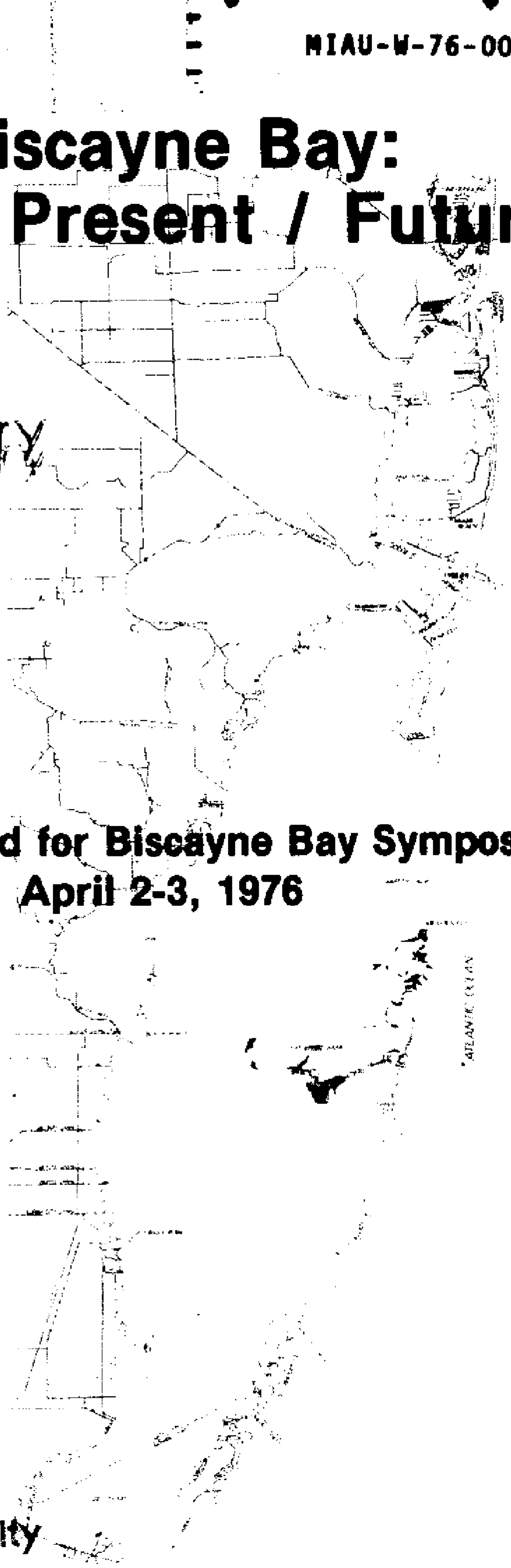
Biscayne Bay: Past / Present / Future



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April 2-3, 1976

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Foreword

The idea of unifying the diverse research activities concerned with Biscayne Bay in Greater Miami, Florida, is not new but no organized attempt to achieve this unity was made until the Chairman of the University of Miami Research Council appointed a Biscayne Bay Ecology Committee in March, 1974. The original committee was chaired by Dr. James C. Carpenter of the Rosenstiel School of Marine and Atmospheric Science and consisted of ten scientists and engineers representing the broad spectrum of research interests in the Bay. In July, 1974, Mr. Thomas W. Bilhorn, then head of the University Sea Grant Advisory Services, offered Sea Grant financial and staff assistance in the event that a workshop on Biscayne Bay could be planned. During the year, Dr. Carpenter's group held a series of well-attended evening seminars at which various members of the faculty presented their work on Biscayne Bay.

As a consequence of the success of the original series of seminars, the Research Council encouraged the committee to continue its coordination efforts on Bay research, and appointed Dr. Anitra Thorhaug, Department of Microbiology, as chairperson in March, 1975. In the summer of 1975, Dr. Thorhaug's committee moved rapidly to a decision to hold a public symposium on Biscayne Bay. It was determined that not only should the presentation cover all areas of known research on the Bay but that there should be an attempt to answer questions about the needs of future research activities by indicating not only what is known about the Bay but just as importantly, what is not known.

As a further response to community needs, the symposium was planned in two separate but related weekends: Symposium I, chaired by Dr. Thorhaug, which was to present all the known research information on the Bay and to publish the presentations prior to the actual forum; Symposium II, co-chaired by Drs. David Cartano and Thomas Clingan, was designed in the American Assembly type format to permit debate on managerial decisions relating to the Bay, using the published papers from Symposium I as a text.

Symposia I and II, as well as the published papers, are jointly sponsored by the University of Miami Research Council, and the Rosenstiel School of Marine and Atmospheric Science, with financial assistance from the University of Miami Sea Grant Program and the U. S. Energy Research and Development Administration.

Eugene H. Man
Dean, Research Coordination
and
Director, Sea Grant Program
University of Miami

Preface

Intensive planning for Symposium I began in the summer of 1975. Later in the fall, Sea Grant offered to underwrite publication of a volume of Symposium I papers to be entitled, "BISCAYNE BAY: Past/Present/Future."

The idea of using Biscayne Bay as a model of subtropical estuaries, although very appealing, had to be discarded in favor of focusing directly on Biscayne Bay itself.

It soon appeared that the material to be presented orally in Symposium I would have required a week to deliver and the written papers could have filled several volumes, so strict priorities were weighed and time and space constraints imposed.

The problem of how much time to devote to each subject was difficult to resolve. The balancing of "hard" science with "soft" science also was a difficult task but it began to resolve itself as lists of speakers were assembled.

We hope this volume will meet at least part of the needs expressed by many groups. The questions of "What is known about Biscayne Bay?", "What are the processes occurring in the Bay?" and "Where do we go from here?" have been addressed by the writers. Extensive bibliographies are included for many subdisciplines. Most important, a synthesis of the physical, geological, and biological processes and man's uses and interaction in the Bay begins to emerge for the first time in this volume.

We wish to acknowledge the financial support of Sea Grant, and the U.S. Energy Research and Development Administration. The Research Council and the School of Marine and Atmospheric Science of the University of Miami, are sponsors of the Symposia and this collection of papers.

Particular appreciation is expressed to the Organizing Committee which arranged Symposium I and the editors and authors who spent many hours preparing this volume.

Anitra Thorhaug
Editor

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MAN'S INTERACTION

MAN'S IMPACT

*These papers were not received in time to be included in this volume, and will be published at a later date.

Oceanography

GEOLOGIC SETTING AND RECENT SEDIMENTS OF THE BISCAYNE BAY REGION, FLORIDA

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ABSTRACT

Biscayne Bay, Card Sound, and Barnes Sound are underlain by a shallow, north-south trending late Pleistocene bedrock basin 2 to 6 meters in depth. It is bordered to the east by a ridge formed by the Key Largo limestone, to the northwest by a ridge of the Oolite member of the Miami limestone, and to the southwest by the low platform of the Everglades. The Basin was first invaded by the sea about 6,000 years ago during the post-glacial Holocene rise of sea level. Sedimentation that has taken place during the subsequent period of slowly rising sea level has been controlled by sediment supply and bedrock topography through its influence on wave energy, tidal currents and wind-driven circulation.

Six major Recent sediment regimes are recognized on the basis of sediment type, sediment body geometry and depositional controls.

(1) Longshore drift of sand from the north has provided an influx of quartz-carbonate sand from the north during the past 4,000 years. This has created the string of sand island barriers bordering northeastern Biscayne Bay. Protection provided by these islands has generated surficial swamp, flat and lagoon environments along the bayward side. A ridge of Pleistocene Key Largo Limestone underlies the northern sand island barriers. This ridge (a) provided seaward protection for lagoon sedimentation prior to about 4,000 years and (b) guided the southward sand drift since.

