar's Pond) lost tops and upper branches, but few main stems broken. Uprooting of Rhizophora not observed.

As above, well developed ground cover of juvenile mangroves. Some cuttting for charcoal in Hellshire, but little around the main pond.

(09.12.88) Air survey: Severe damage all round Great Salt Pond, with defoliation and fallen trees (Figure A3.2). Long Pond mangroves only slightly defoliated, minor breakage. The Flashes area shows 20-30% of trees fallen, but there is evidence of much cutting of mangrove and other timber and active charcoal burning. Percentage of damage caused by hurricane not clear.

(09.12.88) Air survey: Wreck Bay - Hellshire Point mangrove area showing 20-30% breakage, particularly to old Rhizophora, but only two or three fallen.

(5) Fresh River/Ferry

(08.12.88) No damage evident to mangroves or herbaceous wetland areas on south side of the Washington Boulevard/Spanish Town Road. Water levels as normal over the past two years; egrets and other waterbirds feeding as normal.

(6) Canoe Valley

(09.12.88) Air survey: No conspicuous damage to tree vegetation and no flattening of herbaceous wetland plants.

(7) Milk River Bay

(09.12.88) Air survey: 10-20% upper branch damage, particularly in tall back mangrove area. Defoliation not conspicuous on fringe areas. Eroded mangrove is present all along the bay, with much undercutting by wave action. This has been noted previously and cannot be distinguished as due to the hurricane.

(8) Macarry Bay

(09.12.88) Air survey: High mangrove at back inland side of the lagoons showing broken and fallen trees; damage 10-20%. Large quantities of tree debris, including some mangroves, off the mouth of the Rio Minho. Large flocks of waders present in this area.

(9) West Harbour

(09.12.88) Air survey: The mangrove fringe of the main harbour/lagoon area shows little hurricane damage. Northwest area fringe with minor defoliation and branch damage, but widespread defoliation and mortality in the back swamp areas (which had been observed prior to

Figure A3.1 Wetland Locations

Hurricane Gilbert). Some of this mortality may be related to pond fish culture and salt production activities in the area, while normal mangrove successional effects are thought to be involved in other areas.

Similarly, some mortality has been observed previously in the centres of small overwash mangrove islands in the eastern harbour mouth area; making the detection of hurricane damage difficult. The seaward fringe/barrier islands area showed minor defoliation and branch damage, 3-% in upper parts only. Dolphin Island showed slight defoliation all across, but particularly on the eastern fringe.

(10) Rocky Point

(09.12.88) Air survey: There was existing severe damage to the mangrove environment prior to the hurricane, so storm damage cannot be assessed. Burial Ground mangrove area is virtually devoid of living trees and there is much mortality on either side of the road to the bauxite dock.

(11) Salt River Bay/ Cockpit-Salt River Swamp

(09.12.88) Air survey: Some defoliation evident on Long Island, about 10%. No damage evident north of Salt River; the large area of marsh showed no evidence of flattening or other disturbance. North of the Cockpit River about 10% of trees fallen.

(12) Goat Islands

(09.12.88) Air survey: 20-30% defoliation along south mangrove shore, especially between Little and Great Goat Islands. At the southeast tip of Great Goat Island 5-10% of trees fallen.

(13) Cabarita Swamp (St. Catherine)

(09.12.88) Air survey: Cabarita Swamp had much dead and dying mangrove, particularly in the inner basins, prior to the hurricane, so this cannot be distinguished readily from storm damage. In the main (western) part of the swamp there was no evidence of defoliation or other damage, no trees fallen in fringe areas. Southeast area fringe, following round through the Needles west of Coquar Bay, 10-20% defoliation only.

(14) Coquar Bay - Manatee Bay

(09.12.88) Air suvey: Minimal breakage evident, less than 5% loss of leaves and branches, although clearly evident in some areas. Some defoliation in taller trees in the back swamp areas.

No damage or defoliation evident at Old House Point.

Figure A3.2 Percentage defoliation and branch breakage around Great Salt Pond, Hellshire, and areas of destructive human impact

B. NORTH COAST

(15) Mammee Bay (St. Ann)

(08.12.88) Much damage to the foreshore and littoral vegetation, which included toppling of several old Conocarpus trectus (button mangrove) trees (Fig. A3.3).

Some defoliation and breakage to mangroves at the western end of the beach also.

(16) Priory

(08.12.88) Relatively little damage to mangroves; some fringe Rhizophora with top branches broken at 3 m above ground (Fig. A3.4). Little defoliation and branch loss, about 5%, on the eastern/windward side.

(17) Llandovery

(08.12.88) Minor damage to low fringe Rhizophora, about 5% upper branch breakage. Two to three large Laguncularia trees fallen, and sand and coral debris thrown into wetland for about 30-40 m where it has covered the mud surface (Fig. A3.5). Crabs (Cardisoma) have already burrowed through this coating of sand. Wave surge has thrown debris across the garden of the adjacent resort and water damage is evident in the wetland south of the track.

Large quantities of seagrass debris thrown among prop roots of the mangrove fringe (Fig. A3.6). Algal epiphytic growth on the prop roots does not appear to have been damaged.

(18) Pear Tree Bottom

(29.11.88) Littoral woodland zone severely damaged, including loss of some button mangrove (Conocarpus) and small Rhizophora (Fig. A3.7). The stand of tall Rhizophora in the central part of the bay used as a roost by egrets and other waterbirds lost two main trees and the tops of several others (Fig. A3.8). Coral rubble and tree debris thrown across road into main wetland area. No visible damage to herbaceous vegetation in the wetland; common waterfowl (moorhens and egrets) present in the expected numbers.

(01.01.89) Despite damage from the hurricane, birds still use the mangrove trees for roosting. Observations between 1740-1810 hrs showed the following numbers:

Cattle egret (Bubulcis ibis)
Little blue heron (Florida caerulea)

(19) Crater Lake, Discovery Bay

(29.11.88) Tall mangrove thinned out (Fig. A3.9), with loss of trees throughout the stand and much defoliation.

(08.12.88) Trees up to 28.4 cm d.b.h. fallen, by bending over or crushing of the trunk just above the prop roots rather than being uprooted (Fig. A3.10). Upper part of forest torn out at from 5-6 in above ground level, with loss of vines and epiphytes. Ground litter of mangrove leaves, vine leaves and stem material of between 300-500 g m^{-2}, compared with previous standing litter crop at 200 g m^{-2}. Prior to the hurricane vines were particularly abundant on trees along the roadside fringe; these were not a natural part of the mangrove forest so their loss may be beneficial to recovery of the forest.

Peter Reeson (personal communication) reports a similar situation in the Royal Palm Forest Park in the Negril Great Morass, with damage to about 30% of the palms by defoliation and removal of epiphytes; particularly Phyllodendron and Ipomoea, whose growth had been promoted by man-made clearings in the forest.

Dense ground cover of mangrove seedlings was observed and much more light is reaching the forest floor as a result of removal of much of the canopy at Crater Lake.

Mangroves fringing Crater Lake itself appear not to have been damaged by Hurricane Gilbert.