(2) Quartz sand deposits, derived from the Pleistocene Pamlico sand of the mainland Atlantic Coastal Ridge, dominate several environments in northwestern Biscayne Bay where quartz sand (a) has washed directly into the bay area and (b) has been reconcentrated from eroding mangrove peat shorelines.

(3) Tidal bars and belts of calcareous sand and mud formed (a) along bay margins in energy shadows behind shallow bedrock thresholds (Safety Valve and Cutter Bank), (b) in association with tidal jets extending into the Bay from passes through the marginal limestone ridge (Featherbed Banks), and (c) as ebb and flood deltas adjacent to Caesars Creek, Broad Creek and Angelfish Creek. Sediment produced by organism communities on these tidal bars and belts is important to their maintenance.

(4) Broad mangrove swamps border those protected shorelines having no focus of freshwater influx. Narrow eroding swamps occur along windward shorelines. Areas receiving moderate discharge from the Everglades had (prior to human intervention) narrow marginal mangrove swamps with a broad freshwater marsh of calcitic mud or sawgrass peat behind.

(5) The open bays, away from these marginal sediment buildups contain two sedimentary environments. A quartzose calcareous sand forms a thin veneer over Pleistocene limestone surfaces less than 3 to 3.5 meters in depth. Where bedrock is deeper, seagrass carpeted lime (calcareous) mud has accumulated to a depth of 3 meters.

(6) Non-tidal mud banks, capped by chains of mangrove islands segment southern Card Sound and Barnes Sound.

Future research should focus on (a) fine grained sediment character and dynamics, (b) detailed mapping of bio-sedimentary environments, (c) detailed reconstruction of the depositional history of certain sediment regimes and (d) biogenic influences on sedimentation.

INTRODUCTION

Biscayne Bay is unique among the urbanized coastal environments of the United States. It differs in four fundamental ways. First, Biscayne Bay, although somewhat estuarine in character, is not a drowned river valley. It is (or was prior to man's intervention*) dramatically influenced by the freshwater influx from the everglades system - both by surface and groundwater flow.

Second, freshwater influx did not carry large amount of mineral detritus into the bay. Unlike other estuaries, Biscayne Bay has never been a coastal marine catch basin for great volumes of riverborne sediment carried in upland runoff.

Third, Biscayne Bay is similar in geometry to the typical lagoons of the Atlantic or Gulf coast - elongate parallel to the coast. In Biscayne Bay, however, a rigid pre-existing limestone topography defines the depression filled in by Biscayne Bay waters and recent sediments. Coastal lagoons to the north are superimposed on a mobile pre-existing sand substrate and topography - one that can both be modified by recent processes and provide sediment to recent sedimentary environments.

Fourth, organisms living within the Biscayne Bay region provide essentially all of the sediment that is accumulating in the Bay. Within Biscayne Bay calcareous and siliceous skeletal remains of benthic organisms produce the sediment (Ginsburg and Lowenstam, 1958; Stockman, et al, 1967). In the marginal mangrove swamps and freshwater marl flats, calcium carbonate precipitation, possibly in conjunction with algal mats produces fine calcareous mud (Gleason, 1972; Barron, 1975). Only in northern Biscayne Bay is detrital sediment influx important and this comes not from river influx but from sand drifting south along the ocean beaches the length of peninsular Florida from an ultimate source in the southern Appalachian mountains. Dominance of local sediment production in Biscayne Bay contrasts sharply with other lagoon and estuarine systems of the continental United States in which most of the sediment is carried into the area by river influx (estuaries) or ocean processes (lagoons and estuaries).

In many ways the sedimentary environments and processes of this marginally tropical Bay are more akin to those of the Florida Keys and the Bahamas than to the coastal environments to the north. Realizing this uniqueness is essential to understanding the contained sedimentary environments and to assessing how urbanization affects them.

Sedimentologic studies in the Biscayne Bay region are few and mostly either superficial (in conjunction with biological research) or focused on a very small area. Vaughan (1910) provides a very general early description of sediments in Biscayne Bay and Sanford (1909, p. 229) comments on the distribution of quartz sand along mainland beaches. McNulty (1955, 1956, 1957, 1961, 1970) and McNulty, Work and Moore (1962), in studies on pollution and benthic ecology, have broadly described the distribution of surface sediment types in northern Biscayne Bay.

Bush (1958), in conjunction with foraminiferal studies, attempted to map sedimentary parameters of central and southern Biscayne Bay. Eardley and Goodell (1968) attempted computer analysis and mapping of sedimentary attributes of Card Sound. Both studies failed to use either diving observations or aerial photographic analyses to aid interpretation and extrapolation of data, and results are of limited value.

Kelly and Boersma (1968) and Kelly (1969), in contrast, used extensive analysis of aerial photography to delineate the distribution of biotic-sedimentary environments in Biscayne Bay. Ball (1967) described sediments of the "Safety Value" mud bar belt. Hoffmeister and Multer (1965) have described and age dated the fossil mangrove "reef" at the north end of Key Biscayne. The U.S. Army Corps of Engineers (1961, 1966, 1969) present some sedimentary analyses in conjunction with various beach nourishment proposals.

In 1969 the author described the sedimentary environments and general depositional history of Biscayne Bay, Card Sound and Barnes Sound including the marginal swamps (Wanless 1969, 1970, 1974, 1975). The text of the 1969 report is used extensively in this article, updating observations and interpretations where possible.

A recent study by Warzeski (1975 and in preparation) on Caesars Creek Bank, marginal to southern Biscayne Bay provides valuable new insight into the late stages of the sedimentary history and sedimentary dynamics of the Biscayne Bay region.

Research to date provides a usable general understanding of the sediments and depositional history of the Biscayne Bay area. We have as yet little understanding of the process of sedimentation in this complex coastal system. Especially lacking is an understanding of the character of fine grained sediments and processes of fine grained sediment dispersal and accumulation.

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*This paper is an attempt to document the natural character, history and processes of sedimentation prior to man's involvement with the Bay. Unless otherwise noted, the present environments are described as they were prior to man's modification. The impact of man on this natural sedimentary system is discussed in another paper by the author later in this volume.

GEOLOGIC SETTING

South Florida rests on top of over 4,500 meters of fossil shallow water limestones and evaporites (Applin and Applin, 1964; Puri and Vernon, 1964). These accumulated during the past 130 million years as southern peninsular Florida gradually subsided about a hinge or structural arch in the Ocala area (Pressler, 1947). This thick sequence of limestones and evaporites record a long history of shallow marine sedimentation generally similar to that found in South Florida and the Bahamas today.

Sediments making up this thick deposit are mostly derived from biogenic (skeletal) or physical (evaporite) precipitation from marine waters passing across the broad peninsular platform. Although far removed from land derived sediment (from weathering in the Appalachians), quartz sands occasionally crept down the peninsula much as it is doing today along the east and west coasts.

During the past 1 million years the gradual limestone building process has been complicated by sharp and repeated vertical migrations of sea level as portions of Earth's water was alternately taken up in and discharged from polar glaciers. Glacial sealevel fluctuations repeatedly dropped some 100m below present level leaving the peninsula high and dry exposing the calcareous substrate to rain-water solution and lithification and then rose 3 to 90 m above present sea level spreading marine carbonate environments across part or all of the South Florida peninsula. Limestones beneath South Florida record this period of sealevel fluctuation by alternating layers of marine limestone and subaerial soil crusts (Perkins, 1974).

We are presently at a nearly stable high sea level stand following a glacial period of lowered sea level about 20,000 years ago. The previous high stand(s) of sea level occurred 95,000 to 125,000 years ago during the Sangamon interglacial. Authors are in general agreement that sea level stood about 8 meters above present sea level during some period between 125,000 and 115,000 years ago. This inundated the entire peninsula south of Lake Okeechobee. Several lines of evidence also suggest that, after a brief sealevel retreat, a second and possibly third sealevel high occurred at about 95,000 (Princess Anne) and 80,000 (Silver Bluff).

The marine sediments that accumulated during the Sangamon interglacial high sealevel stand(s) are important for they were lithified essentially preserving their depositional morphology leaving depressions that were to become Biscayne Bay and the Everglades and ridges on which the mainland and Florida Key's cities rest.

The interior of South Florida was a 3-5 meter deep bank blanketed by seagrass-stabilized shelly lime (calcium carbonate) mud, probably very similar to the present interior of Great Bahama Bank (Hoffmeister, Stockman and Multer, 1967; Hoffmeister, 1974). This shelly lime mud is preserved as a shelly limestone, termed bryozoan facies of the Miami Limestone (ibid.) and can be seen in the dredge spoil of western Dade County.

Intense skeletal production, calcium carbonate precipitation and sediment reworking produced two major elongate sediment ridges towards the southeastern shelf margin - an outer coral limestone ridge (Key Largo Ridge) and an inner oolite-quartz sand ridge (Atlantic Coastal Ridge). The resultant depression between is the limestone basin now filled by Biscayne Bay, Card Sound and Barnes Sound (Figure 1).

Key Largo Ridge

In most cases coral reef growth is focused on the exposed margin of a platform open to deeper water. During the Sangamon interglacial, however, a major line of coral reef growth occurred some 4-8 km in from the margin (see Hoffmeister and Multer, 1968; Stanley, 1966). This line of reef growth, broken by channel passes, is preserved as a discontinuous ridge, extending from north of Miami Beach south to the lower keys. From Soldier Key southward this arcuate coral limestone ridge is largely emergent and forms the Florida Keys; north of Soldier Key the ridge extends as a submerged feature beneath the Safety Valve, slightly seaward of Virginia Key and beneath Miami Beach.

General cross-sections of the ridge, termed the Key Largo Ridge, are shown in Figures 6 and 7. Characteristically there is a sloping rampart to the seaward and an abrupt rise to the crest where emergent. Bayward the Ridge drops sharply commonly to 4 meters below sea level within 50 meters of the crest. Sanford (1909, p. 214) termed the coral limestone of the Ridge the Key Largo Limestone.

Along Elliott Key and Key Largo, the Key Largo Ridge is a quite continuous single ridge. In the Old Rhodes Key area the Ridge becomes broad and complex and three major tidal channels cut across the Ridge. Irregularity of the Key Largo Ridge here suggests that the channels were present during its formation.

Atlantic Coastal Ridge

The landward "Atlantic Coastal Ridge" extends along the mainland shore of South Florida through Ft. Lauderdale and Miami to Homestead where it swings inland well into the Everglades. The ridge is 3-8 meters in elevation and 3-15 kilometers in width. North of about 250th Street the ridge is composed of fine unconsolidated quartz sand (Pamlico Sand; Cooke, 1945) but to the south calcium carbonate rapidly increases and the Ridge is a cemented limestone from Miami southward. The limestone ridge is composed of ooid sand grains - spherical, concentrically laminated grains of calcium carbonate. The broad ridge is dissected by transverse channels or vales partially sediment filled. These are interpreted as fossil tidal channels such as transverse the actively forming oolitic sand shoals of Cat Cay area, Bahamas. Fossils and sedimentary structures preserved in this oolitic limestone indicate that the oolitic limestone is of shallow marine origin and very comparable to the shallow, tidal-agitated oolite banks forming today in the Cat Cay area, Bahamas (Hoffmeister, Stockman, and Multer, 1967).

Resultant Basins

Between the Key Largo Limestone ridge and the oolitic limestone-quartz sand Atlantic Coastal Ridge is an elongate shallow basin now filled by Biscayne Bay, Card Sound and Barnes Sound. At the south end of Biscayne Bay a very shallow limestone platform protrudes eastward from the Oolite Ridge dividing the basin into two sections - Biscayne Bay Basin to the north and Card-Barnes Basin to the south. The limestone of this shallow platform is a coarse calcareous sand containing abundant corals. It is interpreted as having formed during one of the late Pleistocene high sea level stands in response to increased water circulation funneled through channel passes across the coral ridge in the adjacent Old Rhodes Key area.

Biscayne Bay Basin is 3-6 meters in depth, being deepest in the vicinity of Key Biscayne. From the Coral Gables area north the basin remains deep across its width. To the south the Basin floor gradually slopes eastward from the Oolite Ridge to a deep axis just west of the Key Largo Ridge. The deep axis of Biscayne Bay Basin deepens from Elliot Key north and Bakers Haulover South to the vicinity of Key Biscayne. Probing and core borings through Key Biscayne indicate that the deep axis of the Basin is continuous with a channel cutting seaward across the submerged Key Largo Ridge in this area. Three additional features complicate the limestone topography of the Biscayne Bay Basin - an elongate ridge 1-2 meters in depth, extending north-south along the middle of northern Biscayne Bay, a low northeast trending hump beneath Black Ledge and another low northeast trending hump bayward of Turkey Point.

The Card-Barnes Sound Basin is a nearly flat continuous basin 3-5 meters in depth extending southward beneath Cross Key (the route of highway U.S. 1) into Buttonwood Sound. To the north the Basin rises sharply onto the shallow Arsenicker Keys Platform except near the Key Largo Ridge where the deep basin axis extends northward and joins with the Biscayne Bay Basin. To the west of Card Sound the Basin is bounded by the Arsenicker Key Platform. This platform fades southward, so that the Basin west of Barnes Sound extends as a very gradually shallowing surface into the Everglades.

Subsequent Modifications

The striking feature of the limestone topography in the Biscayne Bay region is that it largely preserves the depositional morphology produced during the interglacial high sea level stands 80,000 to 125,000 years ago. As sea level retreated, leaving the South Florida platform emergent, rain water superimposed three important modifications onto the depositional morphology. First rainwater dissolution and reprecipitation in conjunction with vegative soil formation cemented the calcareous surface and slowly produced a very hard reddish limestone "soil crust" over the surface (Multer and Hoffmeister, 1968). Second, rain water dissolved solution holes or pipes deep into the underlying limestone. Thousands of these small holes, 5 to 10 meters in diameter, dot the limestone surface of South Florida. These are now mostly filled with sediment. Their abundance can best be seen in aerial photographs of southern Biscayne Bay. There are in addition some very large solution holes 60 to 100 meters across. In South Florida these are all filled with Recent sediment. The Bahamas contains similar large solution holes many of which are not sediment filled. These, called "blue holes" (Newell _et al_, 1959), extend 75 to 100 meters below present sealevel. These small and large solution holes were the primary pathways for draining the South Florida and Bahamas platforms during low sea level stand.

Solution hole (sink hole, karst) drainage is typical of limestone terrains, and it is striking to also see dendritic (branching channel) drainage patterns on exposed limestone portions of the Biscayne Bay bottom. The dendritic channels are cut into the limestone and bifurcate up slope. Channels are mostly continuous with tidal creeks penetrating the marginal swamps. Whether the dendritic channels formed during lowered sea level stand or during the recent marine inundation is not certain. Tannic acid released from the mangrove margin of tidal creeks may well have "etched" the channels during the recent rise of sea level.