(30.12.88) Fallen trees at Crater Lake were oriented generally south or south-south-west, suggesting that they were felled by winds from the north or north-north-east sector.

Measurements made in the northern area of the Crater Lake mangroves, where damage was most severe, showed approximately 60% of Rhizophora trees broken or fallen. Damage was spread over an area from 50-100 m wide for about 600 in parallel to the main road, or about 4.5 ha. Loss of potential timber crop from this mangrove stand was estimated at approximately 2,000 m.

(20) Rio Bueno

(08.12.88) West of the town, large quantities of coral debris and sand thrown into littoral woodland and mangrove fringe. Scrub Rhizophora and Laguncularia uprooted and upper branches damaged along western margin (Fig. A3.1 1).

The calculation was based on data previously recorded on forest structure at Crater Lake and measurements of fallen timber sizes, as follows:

Density of trees	1,800 ha^{-1}
Mean length of usable timber (above buttresses, below small branches)	15 m
Mean circumference of fallen trees	60 cm
Mean timber volume per tree	0.4 m^3
Timber volume in plot	720 m^3 ha^{-1}

Figure A3.3 Damage to Conocarpus, Terminalia *and coconut trees at Mammee Bay.*

Figure 3.4 Minor wind damage to fringe Rhizophora *at Priory.*

Figure A3.5 Sand thrown into wetland at Llandovery.

Figure A3.6 Seagrass blade debris thrown into fringe Rhizophora *at Llandovery.*

Figure A3.7 Littoral woodland, including Conocarpus *and* Laguncularia. *uprooted at Pear Tree Bottom.*

Figure A3.8 Damaged Rhizophora *at the egret roost at Pear Tree Bottom.*

A good ground cover of mangrove seedlings was present, so that some regeneration of the forest is expected. Measurements made in two study plots gave the following data:

Mean number of Rhizophora seedlings	12 m^{-2}
Mean height of Rhizophora seedlings	56.88 cm
Size range of Rhizphora seedlings	42 to 104 cm
Mean number of Laguncularia seedlings	55 m^{-2}
Mean height of Laguncularia seedlings	17.27 cm
Size range of Laguncularia seedlings	12 to 30 cm

Seedling have been labelled in the sample plots for further study of Growth and regeneration in the forest stand.

(21) Trelawny Beach Hotel

(29.11.88) Major part of mangrove area east of the hotel suffered some damage, but largely as broken upper branches and some defoliation. Mangrove on western side is being cut and cleared or filled in.

(22) Falmouth

(29.11.88) Florida Lands area, east of Glistening Water, much thinned and over 50% de foliated (Fig. A3.12) with breakage to upper branches and loss of nearly all tall trees. 50-60% of the felled (Fig. A3.13). Trunks were broken above the buttresses; but there was little disturbance to the prop roots and no uprooting

Unpublished data from an April 1986 forest mensuration study at Florida Lands show there were only 12 trees in a 300 m^2 plot, with the following characteristics:

Parameter	Mean size	Largest tree
Height of tree	16 m	20 m
Height of but tresses	4.6 m	6 m
Diameter (breast height)	23.3 cm	35.7 cm

Large quantities of dead mangrove debris, including large trunks, from the dyked area to the east of the remaining live mangrove, was washed onto the dirt road and into the mangrove fringe. Debris showed signs of having been transported from NE to SW, probably by wave surge.

Stands of black mangrove on south side of the road heavily damaged with only 10-20% of trees uprooted, but about 80% defoliated (Fig. A3.14).

(29.12.88) Florida Lands, much standing water; waterbirds present in small numbers. Pelicans and little blue herons still roosting on mangroves at the eastern margin of Glistening Water Bay, despite the tree damage.

Figure A3.9 Wind damage to tall Rhizophora *basin forest at Crater Lake, Discovery Bay*

Figure A3.10 *Rhizophora* *tree bent above the buttresses at Crater Lake, Discovery Bay.*

(01.01.89) Mangrove area immediately east of the Martha Brae River, north side, showing little damage; previous records show that this site had lost the majority of the large trees to charcoal cutters before the end of 1987.

(29.11.88) Main road west of Martha Brae River, with some Rhizophora and Laguncularia uprooted in coastal fringe. Hague Swamp area, south of road, showing moderate damage; some slight defoliation of scrub mangroves and drying of large areas of Acrostichum, the latter possibly as a result of storm surge throwing salt water over the fronds of this swamp fern.

Half Moon Bay mangrove area, west of Falmouth Town, appears greatly thinned out, but this may be as a result of charcoal burning rather than the hurricane. Previous records show that the majority of large mangrove trees had been removed before the end of 1987.

Safari Park mangrove area, west of Falmouth Town, 30- 40% defoliation of mangroves north of the road, several trees down and much upper branch breakage.

(23) Salt Marsh

(29.11.88) South of the road: all the Rhizophora has gone from the western side of the main pond; but appears to have been cleared for a construction camp rather than by the hurricane.

South of the road, west of the pond, the stand of mature Avicennia has been severely damaged. There is almost 100% defoliation, and 40-50% of trees uprooted. Fallen trees are oriented in a southwesterly direction (Fig. A3.15). The stand has sparse seedling cover, but scattered young trees and some coppice regrowth, both at about 2 m high.

North of the road: Some defoliation and 25-30% breakage to upper branches.

The landward side of Saltmarsh Lagoon showed similar damage. However, sessile biota attached to mangrove roots on this side of the Lagoon appear not to have been disturbed. Populations of the flat tree-oyster, Isognomon bicolor, the mussel, Brachidontes citrinus, and common algal species show densities similar to those recorded previously.

The seaward side Rhizophora fringe of Saltmarsh Lagoon showed severe defoliation and upper branch breakage. Damage was spread throughout the whole stand, and marked above 3-4 m.

Egrets and herons still roosting on damaged trees in the central part of the mangrove fringe.

Figure A3.11 Coral debris thrown into wind damaged fringe mangrove and littoral woodland, Rio Bueno.

Figure A3.12 Defoliation of tall <u>Rhizophora</u>, *Florida Lands, Falmouth.*

Figure A3.13 Tall Rhizophora broken above the buttresses, Florida Lands, Falmouth.

Figure A3.14 Defoliated Avicennia *woodland, east of Falmouth*

Figure A3.15 Uprooted Avicennia *trees, Salt Marsh.*

Figure A3.16 Defoliated and felled trees, Wyndham Rose Hall wetland.

(24)Seacastles/Wyndham Rose Hall Wetland

(29.11.88) Storm damage includes breakage to 20-25% of trees, largely Laguncularia, Conocarpus and mahoe. Defoliation of most of high branches (Fig. A3. 16). Less than 10 trees uprooted and fallen; major damage appears as slight displacement of sprouting coppiced Laguncularia, which show the northern side of the knolls uprooted and/or loosened. The wetland appears to have restabilised after the hurricane (see Greenaway report below), as freshwater aquatic plants and waterfowl populations appear riot t6 have been damaged by salt water wash or spray.