HOLOCENE SEDIMENTARY REGIMES

Following the Wisconsin Glacial episode, sea level rapidly rose from about 100m to near its present level (Figure 2). Sea level first invaded the deeper reaches of the Biscayne Bay Basin 6,000-7,000 years ago. At 4,000 years BP (before present) sea level has come to within 2 meters of the present level; within 1 meter by 2,700 years BP. It has since gradually risen to its present, near stationary, level.

During this "Holocene" or "Recent" rise of sea level, six general sedimentary regimes have formed in response to physical and biogenic processes acting in the Bay area (Figures 3-5). These regimes, defined by sediment type and depositional environments are:

1) Quartz-Carbonate sand island barriers and associated environments generated by coastal influx of sand from the north (northeastern Biscayne Bay);

2) Quartz sand accumulation within the bay (western Biscayne Bay);

3) Tidal bar belts of calcareous mud and sand (marginal to and dividing central Biscayne Bay and Card Sound);

4) Paralic and freshwater swamp and marsh deposits (adjacent to protected bay margins);

5) Open bay calcareous mud blanket and sand veneer (Biscayne Bay, Card Sound and Barnes Sound); and

6) Non-tidal mud banks (marginal to and dissecting Card Sound and Barnes Sound).

In attempting to visualize the growth history of these sediment regimes, one must understand that sea level rise over the pre-existing limestone topography produced a constantly changing pattern of depositional controls and bottom sedimentary and biotic environments.

SAND ISLAND BARRIERS AND ASSOCIATED ENVIRONMENTS

Northeastern Biscayne Bay is bordered by a string of sand island barriers and associated shoals, flats, swamps, channels and lagoonal environments. These formed as the result of an influx of clastic (derived) sediment from the north and offshore. The bulk of this regime is composed of medium to coarse grained sands that are a mixture of quartz and skeletal carbonate grains. Quartz grains are subrounded and frosted. Skeletal grains consist mainly of mollusc fragments, foraminiferal tests and Halimeda (calcareous algae) plates. A large portion of these calcareous grains are rounded and highly polished. This g neral sediment type is distinct from other sediments in the Biscayne Bay area, but is very similar to that found on the ocean beaches further north.

Influx of this "longshore clastic sand" has been the dominant influence on the formation of (1) the sand island barriers of Miami Beach*, Virginia Key, and Key Biscayne, (2) a subtidal sand spit extending southeast from Key Biscayne, (3) the tidal bars associated with Bear Cut and Norris Cut and (4) the resultant protected lagoon, flats and swamps on the bayside of the islands.

Miami Beach, Virginia Key and Key Biscayne have formed during the last 4,000 years by gradual southerly spit extension as sand was carried in from the north. They represent the southern most extension of the nearly continuous string of sand island barriers along the Atlantic coast. These differ from more northerly barrier islands in several ways. They formed on top of the now submerged northern extension of the Key Largo Limestone Ridge; sand comprising the islands contains a higher percentage of calcareous grains than found in beaches to the north; mangrove swamps, peats and lagoonal carbonate muds behind the barrier are distinct from the Spartina marshes and detrital mud lagoons to the north.

The submerged Key Largo Limestone Ridge presently lies 3-5 m below sea level under Miami Beach, less than 1 m below sea level just seaward of Fisher Island and northern Virginia Key and 3-5 m below sea level beneath the littoral sand platform seaward of southern Key Biscayne. The ridge has not been found in the central Key Biscayne area.

Sand Island Barriers

Core borings ofthe Recent sedimentary sequence beneath the barrier islands provides a general insight into their depositional history but leaves several important questions unresolved. West (bayward) of the submerged Ridge, the Pleistocene limestone surface is overlain by a thin band of woody peat, a thin sandy layer (of fine-grained angular quartz and fragile, unworn foraminiferal tests and mollusc fragments) and 1-2 meters of carbonate mud, homogenized by burrowing organisms and permeated by seagrass rootlets (Figure 7B, C). The contained molluscan and foraminiferal assemblages indicate this mud zone formed in a shallow, protected lagoon comparable with modern northeast Florida Bay. Shells from this basal carbonate mud yield a carbon-14 date of 4,200 years BP (from a sample 494 cm below present sea level beneath northern Virginia Key). Longshore clastic sediment, as defined above, is completely absent from this basal sequence.

The top of the protected lagoon mud deposit lies 4-6 m below present sea level beneath the barrier islands. It is sharply overlain by longshore clastic sands that made up the bulk of the island sequence. To the east of the Key Largo Limestone Ridge, the basal mud unit is absent and longshore clastic sands extend to the rock surface.

At the time the basal lagoon muds were forming, some 4,200 years ago, sea level was about 3 meters below the present level, and the Key Largo Limestone Ridge would have been slightly emergent. The Ridge thus provided the necessary protection from offshore wave energy during accumulation of the basal lagoonal mud. If a longshore clastic sand body also flanked the seaward margin of the ridge at this time, it would have provided additional protection. This seems unlikely, however, because hurricane surges and washovers should have spread this distinctive sand into the bayward lagoonal muds (as happens today). This is not observed.

Longshore clastic sediment forms the body of the sand barrier sequence, directly overlying bedrock to the east of the Key Largo Limestone Ridge and sharply overlying the basal lagoonal mud to the west of the ridge (Figure 7A-D). Core boring samples show that the sand sequence is well layered throughout, however no distinction has been made between nearshore marine and beach depositional origin. While the body of the sand island barriers are composed of an essentially uninterrupted sequence of bedded sand, a number of sediment types become present towards the surface reflecting the variety of sedimentary environments superimposed during the late stages of barrier island formation.

Strand lines, representing old beach ridges, are clearly revealed in pre-development aerial photographs of Virginia Key and Key Biscayne. These arcuate strand lines record the step by step southward cape-accretion growth history of these islands. Key Biscayne's growth has been an alternation of rapid southward extension accompanied by seaward progradation and cape development with strands swinging bayward. Once formed, these strand ridges are stabilized by vegetation. Older ridges are lower than more recent ones because of inundation by gradual sealevel rise. Aerial photography is not available of Miami Beach prior to development, at which time the surficial strand line history was destroyed. Miami Beach is a very narrow island strip as compared to the islands to the south, and likely had little seaward progradation following formation.

Mangrove Peat

Coarsely fibrous mangrove peat, containing roots of the red mangrove, Rhizophora mangle, occurs near the surface of the barrier islands. While red mangrove peat elsewhere in the Bay is free of calcareous matter, peat of the barrier islands does contain a significant amount of longshore clastic quartz and carbonate sand. Mangrove forests are abundant on the bay side of the barrier islands, but generally have less than 30 centimeters of peat beneath. Red mangrove peats extend about 1 meter below sea level beneath and just landward of the oldest strand lines. At several localities on the eastern shoreline of Virginia Key and Key Biscayne, where recent erosion has been extensive, this fibrous peat is exposed as an eroding bank. These are areas where the recent beach and strand line have migrated (eroded) landward sufficiently to expose bayside peat deposits beneath or west of older beach ridges.

Mangrove Root Rock

Hoffmeister and Multer (1965) have described an exposed lithified sand platform at the north end of Key Biscayne. The framework of this rock, which they term a "fossil mangrove reef", is composed of lithified casts of the rootlets of the black mangrove, Avicinnia nitida, overlain by a cemented sandstone crust 3-5 centimeters in thickness. Less extensive intertidal outcrops of this also occur along the erosional outer beaches of Virginia Key and Key Biscayne. Recent coring through the "reef" by the author shows that the cemented sandstone is a very well sorted longshore clastic sand with well-preserved fine scale laminations dipping slightly seaward. The "reef" platform at the north end of Key Biscayne contains lineations that are continuous with the oldest strand lines of the island. This lithified platform is interpreted by the author as an old beach-dune ridge deposit, the lower parts of which were brought within the intertidal zone with slowly rising sea level. Black mangrove forests colonized the interstrand or dune depressions, the roots penetrating the beach sand. The buried roots were subsequently replaced by a carbonate "paste" 1000-2000 years ago (Hoffmesiter and Multer, 1965, p. 851). Exposure following recent erosion has caused case hardening of the paste resulting in the rocky platform.