(25) Wyndham Rose Hall to Montego Bay

(29.11.88) Similar level of damage all along on north side of main road; 25-30% upper branch breakage and severe defoliation, but little uprooting.

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Appendix 4

POST HURRICANE GILBERT REPORT: LLANDOVERY AND PORT ROYAL

By. Pamela Clarke
Zoology Department
University of the West Indies, Jamaica

(1) Llandovery (St. Ann)

The site was visited approximately two weeks after Hurricane Gilbert. Before entering, the mangrove, a grassy lawn is normally encountered. This area, approximately 30 in wide from the shore inland, was completely covered with sand and coral debris. The depth of the covering was approximately 6 cm. The moist, black surface of the mangroves was also covered with sand. It was noted that the sand covering did not extend to the landward limit of the mangroves, but only for about 20 in from the beach.

Another clear result of Gilbert was the loss of leaves in the mangrove canopy; about 60% defoliation. Sunlight penetrated the mangroves more readily than before Gilbert, making the environment very hot.

The number of broken tree limbs and trunks was minimal, approximately 10-15%. Progress through the mangrove area was not impeded by fallen or broken branches.

The sand bar running parallel to the beach which was previously below the water surface at low tide was now clearly visible. A fisherman was seen standing on the bar above water level.

(2) Port Royal

Mangroves on the north side of the Palisadoes near Port Royal were surveyed three to four weeks after the Hurricane; the site being close to Warlands - second cemetery. Compared to Llandovery, there was approximately three times as much damage to trunks and branches. The once clear pathways from road to lagoon were impassable.

Red mangroves sustained the most damage. This was very distinct in the region behind the cemetery. The black mangroves appear to have been more resilient. Within some areas the degree of loss in the canopy was greater than others. Again, the region behind the first cemetery suffered a loss of approximately 50%, compared with the region between Warlands and the Old Naval Cemetery which experienced a loss of less than 10% in the canopy. The usually cool mangrove environment was much hotter as a result of loss of the canopy. There was also a marked odour coming from the mangrove substratum, suggesting that hurricanesurge or waves had disturbed the decomposing organic matter in the sediments.

Few termite nests were thrown to the ground following breakage of their supports (4 out of 34 counted earlier). Some large nests remaining on their supports had been loosened, where they are normally firm to the touch. Loss of outer nest material was evident in places, probably due to damage by failing timber, but had been patched up by the time of the survey.

Among the mangroves fringing the lagoon there was marked increase in the level of solid waste pollution. Large numbers of drink cartons and other debris were observed. This suggests that floodwaters had washed increased quantities of garbage into the Harbour.

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Editor's *Note:The effects of greatly increased quantities of fallen timber and damaged branches on termite populations in mangrove areas require investigation. Increase in potential food supply may be offset by the accompanying habitat damage in mangrove environments.*

Appendix 5

PHYSICAL AND CHEMICAL EFFECTS OF HURRICANE GILBERT ON THE WETLAND ADJACENT TO WYNDHAM ROSE HALL HOTEL

By: Anthony M. Greenaway
Department of Chemistry
University of the West Indies, Jamaica

(The following data results from studies done under contract to Caribbean Environmental Consulting Services Ltd., and is reproduced by kind permission of Mr.John Algrove,Urban Development Corporation, Kingston.)

In the small coastal wetland adjacent to the Wyndham Rose Hall Hotel, St. James, the effect of Hurricane Gilbert was to raise the water level and alter the specific conductivity of the water. Water level was measured at a stave at Site 1 (Figure A5.1). Conductivity changes differed at different sampling sites.

Water level rose slightly at Site 1, but returned to pre-hurricane levels within one month. Conductivity at Sites 1 and 6 rose to approximately twice pre-hurricane levels, and was slightly elevated at Site 5, suggesting that sea water had entered the normally isolated wetland. At the more landward Sites 7 and 9, a decrease in conductivity indicated increased input of fresh-water, probably from increased surface run-off. Conductivity levels had begun to return to pre-hurricane levels one month later (Table A5.1).

Table A5.1 Water Level and Conductivity at Wyndham Rose Hall Wetland

Parameter		pre-hurricane 23.08.88	post-hurricane 1 01.10.88	post-hurricane 2 29.10.88
Water level (cms)		64.0	73.0	57.5
Conductivity	Site 1	1720	4800	3800
(microMhos)	Site 5	3800	4100	-
	Site 6	2700	5200	4300
	Site 7	3250	2700	2430
Site 9	Site 9	3200	1680	2520

Received: 14 December 1988

Figure A5.1 Sampling sites in wetland at Wyndam Rose Hall

APPENDIX 6

EFFECT OF HURRICANE GILBERT ON BEACHES AND THE STATUS OF COASTAL OIL POLLUTION

By. Margaret A.J. Jones
Zoology Department
University of the West Indies, Jamaica

Beach profiles and general environmental conditions and levels of beach tar have been recorded on 28 beaches around Jamaica (Figure A6.1) over a 13 month period, December 1987 to December 1988. After Hurricane Gilbert these beaches were surveyed on the following dates:

- South coast	- Saturday, September 24
- West coast-	- Saturday, September 24
- North coast	- Sunday, September 25 & Thursday, October 6
- East coast	- Thursday, October 6
- Kingston Harbour	- Thursday, October 6

(1) South Coast: Blueflelds, Parker's Bay, Gut River, Barnswell

Beach profiles on the south coast remained more of less the same and so did the status of oil pollution.

At Barnswell there was a large quantity of dried and rotting Thalassia testudinurn, as well as beach litter, but this was the case before the Hurricane also. Oysters were being cultured on cultch hung from peripheral prop roots of Rhizophora mangle and these were intact and not entangled. This is testimony to how little damage occurred to this section of the mangroves. However, the growth of Crassostrea rhizophorae has been stunted, which may be due to increased sediment.

Levels of stranded beach tar before (August, 1988) and after (Sept/Oct, 1988) the event are shown in Table A6. 1.

Water samples for the analysis of dissolved and/or dispersed petroleum hydrocarbons (DDPH) have also been collected before and after the hurricane. Analysis of these will indicate the effects of terrestrial run-off.

(2) West Coast: Negril, Bloody Bay

The beach at Bloody Bay was covered with rotting blades of Thalassia testudinum, shells, driftwood and litter as far as the back beach vegetation. This beach is normally free of driftwood and litter. The sand was “mushy” and difficult to walk on as a result of layers of seaweed, sand and water beneath. The beach behind Negril Village, beside the jetties, appeared the same. However, as an important tourist area there was ample time for it to have been cleaned, as this survey took place 12 days after the hurricane.

The status of oil pollution remained the same.

(3) North Coast: Hope Bay, Annotto Bay, Ocho Rios, Mammee Bay, Pear Tree Bottom, Discovery Bay, Rio Bueno, Burwood, Montego Bay & Sandy Bay.

Generally, the beaches on the North Coast showed severe sand erosion, which exposed roots of trees, piled banks of sand up to 1 m high amidst the vegetation and piled dried and rotting seaweed on the beaches.

At Annotto Bay, the beach was strewn the whole length with driftwood-and litter about 5 m wide, makina it almost impossible to get from the road to the waterline.

The beach at Discovery Bay is normally accessed through mangroves and rocky shore. Many of the mangroves were uprooted and removed from the waterline, branches were broken and entangled. Getting to the beach through the mangrove after the hurricane was easier than before, as there was now a clear pathway and a reduced number of trees. The beach was originally coral rubble (thrown up from Hurricane Allen, 1980) on top of rock slabs. At the time of this survey the rocks were visible and the coral rubble had been thrown up to and among the vegetation, which is about 20 m from the waterline. The areas with the coral rubble and extensive mangroves and other foliage look "scoured". Oil melted onto rock surfaces and tar balls previously caught amongst prop roots remained the same. In "Scoured" areas a few pieces of tar were found, but most had been thrown to the backbeach. Some fresh pieces of tar were found, which may have been brought up by the Hurricane. Oysters being cultivated under a finger pier were intact, but the strings and cultches were entangled with each other.

At Rio Bueno, the beach was also coral rubble and this rubble is now strewn away from the beach area to cover the pasture land between the beach and the road. The road is approximately 60 m from the beach. No tar was visible after the Hurricane.

(4) Eastern Coastal area: Lyssons, Bowden, Holland Bay, Manchioneel, Long Bay, Blue Hole.

The beaches at Lyssons, Bowden and Long Bay appeared to be only slightly changed, with much redistribution of sand. The status of oil pollution remains the same. The most severely damaged beach was Holland Bay, which now has a very distinct storm beach profile. Originally, this beach was gently sloping and about 30 - 40 m wide from the waterline to stable vegetation (a coconut plantation). The beach is now quite flat with a verticial sand berm about 1 m high on which the coconut trees stand. It appears that the roots of the trees prevented further erosion. The course of the river which empties in this area was lightly altered.

Older pieces of tar were found adjacent to the berm and fresher pieces, as usual, closer to the waterline. The oil pollution at Holland Bay and Manchioneal does not appear to be significantly different from the previously recorded level.

The road leading from Blue Hole was impassable, as it was completely broken away by wave action. Sand was thrown up to form a bank about 1.5 m high against a brick wall that is about 10 m from the waterline. Oil pollution status remained the same.

Coconut trees fringing the beaches of the east coast were badly damaged; branches totally or partially torn off, roots exposed and whole trees uprooted. At Holland Bay, for every tree that was left standing at least five were down. The vegetation was badly damaged at this site making the entire Bay visible from a point just off the main road, which was not possible before.

There was considerable slumping and collapse of the cliff area near Hector's River. Information received suggests that oyster culture racks at Bowden were damaged by the Hurricane with consequent economic losses.

(5) Kingston Harbour and its Environs: Plumb Point, Great Salt Pond

Because of the nature of the rocky shore environment at Plumb Point (huge boulders and rock slabs) no physical change in the coastline was observed. Visible oil pollution occurred as tar melted onto rock surfaces and, therefore, the amount remained the same. At Salt Pond Beach, there was a large amount of litter, driftwood and specks of fresh tar before the Hurricane and this situation remained unchanged after the event.

Mangrove oysters, Crassostrea rhizophorae, were being cultured for experimental purposes under a board dock at the Port Royal Marine Laboratory. There was complete structural damage at the dock with total loss of the oysters.

Conclusions

The beaches on the eastern and north coasts were more severely damaged, as was visible by the extent of sand erosion, exposed roots, uprooted trees and scouring. The south coast beaches appeared not to have sustained as much damage.

From the data presented (Table A6.1), it can be seen that oil pollution by beach tar occurred mainly in three areas of the island. After the Hurricane, the pollution was still restricted to these areas although there were variations in the actual quantities of tar found at individual sites. In some cases there was more tar, in other cases there was less. It must be noted that over the whole sampling period there was variability in the amounts of tar found at each site from month to month. Until all data is collected and properly analysed, firm conclusions should not be drawn on the two month's data presented.

However, on the north coast the absence of tar after the Hurricane is anomalous, as tar was always recorded at those sites. It appears that some of the tar was washed out to sea and some was thrown amongst the backbeach vegetation.

Figure A6.1 Levbels of Stranded Tar (g m^{-1})

Site	August 1988	Sept/October 1988
Negril	0	0
Bloody Bay	0	0
Sandy Bay	0	0
Montego Airport	0	0
Montego Freeport	13.4	0
Falmouth	0	0
Burwood	546.6	0
Rio Bueno	37.4	0
Discovery Bay	4075.4	605.0
Pear Tree Bottom	10.9	0
Priory	4.5	0
Mammee Bay	7.3	0
Ocho Rios	0	0
Annotto Bay	0	0
Hope Bay	0	0
Blue Hole	0	0
Long Bay	0	0
Manchioneel	20.6	86.1
Holland Bay	186.0	95.9
Bowden	0	0
Lyssons	0	0
Salt Pond Beach	7.0	77.9
Plumb Point	10%	10
Barnswell	192.7	65.2
Gut River	0	0
Alligator Pond	0	0
Parker's Bay	0	0
Blue Fields	0	0

* recorded as % cover of rock surfaces

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Appendix 7

EXTRACTS FROM NATURAL RESOURCES CONSERVATION DEPARTMENT. FILE NO. 11/2/7 - HURRICANE GILBERT 1988

Made available by Dr. Marcel Anderson
Natural Resources Conservation Department

The following extracts are taken from memorandA and notes made following field surveysconducted from 20th to 27th September 1988. The Natural Resources Conservation Department (NRCD) has a collection of colour photographs taken during these surveys. Localities mentioned in this list are shown in Figure A7.1.

(a) Memorandum: L. Gardner, P. Campbell, E. Foster, 20.09.88

Survey from Turtle River to Cibony:

(1) Public Beach West of Fishermen's Point

Beach erosion up to 35 ft. Mouth of Turtle River blocked by sand and debris.

(2) Mallard's Beach

Wave action 25-30 ft, shown in damage to tree roots.

(3) Americana Hotel Beach

Accumulation of reef debris.

(4) Hotel Sombra

Major sand loss from the beach.

(b) Memorandum: L. Thompson, J. Taylor, P. Campbell, 22.09.88,

Portland and St. Mary:

(5) Annotto Bay

Sand accretion and much debris giving foul odour to the water. River at western end with mouth opened to the sea.

Figure A7.1 Beach Localities

(6) Lynch Park Bathing Beach

Sea came 100 m into coconut trees.

(7) Buff Bay

Main road under water during the Hurricane, as shown by accumulated debris. Sand accretion at Buff Bay Seaside Park.

(8) Orange Bay

Sand accretion. Fresh corals, Acropora, Montastrea and brain coral, thrown up on the beach.

(9) Hope Bay

Sand accretion.

(10) St. Margaret's Bay

Sand removed from the beach. Evidence of flooding across the roadway.

(11) Norwich Beach

Notes “reappearance of the beach”.

(12) Port Antonio

Sand accretion in the East Harbour. Many coconut trees down and high of debris on the shore.

(13) San San Beach

Loss of littoral trees.