Storm-trapped Mud

Storm trapped layers of sediment occur near the surface on Key Biscayne and Virginia Key. These form broad layers of laminated calcareous silt with plat debris concentrated along bedding planes. This material accumulates during high storm tides of hurricanes as sediment-laden storm waters cover much or all of the sedimentary barrier islands. As much as 5 centimeters of silt was deposited over parts of Key Biscayne during the minor storm tide of Hurricane Betsy in September, 1965 (see also Craighead, 1964, p. 9).

Littoral Zone

Seaward of the beach and seasonal offshore bar off Miami Beach, the sand bottom rapidly deepens until it intersects the underlying Pleistocene limestone surface at a depth of 5-8 meters less than 0.5 km from the shore. The zone of active longshore drift is in the very narrow beach-offshore bar zone.

Virginia Key and Key Biscayne beaches are bordered by a broad, shallow littoral sand platform extending as much as 1.5 km seaward of the shore. Much of these littoral platforms are carpeted with dense seagrass growth beneath which unusually fine grained sands are accumulating. The seaward flank of the littoral platform is a rippled mobile sand that drops off sharply, again exposing the pre-existing limestone surface less than 0.5 km to the seaward. Both the beach and the flank of these littoral platforms are zones of active longshore sand transport.

Tidal Inlets

Two natural tidal inlets cut across the sand island barriers. Norris Cut passes between Fisher Island and Virginia Key. It appears to have formed during the Great Hurricane of 1935 as a stormwashover (Chardon, this volume). It likely remained shallow because of the shallowness of the limestone Ridge lying just to the seaward. Dredging in the 1920's deepened Norris Cut to nearly 7 meters (see author's article on Impact, this volume).

Bear Cut passes between Virginia Key and Key Biscayne. Across its narrow portion it cuts to bedrock 4-5 meters below sea level. Bear Cut digitates bayward among an arcuate flood tide sand delta. Ebb tidal flow has bulged the seaward littoral sand platform seaward. The time of origin of Bear Cut is uncertain but may have been within the past 1,000 years as storms and changing longshore current patterns reworked the newly formed barriers.

Southerly Offshore Trending Bank

Longshore clastic sediment extends south from Key Biscayne as a shallow subtidal sand bank lying 1 kilometer east of the Key Largo Limestone Ridge and the Safety Valve (Figures 5, 7E, 8). This bank narrows southward and fades, in the vicinity of Soldier Key, onto a broad sand flat 6-8 meters in depth. The sand bank is pushed seaward by the ebbflow discharge through the series of tidal channels cutting the Safety Valve. It is not certain whether longshore clastic sediment drift is actively extending this bank southward or whether waves and currents break up the barrier island extension at this point.

Protected Lagoon Shoal

Within northern Biscayne Bay, behind Miami Beach and Virginia Key is a shallow lagoon 1-2 meters in depth. Sediments in the eastern half of the lagoon are a shelly, sandy lime mud that grades eastward into longshore clastic sands of the island barriers (Figure 7A). The western limit of this lagoonal lime mud is a narrow, submerged bedrock ridge extending north-south along the center of the bay (Figures 1 and 7A-C). To the west of this ridge, clean quartz sand fills the bay to a depth of 1-2 meters (see "Quartz Sand Deposits").

Bedrock lies 4-6 meters below sea level in the eastern portion of northern Biscayne Bay giving a sediment thickness of 2-4 meters. Probing indicates that here, as under the islands, a peat layer and a band of coarse sand form the basal sequence over an irregular bedrock surface. Lagoonal muds and muddy sands overlie this. The lower portions of the lagoonal muds are similar to and probably continuous with the basal lagoon deposits beneath the islands. The upper portion of the lagoonal muds in northern Biscayne Bay is much sandier. Longshore clastic sands become an important admixture, constituting as much as 30 per cent of the sand fraction. This sand was probably introduced into the lagoon muds by storm surges washing across the barrier islands. The upper half of the lagoonal sequence is thus a gray, muddy, quartzose shelly sand in which seagrass rootlets are abundant.

QUARTZ SAND DEPOSITS

Quartz sand occurs in varying amount in nearly all sediment accumulations in Biscayne Bay, Card Sound and Barnes Sound except in freshwater marsh marls and peats. This quartz is medium to very fine grained, clear and angular, a sharp contrast to the "longshore clastic sand". The source for this quartz sand is the Pleistocene Pamlico Sand (Cooke, 1945, p. 51-58) that forms the Atlantic Coastal Ridge at the very northwestern corner of Biscayne Bay (Vaughan, 1910). There are several areas in the bay where this introduced quartz sand forms nearly pure sand bodies, free of calcareous admixture.

1) The deep bedrock depressions and channels of northern Biscayne Bay contain basal sequences of nearly pure, unconsolidated quartz sand (Figure 7C, E). This may well be a relic pre-Holocene feature. Core borings through Virginia Key and along Government Cut have encountered Pleistocene quartz sands, in some cases, less than a meter below the limestone surface. Where channels or solution features removed the surface limestone, Holocene sediments would directly overlie these quartz sands and be difficult to differentiate from them. (See also Wanless, 1969, pp. 63, 64)

2) The northwestern part of Biscayne Bay Basin is filled with a nearly pure quartz sand sequence (Figures 3 and 7A-D). Carbon-14 dating of a black fibrous peat band 360 cm below sealevel in the quartz sand sequence adjacent to "Vizcaya" yielded an age date of 4,270 ± 100 years BP (Figure 7C). This lies very close to the sealevel curve of Scholl et al (1969) and indicates that the quartz sand body accumulated in close association with sea level. The environment and process of sedimentation is not understood.

3) Quartz sand beaches and shoals occur along the mainland shore from the north end of Biscayne Bay south into Card Sound (Figures 7D-G, I, J). South of the Cutler area the beaches are spotty, occurring mostly on eroding peat shoreline projections. These quartz sand shore deposits are less than 2 meters in thickness capping an eroded mangrove peat platform. Seaward of the intertidal quartz shoal the calcareous content of the sediment increases sharply.

The mangrove peat and its subsequent erosion is considered responsible for these quartz sand deposits in the following manner. Storm tides of winter storms and hurricanes spread large amounts of quartz-carbonate bay sediment across marginal mangrove swamps. The acidic environment of the red mangrove peat quickly leaches all calcareous material leaving only quartz grains and organic material (Goodell and Gorsline, 1961, p. 84; Craighead, 1964, p. 9). Subsequent erosion of the peat along the retreating mangrove shorelines leaves a pure quartz sand, the lighter organic fraction being washed away. This treadmill process both formed these beaches and is the mechanism for natural renourishment. Southward littoral drift is also important along the Matheson Hammock to Black Point sector.

4) Offshore, in central and southern Biscayne Bay, quartz sand forms two shoals atop two gentle humps in the bedrock surface. The northern shoal is known as Black Ledge; the southern, Pelican Bank. Origin of these features is uncertain. Selective physical concentration of quartz grains on a shoaling ridge, suggested by Wanless (1969, p. 68) is a nice theoretical idea but rather unreasonable in practice. A more likely possibility is that mangrove shorelines, retreating across the bay with rising sea level were isolated and then obliterated from these bedrock highs, leaving their concentrated quartz shorelines, now reworked, as the only evidence of their former presence.