(c) Memorandum: L. Gardner, 0. Morgan, 26.09.88

St. Ann.

(14) Public beach between Turtle River & Sailor's Hole River

Erosion to 12 m. Sand deposited at back of beach.

(15) Fishermen's Beach - Ocho Rios

Erosion to 10 m. Wave surge reached to 180 m. Sand accumulation at the back of the beach.

(16) Between Fishermen's Beach & Bauxite Pier

Wave heiaht estimated at 7 ft (from broken littoral trees); shoreline cliff behind bus shelter eroded.

(17) Dunn's River Falls Beach

Significant sand deposit at back of the beach. Much coralline debris on the reef West of the beach.

Wave height estimated by local resident as 20 ft; but damage to littoral vegetation suggests it was more like 12 ft.

(18) Eden II

Eastern beach eroded to 60 m inland; sand loss replaced by pebbles. Some sand thrown up onto back beach. Much of the littoral vegetation uprooted.

Western beach accreted.

Highest waves 3-5 ft, at 8-20 m from the waterline. Waves estimated at 30 ft at the reef by an observer.

(19) Mammee Bay Estates

Erosion extensive to 60 m inland. Wave surge to 180-200 m inland. Littoral vegetation extensively damaged to 60 m inland. Sand accretion behind the vegetation area.

(20) West Point Villas

Waves overtopped a 2 ft berm. Coral debris and sand thrown 300-350 m inland.

(21) Roxburgh Public Bathing Beach

Erosion to 5 m inland. Rock debris thrown to 50 m inland, plus some sand. Plant debris thrown to 90 m inland.

Highest waves estimated at 6 ft.

(22) Priory Public Bathing Beach

Erosion to 15 m. Sand deposited at the back of the beach. Wave surge to 120 m.

(23) Western shoreline of Priory

Erosion to 50 m. Wave surge to 70 m inland. Littoral vegetation completely destroyed, plus 10% loss of coconuts.

(24) Peter's Point

Extensive erosion to 20 m inland. Coral debris thrown to 50 m and plant debris to 60 m. Littoral vegetation damaged by wind and wave action.

Accumulation of coral debris on the reef.

(25) Salem

Severe erosion. Wave surge to 110 m.

(26) Club Caribbean

Total erosion of eastern beach; sand pushed inland. Wave height estimated by local observers as 30 ft at the reef and 10 ft at the poolside.

(27) Silver Spring Hotel

Slight erosion of beach. Extensive damage to littoral vegetation.

(28) Jamaica Jamaica Hotel

Slight erosion up to 50 rn inland. Sand accreted to back beach.

(29) Jack Tar Hotel

Partial erosion, exposing coralline rock foundation of beach.

(30) Ambiance Jamaica Hotel

Severe erosion of beach. Wave height estimated by local observer at 30 ft seawardside of reef and 7 ft at 65 m inland.

(31) Pear Tree Bottom

90% loss of littoral vegetation. Coral and plant debris thrown across the main road and into the wetland.

Accumulation of debris on the reef.

(32) Puerto Seco Bathina Beach

Slight erosion.

(33) Bengal - Queen's Highway

Erosion to 60 m. Wave surge to 150 m. Debris removed from the shore and thrown 120 m inland. Almost total destruction of the littoral vegetation, including seaside almond, sea grape and seaside mahoe.

(34) Bengal - Rio Bueno

Slight erosion to 12 m. Wave surge to 25 m. Slight wind damage to the littoral vegetation.

Massive sediment load producing discoloration in the bay.

(d) Memorandum: J. Taylor, P. Campbell, E. Foster, 26.09.88

(35) Burwood Public Beach

Small net sand accretion.

(36) Seabord Street Fishing Beach

Beach severely eroded.

(37) Half Moon Bay Public Beach

Little damage evident to beach; whereas mangrove forest adjacent to Swamp Safari completely defoliated.

(38) Flamingo Beach

Reef system "exposed" by much fresh debris extending about 20 m seaward.

(39) Ironshore/King Arthurs

Fresh accumulation of reef debris.

(40) Sunset Public Beach

Sand accretion evident.

(41) Club Paradise

Sand accretion evident.

(42) Doctor's Cave Beach

No beach erosion evident.

(e) Memorandum: J. Miller, 26.09.88

Bull Bay to Prospect Beach

(43) Bull Bay

Some erosion.

(44) Albion Beach

Mangrove defoliated ("burned").

(45) Rozelle Beach

Beach 75% destroyed, including the groynes.

(46) Lyssons Beach

Build up of sand about 1 ft high.

(f) Memorandum: A. Bailey, 27.09.88

(47) Western Kingston

No damage to the foreshore evident at the fishing beach beside the Causeway, Port Henderson Fishing Beach or Fort Clarence Beach.

(g) Memorandum: O. Morgan, L. Gardner, 27.09.88

White River to Oracabessa

(48) Beach east of White River delta

Storm surge reached 100 m inland. Increase in beach debris.

(49) Sans Souci

Natural beach eroded approximately 25 M inland. Storm surge reached up to 180 m inland.

(50) Tower Isle (Mr. Marsh-Dixon Property)

Beach eroded 55 m. Sand and debris deposited inland. Storm surge reached 90 m inland.

(51) Couples Hotel

Beach eroded over entire 70 m width. Sand stacked inland against buildings. Littoral. woodland suffered minimal damage. Much seaweed deposited on the beach.

(52) Oracabessa

Extensive damage to entire shoreline.

(53) Golden Seas Hotel

Natural beach partially eroded; significant amount of debris and pebbles on the beach.

(54) Boscobel Beach

Beach severely eroded with approximately 90 9c loss of sand. Storm surge 70 m inland.

(55) Plantation Inn

Beach severely eroded; some sand pushed to back of beach but most lost.

(56) Jamaica Inn

Beach eroded, but sand accumulated at back of beach and some quickly returned by natural accretion.

(h) Memorandum; L. Gardner, 28.09.88

Gives the following estimates of costs resulting from the Hurricane -

	JA$000's
Repair to change facilities on public beaches	2,410
Repairs to sea walls (6017,c damage	22,000
Repairs and replacement of groynes and jetties (8017,c damage)	16,000
Watershed rehabilitation	66,000

Rehabilitation of wetlands used as a nursery	7,000
Rehabilitation of severely eroded	500

Note: *Reports damage to grqynes on the Palisadoes, Long Bay, Buff Bay and White Horses, affecting stability of these beaches.*

(i) Memorandum; D. Lee, 28.9.88

Storm surge varied between 50 ft and 100 yds along the south coast and 50 ft to 350 yds along the north coast in areas visited. Both erosion and accretion were noted. Memorandum suggests recommending set-back of infrastructures as part of the planning, for future storms.