TIDAL BARS OF CALCAREOUS MUD AND SAND

Calcareous tidal bars have formed in five areas of Biscayne Bay in response to thresholds and channels in pre-existing bedrock topography and resultant tidal (or storm) current anomalies. These are: Featherbed Bank, Safety Valve, Cutter Bank, Caesars Creek Bank, and Broad-Angelfish Creek shoals (Figure 3).

Featherbed Bank - Safety Valve Complex

These two calcareous sand and mud banks are quite distinct in geometry, sediment composition and texture. They are considered together because they are a striking example of the changing influence that preexisting topography has had on sedimentation during the Recent rise of sea level (Wanless 1969, 1974a). Featherbed Banks are a series of skeletal carbonate sand shoals trending perpendicular to the axis of Biscayne Bay in an area where the Key Largo Limestone Ridge is partially emergent (Figure 8). The Safety Valve, to the north, is a mud bar belt trending parallel to the Bay axis in an area where the Key Largo Ridge is completely submerged. Between is a critical area of overlap of these two distinct sediment bodies.

Featherbed Banks

In south-central Biscayne Bay, the Pleistocene Key Largo Limestone Ridge is slightly emergent (forming the Ragged Keys) and cut by natural channel passes. Two elongate sand bodies, the Featherbed Banks, extend bayward from near two of these passes. These sand bodies, here termed "stringer shoals", extend well into the bay nearly transverse to the trend of the bedrock restriction. The shoals broaden and terminate across the deep bedrock axis of the bay. Hand probing and coring has shown that there is no anamalous bedrock relief under the Featherbed Banks (Figure 8).

The sediment of the elongate stringer shoals is a medium to coarse grained skeletal carbonate sand (Figure 7G). Plates of the calcareous green alga, Halimeda, and mollusc fragments are the predominate constituents. That the sands of the stringer shoals are, at least in part, of clastic origin is demonstrated by (1) the fragmental nature of much of the algal plates and mollusks, (2) the presence of quartz-carbonate aggregates (fragments of bedrock) in the coarser size fractions, and (3) the abundance of angular quartz in the finer fractions. Quartz accounts for about 25% of the total sample.

In contrast, the sediment in the western cup shaped terminus is an algal-plate lime mud (Figure 7G).

Each stringer shoal is interpreted as having developed in association with tidal currents which were constricted and directed by channels through the bedrock ridge. A mechanism of twin tidal jets with a single eddy feature between is suggested for the initiation and extension of these stringer shoals (See Wanless 1969, p. 72-76). This mechanism is similar to that proposed by Off in 1963 for the formation of rythmic series of sand tidal ridges. There is supporting evidence that the transporting sediment and depositing currents are from the channel passes. The southern stringer shoal is still active. A breach through the shoal was formed by storm tides sometime before 1940. Field observations and aerial photography in 1967 show that movement of sand from the east along both flanks of the shoal hae nearly reconnected this breach. It is not certain whether day to day or storm currents are the significant control on the formation and maintenance of the Featherbed Banks.

The role of clastic sedimentation appears to be so important to these sand bodies that when the tidal current jets responsible for their formation are cut off, the shoal will not be maintained. The northern stringer shoal is now cut off to the east by a small arcuate shoal. The stringer shoal to the west is slowly dissipating as the result of wind and tidal currents.

Safety Valve

To the north the Pleistocene Key Largo Limestone Ridge is submerged 1-3 meters below MLW, permitting unrestricted tidal circulation over the Ridge (Figure 8).

In this area a well-developed carbonate mud bar belt, the Safety Valve (11 kilometers in length by 1.5 kilometers in width and up to 7 meters in thickness), parallels the bedrock ridge and lies along its bayward side (Figure 7E).

Quite evenly spaced tidal channels about 100 meters in width and 5 to 6 meters in depth have formed perpendicular to the belt.

Core boring samples from the Safety Valve are mostly an algal-plate carbonate muds in which over 80% is finer than 62 microns. The sand fraction consists of locally derived whole plates of the calcareous green alga *Halimeda opuntia*. The mud fraction is composed mostly of magnesian calcite and aragonite, but sufficient abundance of calcite and quartz is present to suggest an outside source for much of the finer fraction. Coralgal-sand, reflecting the present *Porites* (finger coral) -- *Goniolithon* (branching coralline algae environment, forms the upper portion of the sediment sequence along channel margins.

A dense growth of the seagrass, *Thalassia*, covers the surface of the mud bar belt. The thick rhizome systems are exposed along undercut channel margins. Coring has shown that seagrass was abundant throughout the growth of the mud bar belt.

This mud bar belt is interpreted as having initiated as a shadow-like deposit behind the protection of the submerged bedrock ridge. Increased translatory currents passing over the shallow bedrock threshold suddenly drop in velocity in the deeper water of the bay and deposit the sediment.

The cover of turtle grass, through its sediment entrapment and binding ability, has aided in the growth of the mud bar belt and has been responsible for extension of the tidal bar belt above the level of protection provided by the bedrock ridge.

Additional protection to the mud bar belt is now provided by medium-coarse grained skeletal sands blanketing the tidal bar belt along its eastern (seaward) margin (Figure 7E). These accumulated as seaward storm spillover lobes.

Transition Zone

Between the two previously described areas is a transition zone. Here the crest of the bedrock ridge lies 0-1 meter below MLW (Figures 7F and 8).

Here relic pseudo-transverse sand stringer shoals are incorporated into a presently developing mud bar belt which parallels the bedrock ridge and lies entirely along its bayward side. Composition and texture of the bioclastic sands of the relic stringer shoals are similar to that of the active stringer shoals to the south. The presently developing mud bar belt in this area is an algal-plate mud similar to that of the mud bar belt to the north.

Tidal channels cutting this tidal bar complex are irregular in form. They originally trend through breaches in the stringer shoals (south). As the mud bar belt develops (to the north) and becomes more restrictive to circulation the channels re-cut transverse to the tidal bar belt.

This zone is interpreted to be in a transition from Featherbed Bank type to Safety Valve type sedimentation. When sea level was slightly lower, the Pleistocene limestone bedrock ridge was partially exposed and was restrictive to circulation. Stringer sand shoals formed in association with passes in the bedrock ridge and extended into the bay to the deep bedrock axis where they broadened and terminated. These stringer shoals became inactive and the mud bar belt was initiated as sea level recently encroached over the bedrock ridge permitting unrestricted circulation of tidal currents. The now inactive stringer shoals have become incorporated into the mud bar belt but are dissected by tidal channels through them.

To summarize, the gently northward sloping crest of the Pleistocene coral limestone ridge which forms the seaward boundary to Biscayne Bay has had a changing influence on the formation of Recent sediment bodies within the bay during the Recent rise of sea level.

(1) As sea level initially encroached over the ridge, tidal currents were restricted to natural channel passes, and bioclastic sand stringer shoals were produced trending more or less perpendicular to the trend of the pre-existing topographic relief. (2) With continued rise of sea level and complete submersion of the ridge, an algal-plate lime mud belt was initiated paralleling the ridge and lying along its bayward side. The now inactive stringer shoals became incorporated into the mud bar belt, though were badly dissected by tidal channels through them. (3) With further submersion of the ridge with respect to sea level the mud bar belt grew upwards completely burying any evidence of the relic stringer shoals. With the extension of sand spillover lobes seaward of the bedrock ridge, the ridge discontinued being the dominant influence on sedimentation. These sand spillover lobes will now determine the trend of future sedimentation in the Safety Valve.

Cutter Bank

Cutter Bank is a small east-west trending tidal bar belt situated at the south edge of Arsenicker Keys Platform. Pleistocene limestone is exposed to the north and south. Small tidal channels cut transversely across Cutter Bank. Mollusc shells are a dominant constituent of the sandy carbonate mud of the tidal bar belt. Halimeda plates are not common. Seagrasses form a moderate carpet on the surface.

The origin of this small feature is interpreted to be the same as for the Safety Valve tidal bar belt - sediment accumulation in a wave and current energy shadow behind a threshold of bedrock topography.

Caesars Creek Bank

Caesars Creek cuts across the Key Largo Limestone Ridge at the north end of Old Rhodes Key (Figure 3). Carbonate mud deltas occur seaward and bayward of the pass. The ebb-tidal delta extends over 3.5 km seaward of the Key Largo Ridge. Warzeski (1975, in preparation) found that the body of this massive bank is a carbonate mud ebb-tidal delta that has rapidly extended seaward over the past 4,000 years. The sudden and rapid growth of the bank since this time is considered to be caused by storm discharge of sediment laden waters from Biscayne Bay once sea level had come within 1.5 to 2 meters of present level, the bedrock sill depth on the bay side of Caesers Creek. Thick subtidal mud layers scattered through the bank sediment are interpreted as major hurricane surge deposits.

A 10-30 centimeter thick storm layer, 10-20 centimeters below the sediment surface, extends across most of Caesers Creek Bank. Warzeski relates this to the 1926 hurricane which caused a massive discharge surge at Caesers Creek. The Bank interior was still largely free of seagrass cover in 1940 aerial photographs.

Whereas the bank itself is interpreted to be caused by detrital mud efflux, the channel margin levees and the bank margin rims are sites of intense coral-algal skeletal production.

Broad-Angelfish Creeks

Small tidal banks occur seaward and bayward of Broad and Angelfish Creeks at the south end of Old Rhodes Key (Figure 3). These have not been studied but their growth history is certainly an interaction of local biogenic sediment production and detrital sediment influx aided by seagrass stabilization.

COASTAL SWAMPS AND MARSHES

Along the shorelines bordering Biscayne Bay, Card Sound, and Barnes Sound, paralic (polyhaline) and fresh water swamps have collected autochthonous (in situ) and allochthonous (detrital) deposits of peat and calcitic mud. The marine to brackish paralic swamps are dominated by the red mangrove, Rhizophora mangle. In areas where a fresh water body is absent behind the mangrove swamp barrier (as to the west of Key Largo), the mangrove forests may be 3 to 4 kilometers wide. Along the mainland (western) shore of southern Biscayne Bay, Card Sound, and Barnes Sound, where fresh water flows from the west across the shallow bedrock platform of the Everglades, the coastal mangrove swamps are restricted to a few hundred meters in width. Along the edges of tidal and drainage creeks, however, these barrier mangrove forests may penetrate several kilometers inland. Landward of the paralic mangrove swamps, fresh water swamps extend to the west over a submerged but gradually shoaling bedrock platform.

The fresh water swamps are characterized by open marshes of sawgrass, Mariscus jamaicensis, and spike rush, Eleocharis spp. Where saline conditions are beginning to encroach, dwarf red mangrove trees will be present and towards marine waters they may dominate the environment (Craighead, 1964, p. 14; Schneider, 1966, p. 964; Spackman, et al., 1964, p. 23). The fresh water swamps are dotted with "hammocks" where hardwoods and shrubs have developed in association wth irregularities in the bedrock floor (Craighead, 1964; Schneider, 1966, p. 963; Spackman, et al., 1964).

The following account is largely excerpted from Wanless (1974b).

Capability of Mangroves in the Production and Maintenance of Peat Accumulates

The red mangrove, Rhizophora mangle, colonizes via a long, cigar-shaped, floating seedling. This seedling floats vertically and extends 10 to 15 cm below the water surface. It may anchor where it touches bottom. Red mangrove colonization is therefore limited to protected waters 15 cm or less in depth at low tide.

The fibrous peat of the red mangrove generally accumulates in the upper half of the tidal range in south Florida but accumulation may extend throughout and slightly below low water level where tidal range is small (Scholl, 1964).

The black mangrove, Avicennia germinans, will grow on surfaces submerged only at high tide. Fibrous peats of the black mangrove thus accumulate within the upper one third of the tidal range.

Once an area of mangrove peat is eroded to a depth of only one-half meter below low water level, the mangrove cannot build back. A mangrove shoreline can, thus, only recede during a period of rising sea level and in the presence of intermittent moderate wave energy, unless very shallow mud or sand flats form, over which red mangroves can again take root.

Mangroves must be considered not as aggressive land builders but as a passive sedimentary environment, offering some resistance to erosion, in which peat accumulates predominate if the area is protected from strong physical agitation and detrital sediment influx. Basic prerequisites for mangrove colonization and subsequent peat accumulation are (a) a bottom very near tidal level, (b) protection from major storm energy or intermittent shore erosion, and (c) minor detrital sediment influx.

Swamp Environments

The marine to brackish paralic swamps bordering the south Florida coastlines are dominated by the red mangrove *Rhizophora mangle*. Black mangrove, *Avicennia germinans*, white mangrove, *Laguncularia racemosa*, and buttonwood may be important inland from the shoreline where the surface is higher.

Coastal swamps in the Biscayne Bay region can be divided, based on environmental setting, into the following three types:

1) Swamps bordering emergent land masses receiving no significant freshwater influx are dominated by paralic mangrove forests ranging from a few hundred meters to over 4 km in width (examples: west of Key Largo or Key Biscayne). Very broad swamp areas commonly enclose small isolated lakes.

2) Swamps bordering emergent land masses receiving some freshwater runoff from the Everglades commonly have a fringing mangrove barrier only a few hundred meters in width separating marine waters from a fresh water swamp. Along the edges of tidal or drainage creeks the barrier mangrove forest may penetrate several kilometers inland. Landward of the paralic mangrove swamps, freshwater swamps ext nd inland over a gradually shallowing bedrock platform. Dwarf red mangroves and scattered mangrove or buttonwood hammocks are present in the seaward zone of many freshwater swamps (Craighead, 1964; Schneider, 1966; Spackman *et al*., 1964).

3) Coastal swamps extended out on recent marine sediment accumulates are characterized by red mangrove forests. Examples of such environments are mangrove colonization on cuspate or anastomosing mud bands (Barnes sound; see Non-tidal Mud Banks).

Swamp and Marsh Sediment

Red mangrove peat is an autochthonous reddish-brown fibrous peat composed primarily of rootlets (Davis, 1940). Along exposed shorelines, such as the mainland coast of Biscayne Bay, fibrous red mangrove peats are dark and contain a fine organic hash, largely detrital debris washed in during storms.

Paralic mangrove swamp deposits may also contain darker brown to black peat of the black mangrove and buttonwood and the very black, nearly homogeneous peat of the sawgrass sedge, *Cladium jamaicensis*. These darker peats generally only form behind the outer red mangrove belt where they accumulate on top of red mangrove peat or other sediment that previously built to near high water level.

Freshwater swamps marginal to Biscayne Bay produce several types of sediment accumulates. The most important are sawgrass peat, freshwater calcitic mud, mangrove peat and peats associated with hammocks.

Sawgrass (*Cladium*) grows only in quite shallow, fresh water. A fine, black autochthonous peat accumulates where this sedge has formed a dense cover over the marsh surface for a considerable time.