(j) Undated Summary Table

Table gives the following data on increase-s in silt load "deposits" in various rivers (see Figure A7.1):

RIVER	PERCENTAGE
Martha Brae River	5
Montego River	5-7
Great River	10
North west coast (Lucea East & West, Davis Cover, Green Island Rivers)	15
Hope River (St. Andrew)	40
Morant River	80
Plantain Garden River	80

Appendix 8

UWI SUB-AQUA CLUB SURVEY OF EXTENT OF DAMAGE AT OCHO RIOS- MARINE PARK DUE TO HURRICANE GILBERT

USAC - University of the West Indies
Kingston, Jamaica
Participants: Ralph Robinson, Expedition Leader
Mona Lindo, Karen Roberts and Gillian Elliot

This preliminary survey was conducted on 18.12.88 along the two transects shown in Figure A8.1.

Transect A

Access to the site was gained via the Americana Hotel. A fresh to strong breeze was blowing, with many white horses in the fore reef area. Visibility in the back reef zone was limited to less than 2 m. Due to these weather conditions and the apparent absence of a negotiable channel leading to the fore reef, it was decided not to investigate the latter zone. Rather, it was considered that safe access to the fore reef area is possible only by means of a suitable boat.

As a safety precaution, we entered the water from the hotel beach with snorkelling gear only, together with materials for recording observations. There was a strong 2-3 knot current in a WSW direction in the back reef area. The bottom was composed mainly of large (5-10 cm) stones, many of which were covered with algae. Three coral outcrops were investigated in a straight line en route towards the reef crest. These were made up primarily of raised coral limestone with suprisingly little encrusting algae. There was strong evidence of erosion of the algal mat, particularly on the east and north portions of the outcrops. However, there was no evidence of breakage of living coral; young, 10-20 cm, Millepora was observed intact, and facing the general direction of the current.

Closer to the reef crest (25-35 m distant) there was evidence of small, dead coral fragments strewn over the stony bottom. They became more plentiful towards the reef crest. It appears that coral damaged prior to Gilbert had been broken from the exposed crest, and deposited in the back reef area. The presence of living algae underneath some of these fragments suggested that the coral debris had been recently deposited.

Transect B

Access to the site was gained via Carib Ocho Rios Hotel. A moderate breeze was present, and the water in the back reef area was relatively calm. Visibility extended to about 15 m. There appeared to be no easy access to the fore reef zone from our vantage point behind the condominiums.

Figure A8.1 USAC dive transect locations

In contrast to Transect A, the back reef area on the eastern side of Mallard's Bay was sandy. Large mats of seagrasses were evident, with coverage approaching 60%. Only a few small brain corals were observed, occasionally with some attached fire coral at their bases, and these appeared upright and intact. Deposition of old coral was equally marked, as in Transect A, and extended some 35-40 m from the reef crest in to the back reef area.

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Appendix 9

THE EFFECTS OF HURRICANE GILBERT ON CORAL REEFS AT DISCOVERY BAY

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Introduction

A hurricane is a violent environmental disturbance, tightly constrained in space and time. Its "footprint" of extreme impact may be only a few score miles across, so that its track can be represented by a line drawn on a map of the Caribbean. Wherever it strikes, it passes on with in a matter of hours. To a human observer, it seems like a very rare, extreme event, unpredictable in its occurrence and movement, highly localised, and contrasting sharply with a background of more benign conditions. On a longer time-scale, however, hurricanes are common and ubiquitous; a map of Caribbean tropical storms and hurricanes for the last hundred years is black with their tracks (Neumann, et al., 1987). Thus, despite their small size and brief duration, any point within the hurricane belt is subject to their influence. The temporal structure of that influence depends upon the time scale of other processes affected by storms. Thus, in relation to ecological processes of reef growth or sedimentation, on a time scale of hundreds or thousands of years, hurricanes can be regarded as continuous force. On such a scale, it may be possible to distinguish different intensities of that force due to differences in hurricane frequency in space and time. On shorter time scales, the occurrence of hurricanes is irregular. Their influence on processes measured on a time scale of the same order as the interval between hurricanes, such as the generation time of living organisms, is better understood in terms of the time elapsed since the previous storm.

This preamble will help in understanding the impact of Hurricane Gilbert on Jamaican coral reefs. After Hurricane Charlie (1951), Jamaica enjoyed thirty years free from the impact of large hurricane-generated waves. All kinds of corals flourished, but those which occupied space by rapid growth were especially successful. Acropora palmata (elkhorn) and A. cervicornis (staghorn) dominated large areas in extensive thickets. Rapid occupation of space was achieved by a slender branching morphology; strong enough to resist routine wave energies, but fragile under extreme conditions. In August 1980, Hurricane Allen passed close to the eastern and northern shores of Jamaica and wrought catastrophic damage on their coral reefs (Woodley, 1980). Branching corals were smashed, some massive corals were toppled or shattered, softer organisms like sea-fans and sponges were ripped up, and all were bombarded with fragments and scoured by resuspended sand (Woodley, et al., 1981). The recovery of reefs to their former luxuriance had not occurred by September 1988, when Hurricane Gilbert struck. Thus, although the physical impact of waves on the north coast was comparable to that of Hurricane Allen, the damage to reef organisms was not as spectacular, because the time elapsed since the previous hurricane was so short.

Injury to Reef Organisms near Discovery Bay

My own observations have been limited to the central north coast, and I will not speculate about other areas. But at Discovery Bay, the reef condition is now approximately what it was after Hurricane Allen. Massive corals on reef spurs that remained erect after Hurricane Allen (eg. 93% of Montastrea annularis at -10 m) mostly (97%) withstood Hurricane Gilbert. In reef channels, survival was less good: 35% in 1980, 56% in 1988. Acropora cervicornis, which had begun to recover at some locations, was completely smashed again. The rubble created by Hurricane Allen (A. palmata slabs from 0-7 m, A. cervicornis sticks from 7-22 m) had become cemented together by crustose calcareous algae and the process known as submarine cementation (Land & Goreau, 1970). Under Hurricane Gilbert, the A. palmata slabs were re-mobilized, scrubbed clean and re-distributed. So were the shallower stretches of A. cervicornis rubble; cemented frameworks in deeper water remained intact, although scoured by sediment. Remobilization of the rubble substratum had serious consequences for corals (and other organisms) that had settled on it since 1980: opportunistic species such as Porites astreoides, P. porites, Agaricia agaricites and Madracis mirabilis. Many sea-fans, sea-whips and sponges were overthrown or broken, and piles of rotting corpses accumulated in channels and chutes on the deeper fore-reef, especially at the sill that separates the fore-reef slope from the vertical deep fore-reef at about -55m.

Physical Effects

Resuspended sediment, macerated tissues and terrestrial runoff greatly reduced underwater visibility (and thus light penetration) after the storm, and it took a couple of weeks to return to normal (visibility after two days, 3- m; three days, 6 m; four days, 10 m; nine days, 15 m). High organic loading in deposited sediments was evident for days or weeks in the blackening due to sulphate reduction under the anaerobic conditions brought on by decomposition.

The waves generated by Hurricane Gilbert may not have been as high as those of Hurricane Allen, but their physically destructive impact underwater may have been greater, judging from changes seen in reef structures and sediments. I attribute this to the difference between the tracks of the two hurricanes. Hurricane Allen passed along the north coast, about thirty miles offshore, rapidly moving West by North. At any point along the shore, the direction of the incoming waves changed rapidly, and the period of maximum impact was brief (Kjerfve, et al., 1986). Hurricane Gilbert came overland from Kingston on a track converging with the line of the north coast. At Discovery Bay, hurricane force winds blew onshore for several hours from an approximately consistent direction (North North-east), before veering as the storm passed by, only a few miles to the south. Abrasive rubble and sediment were flung back and forth in the same direction for hours. Linear scarification of the West Fore-reef at Discovery Bay is clearly evident even now, three months later.

Quantities of sediment were removed from the reef terraces. Some was dumped onshore as rubble ramparts or floods of sand, but most was carried downslope; not directly, but North North-east, aligned with the major waves. At 20-25 m, therefore, reef lobes to the east of channels suffered encroachment by sand. Sand clearly flowed down the fore-reef slope and some of it will have passed through the intermittent chutes, off the terrace to the island slope below. On the shallow terrace (3-15 m), small sand channels tributary to the major chutes, have been swept clean. Hardgrounds, apparently representing a Pleistocene basement (L.S. Land, personal communication), have been re-exposed.

At West Rio Bueno, a shallow terrace gives way to a vertical cliff at only -9 in. That terrace supports dense reef growth between deep, narrow sand channels. Hurricane Gilbert caused far more erosion here than did Hurricane Allen. Not only were the sand channels flushed clean, but the sides of same channels were torn out, removing corals and revealing older reef fabric. On the cliff itself, where Hurricane Allen caused little damage to plating corals at -10 and -20 m, Hurricane Gilbert removed most of them (T.P. Hughes, personal communication).

Algae

Since 1983, when a natural epidemic almost eliminated the important herbivorous sea-urchin Diadema antillarum (the long-spined black sea-egg; Lessios, 1984; Hughes, et al., 1985), free-living algae have proliferated on Jamaican reefs (Liddell & Ohlhorst, 1986; Hughes, 1987). Unrestrained by grazing (since herbivorous fish populations have been depleted by fishing), these plants grew more quickly than corals and were out-competing them for space. Small corals were smothered, and larger corals were being slowly overgrown from around their edges. Hurricarne Gilbert scoured the reefs and removed most of this algal growth, giving a brief respite from competition to the surviving corals. But algae were the first obvious colonisers of the bare spaces created by the storm; a fine green turf in shallow water, and carpets of the red alga Liagora throughout the terrace. The brown alga Dictvota also grew quickly in the first three months.

Fish and Fishing

Immediately after the storm, individual fishes showed changes in behaviour similar to those recorded after Hurricane Allen; loss of territories, unusual shoaling, behaviour. In the longer term, Hurricane Gilbert, like Hurricane Allen, will have reduced the carrying capacity of the reefs by reducing their three-dimensional complexity, although the change is less this time. Some fishermen reported increased trap catches after the storm. This could have been due to seasonal movements: to the fact that reef cover was reduced and traps offered more shelter, as well as being more visible; and to the fact that the number of traps in use was greatly reduced. Most fishermen had sufficient warning of the storm only to make their boats secure. Fishtraps shallower than about -25 in were destroyed, while deeper ones were swept downslope to lodge at the sill or drop over the edge.

Conclusion

Hurricane Gilbert was a very severe storm which generated waves of great destructive power. They had a major impact on reefs of the central north coast, which would have been even more catastrophic had not the damage already been done by the close passage of the equally severe storm, Hurricane Allen, in 1980. As it is, Hurricane Gilbert has reset the clock of reef recovery; they are now in a very similar condition to what they were after Allen.

References

Hughes, T.P. 1987. Herbivory on coral reefs: community structure following mass mortalities of sea urchins. J. Expt. Mar. Biol. Ecol., 113; 39-59.

Hughes, T.P., Keller, B.D., Jackson, J.B.C. & Boyle, M.J. 1985. Mass mortality of the echinoid Diadema antillarum Philippi in Jamaica. Bull. Mar. Science, 36; 377-384.

Kjerfve, B., Magill, K.E., Porter, J.W. & Woodley, J.D. 1986. Hindcasting of hurricane characteristics and observed storm damage on a fringing reef, Jamaica, West Indies. J. Mar. Res. 44; 119 - 148.

Land, L.S. & Goreau, T.F. 1970. Submarine lithification of Jamaican reefs. J. Sediment. Petrol., 40; 457-462.

Lessios, H.A., Robertson, D.R. & Cubit, J.D. 1984. Spread of Diadema mass mortality through the Caribbean. Science, 226; 335-337.

Liddell, W.D. & Ohlhorst, S.L. 1986. Changes in benthic 6ommunity composition following the mass mortality of Diadema at Jamaica. J. Expt. Mar. Biol. Ecol., 95; 271-278.

Neumann, C.J., Cry, C.W., Caso, E.L. & Jarvinen, B.R. 1978. Tropical cyclones of the North Atlantic Ocean. NOAA, Washington, D.C.

Woodley, J.D. 1980. Hurricane Allen destroys Jamaican coral reefs. Nature (Lond.), 287; 387.

Woodley, J.D. and 19 others. 1981. Hurricane Allen's impact on Jamaican coral reefs. Science, 214; 749-755.

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Appendix 10.

EFFECTS OF HURRICANE GILBERT ON SELECTED OYSTER CULTURE SITES

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(1) The Great Salt Pond/D'Aguilar's Pond, St. Catherine

The single bamboo and mangrove rack structure set up for experimental purposes in the pond was undamaged. The strings of oysters became twisted among themselves, but the oysters were undamaged. This suggests that wave action and swell were not excessive.

The surrounding mangrove trees were battered by the wind, but none of the trees were uprooted and few of them lost more than their top branches.

The pond has a man-made entrance channel. This was undamaged and there appeared to be no significant chancre to the profile or extent of the beach on either side of the channel mouth.

When the Pond was visited one week after the hurricane there was no visible difference in the colour or clarity of the water from that observed during pre-hurricane sampling periods.

(2) Port Morant, St. Thomas

Many of the bamboo and mangrove rack structures were destroyed. All the bamboo rafts sank or were washed away.

During the hurricane, strings of oyster spat collectors became twisted and coiled around the rack structure supporting them. As a result of this, at low tide these strings were exposed for unusually long periods of time. It was 2-3 days before anyone could get to the strings to unravel them. By the time they were attended to about 60% of the spat had died (Information supplied by Ministry of Agriculture staff). In the near future, this can be expected to have a serious adverse effect on oyster production and the supply of spat to farmers.

There was no serious damage to mangrove trees in the area; and the stands of Rhizophora supporting the natural oyster beds appeared not to have been damaged.

Loss of vegetation on the surrounding hillside could, in the long run, affect soil erosion, which will increase sedimentation in the Bay. An increase in sedimentation could affect filtration rates of the oysters and influence their growth and survival.

(3) Further note added on 03.01.89

Information obtained from the staff of the Ministry of Agriculture's Oyster Culture Project on 3rd January 1989 indicated that a total of 14 rafts and 10 racks had been destroyed by Hurricane Gilbert.

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Appendix 11

LIST OF PAPERS ON HURRICANE EFFECTS ON COASTAL AND MARINE RESOURCE AREAS OF JAMAICA

Aiken, K.A., Bacon, P.P, & Mooyoung, R.R. (In press) Hurricane Gilbert and its effect on Jamaican fishery resources. Proceedings 42nd Annual Gulf and Caribbean Fisheries Institute, Ocho Rios, Jamaica, 5-10 November 1989.

Bacon, P.R 1989a. More on Hurricane Gilbert. World Birdwatch, 11(2); page 14.

Bacon, P.R. 1989b. Editorial. Neotropical Wetlands Newsletter, 4; 1-2.

Clark, J. 1988. Hurricane Gilbert assails Caribbean. ICBP Pan American Bulletin, 3(2); p. 2.

Eyre, L.A. 1968. Preciptation from Hurricane Flora, 1963. J. Tropical Geography, 26; 29-36.

Eyre, L.A. 1989. Hurricane Gilbert: Caribbean record-breaker. Weather, 44(4); 160-164.

Goreau, T.F. 1959. The coral reefs of Jamaica. 1. Species composition.and zonation. Ecology, 40; 67-90.

Goreau, T.F. 1964. Mass expulsion of zooxanthellae from Jamaican reef communities after Hurricane Flora. Science, 145; 383 -386.

Graus, R.R., Macintyre, F.G. & Herchenroder, B.E. 1984. Environmental control of Caribbean reef zonation Experiments in computer simulation. Advances in Reef Science: Atlantic Reef Commission, R.S.MAS. Univ. Miami, joint meeting; 45-46.

Gray, C. 1988. History of tropical cyclones in Jamaica, 1886 to 19S6. National Meteorological Service, Kingston, Jamaica; 23 pages.

Haynes-Sutton, A. 1988. Hurricane Gilbert strikes Jamaica's unique birdlife. World Bird-watch, 10 (3-4); 1 & 11.

Hendry, M.D. 1979a. Historical evidence of shoreline evolution for the Palisadoes, Kingston, Jamaica. Journal of Geological Society of Jamaica, 17.

Hendry, M.D. 1979b. A study of coastline evolution and sedimentology: the Palisadoes, Kingston, Jamaica. Ph.D. Thesis, University of the West Indies, Mona, Jamaica; 225 pages.

Hendry, M.D. & Bacon, P.R. (In press) Effects of Hurricane Gilbert on the Jamaican coast, with particular reference to damage and recovery of beaches. Proceedings 12th Caribbean Geological Congress, St. Croix, 7-11 August 1989.

Jones, E.B. 1986. Coastal vulnerability study of the Caribbean, Volume 3, Jamaica. Report to the Pan-Caribbean Disaster Preparedness Project, Antigua.

Kjerfve, B., Magill, K.E., Porter, J.W. & Woodley, J.D. 1986. Hindcasting of hurricane characteristics and observed storm damage on a fringing reef, Jamaica, West Indies. J. Marine Research, 44; 119-148.

Knowlton, N., Lang, N.C., Rooney, PA., et al. 1981. Evidence for delayed mortality in hurricane damaged Jamaican staghorn corals. Nature (Lond), 294; 251-252.

Liddell, W.D., Ohlhorst, S.L. & Boss, S.K. 1984. Community patterns on a Jamaica fringing reef (1976-1983). Advances in Reef Science: Atlantic ReetCommission, R.S.MAS., Univ. Miami, joint meeting 69-70.

Naughton, P.W. 1982. The Jamaica hurricane season - changing the rhyme. Caribbean J. Science, 18; 107-111.

Naughton, P.W. 1984a. Storm surge risk problems for Kingston, Jamaica Revista Geográfica, 99; 93-97.

Naughton, P.W. 1984b. Flood and landslide damage-repair cost correlations for Kingston, Jamaica. Caribbean Geography, 1(3); 198-202.

N.R.C.D. 1988. Hurricane Gilbert Impact Assessment Update and Plans for Conservation Restructuring. Natural Resources Conservation Department, Ministry of Agriculture, Jamaica; 8 pages.

Ohlhorst, S.L. 1984. Spatial competition on a Jamaican coral reef. Advances in Reef Science: Atlantic Reef Commission, R.S.MAS., Univ. Miami, joint meeting; 91-92.

Ohlhorst, S.L. & Liddell, W.D. 1981. Hurricane damage to Jamaican coral reefs. Geol. Soc. Amer. Abstracts with program., 13; 522.

PCDPPP 1988. Lessons from recent events: Hurricane Gilbert. Caribbean Disaster News, Double Issue 15 & 16, Sept./Dec. 1988; 20 pages.

P.I.J. 1988. Quarterly Economic Report, July-September 1988. Planning Institute of Jamaica, 5(2); 63 pages.

Porter, J.W., Woodley, J.D., Smith, G.J., Neigel, J.E., Battey, J.F. and Dallmeyer, D.G. 1981. Population trends among Jamaican reef corals. Nature, 294(5838); 249-250.

Ralph Fields Associates Inc. 1984. Summary of Proceedings of the Workshop on Storm Surge and Wave Effects (Kingston Harbour Area), November 28, 1984. Report to the Office of Disaster Preparedness and Emergency Relief Coordination, Kingston, Jamaica; 19 pages.

Rosesmythe, M.C. 1984. Growth and survival of sexually produced Acropora recruits: a post-hurricane study at Discovery Bay. Advances in Reef Science: Atlantic Reef Commission, R.S.MAS., Univ. Miami joint meeting; 105-106.

Scoffin, T.P. & Hendry, M.D. 1984. Shallow water sclerosponges on Jamaican coral reefs and a criterion for recognition of hurricane deposits. Nature, 307; 278-279.

Seon, K. (Undated) Preliminary Disaster Catalogue - Jamaica 1559-1951. Office of Disaster Preparedness, Kingston, Jamaica; 32 pages.

Tunnicliffe, V.J. 1983. Caribbean staghorn coral populations: pre-Hurricane Allen conditions at Discovery Bay. Bull. Mar. Sci., 33(1); 132-151.

Williams, A.H. 1981. Effects of Hurricane Allen on back-reef populations of Discovery Bay, Jamaica. J. Mar. Biol. Ecol., 77(3); 233- 244.

Woodley, J.D. 1980. Hurricane Allen destroys Jamaican coral reefs. Nature, 287; p. 387.

Woodley, J.D., and 19 others. 1981. Hurricane Allen's impact on Jamaican coral reefs. Science, 214; 749-755.

CEP Technical Reports

1. *1989*. The Action Plan for the Caribbean Environment Programme: Evaluation of its Development and Achievements (1976-1987).

2. *1989*.Regional Overview of Environmental Problems and Priorities Affecting, the Coastal and Marine Resources of the Wider Caribbean.

3. *1989*. Implications of Climatic Changes in the Wider Caribbean Region - Preliminary Conclusions of the Task Team of Experts.

4. *1989*. Assessment of the Economic Impacts of Hurricane Gilbert on Coastal and Marine Resources in Jamaica.