Where *Cladium* is present in only moderate abundance or where *Eleocharis* (the spike rush, more characteristic of slightly deeper water) forms a sparse cover to the swamp, calcitic muds commonly accumulate (Schneider, 1966; Spackman *et al*., 1964). The calcitic mud forms in association with "algal mats". These mats of living periphyton are composed of "a complex mixture of filamentous and colonial algae, diatoms and bacteria plus entrapped organic and inorganic debris" (Spackman *et al*., 1964). While these algal mats (largely blue-green algae) seem to be responsible for the formation of the calcitic marl, it is not yet understood whether the calcite crystals are secreted by a specific alga or bacterium (Dachnowski-Stokes and Allison, 1928) or are precipitated in a physico-chemical manner within the total micro-environment produced within the algal mat (Spackman, *et al*., 1964, p. 18 Gleason, 1972; Barron, 1975). Freshwater aragonitic snails, *Helisoma*, *Physa*, and *Planorbis* are common in calcitic muds.

Brown to reddish-brown fibrous peats are present but not abundant in the fresh-water swamp environments and record isolated patches (hammocks) of mangrove, buttonwood or hardwood forests. Many of these formed in association with irregularities in the underlying bedrock. Detailed descriptions of hammocks and associated sediment accumulation are given by Spackman *et al*., (1964) and Craighead (1964).

Swamps Bordering Emergent Land Masses Receiving No Significant Freshwater Influx

Accumulation in the Lee of Mobile Topography

Mangrove peats have accumulated on the lee side of the mobile sand barrier islands of Key Biscayne, Virginia Key and Miami Beach. These peat accumulates begin only after a seaward barrier strand has been thrown up to provide effective protection to the area behind. Peat accumulates resulting from regressive and transgressive barriers are recognized.

Regressive. Key Biscayne, the most southerly barrier island along the Atlantic coast, is largely the result of southward extending cape accretion (Ball, 1967) during the latter part of the Holocene. Mangrove peat accumulates commonly overlie a cross-bedded shallow-marine sand and occur behind a seaward-expanding series of low beach ridges. Peat accumulation is not a continuous thick sequence but rather an alternation of fibrous mangrove peat layers and shelly muds from shallow lagoons (Figure 9). The significance of these sharp alternations is not clear but may record growth expansion and storm erosion retreat of a mangrove swamp fringe over the leeside mud flat.

Transgressive. In those areas that are mainly transgressive (as Virginia Key), fibrous mangrove peat commonly caps a shallowing lagoon or washover sand along the island's lee side. The peat accumulate itself is then overridden by the transgressive island strand (Figure 9). Landward barrier migration is commonly sufficiently rapid (with respect to sea-level rise) to re-expose the peats and lagoonal muds on the seaward shoreline at a level only slightly below that of its origin. Fibrous peats contain a small to large amount of detrital sand, and sand washover layers may interrupt the peat sequence.

Accumulation in the Lee of rigid Topography

The emergent, linear ridge of Key Largo Limestone provides continuous protection to a coastal mangrove swamp as much as 4 km in width along northern Key Largo (Figure 7, cross-sections J, K, L, right side). Red mangrove is exclusively present at the bayward shoreline and is dominant throughout the swamp. Black and white mangroves and some buttonwoods are locally important where peat has accumulated to near high tide level. Within the swamp, shell layers of whole and broken Anomalocardia cunimeris are concentrated on small, grassy openings in the swamp that are slightly above sea level and associated with black allochthonous peat accumulation.

This paralic mangrove swamp consists of a nearly continuous sequence of fibrous mangrove peat above the 3 to 4 meter deep bedrock surface. At the bayward shore, red mangrove peat extends to bedrock and roots of the red mangrove penetrate cracks and holes in the bedrock. Behind the outer mangrove barrier, is a 20 to 30 cm thick basal sequence of carbonate mud containing freshwater gastropods and patches of black-brown peat. This is commonly topped by a thin shell band. Fibrous mangrove peat then overlies these basal units and extends to the surface. A broad mangrove forest has survived in this area since marine waters first entered the Card-Barnes Sound bedrock basin and provides a good example of an equilibrium (non-migrating) swamp accumulate.

Accumulation Along Unnourished or Unprotected Windward Shorelines

Mangrove peat environments along windward shorelines have continuously retreated during this Holocene sea-level rise because of exposure to persistent small waves from prevailing winds and intermittent larger storm waves. The present peat accumulate shoreline is eroded back to where the landward shoaling bedrock platform effectively dissipates much of the wave energy. Such a shoreline in south-central Biscayne Bay has migrated much further landward than adjacent shorelines to the north or south. In some zones the peat accumulate is absent (Figure 3).

The record of such totally transgressive peat environments is preserved, if at all, as small peat lenses in pockets in the rock floor. Freshwater or terrestrial peat commonly fills these pockets prior to transgressive encroachment of paralic peat making a preserved record of this transgressive paralic swamp even more unlikely.

Accumulation Along Nourished Windward Shorelines

Paralic swamps along much of the mainland shoreline of Biscayne Bay, Card Sound and Barnes Sound extend well seaward of the emergent limestone. Preservation of such accumulates appears related to protection provided by nearshore sediment banks (Figure 7E and G, left side). The emergent coastal ridge of Pleistocene oolite limestone lies within 2 km of the mainland shoreline in central Biscayne Bay and has essentially isolated the coastal mangrove swamp from the fresh water body of the Everglades to the west. The entire swamp deposit here is thus that of a marine to brackish water paralic mangrove swamp. The mangrove swamp barrier is broken by numerous tidal and drainage creeks. These bedrock floored creeks are connected to small backswamp bays where the swamp is broad. Red mangrove forests are generally dominant along the shoreline and bordering the creeks and bays and are present throughout the paralic forest. Black mangrove, white mangrove, buttonwood and other trees of more restricted range commonly dominate within the swamp complex. Black mangrove trees occur at the shoreline in some areas, an indication of shore erosion of the swamp complex.

Seaward of the mangrove forest bordering central Biscayne Bay is an eroding peat bank capped by a protective quartz shoal and beach. During high storm tides, wave energy may spread this sand, along with mud and organic hash (mainly Thalassia blades) suspended in the water, into the swamp complex producing a mixed autochthonous (mangrove) and allochthonous (grass hash, sand and mud) accumulate. The sand shoal and beach retard erosion of the swamp by absorbing much of the wave energy.

Coring through this mixed peat margin reveals a similar brown to black fibrous peat with moderate quartz sand extending nearly to bedrock. Red mangrove rootlets bind this peat but are mixed with woody detritus and organic hash. Mangrove peat sequences further landward within the paralic swamp complex are a more typical autochthonous reddish-brown fibrous mangrove peat with little allochthonous organic detritus.

As the ridge of oolite limestone is approached to landward, sawgrass, cattails, reeds, ferns, low shrubs and weeds characterize the surface environment. Sawgrass, cattails and reeds may occur naturally, but the ferns and shrubs indicate draining of the marsh (Davis, 1940). Man-made drainage canals do penetrate the swamp throughout this area. The landward peat accumulate is a brown to black fibrous peat which may have formed in rush marshes (Davis 1940) prior to draining (see Teas, Wanless and Chardon, this volume).

Coastal Swamps Bordering Emergent Land Masses Receiving Moderate Freshwater Runoff from the Everglades

Along the mainland side of Biscayne Bay, Card Sound and Barnes Sound, freshwater swamp deposits have accumulated behind a narrow paralic mangrove swamp fringe. This freshwater swamp is a marginal eastern extension of the expansive swamps of the Everglades. The specific geometry of paralic and freshwater swamp accumulation seems to depend on the degree of shoreline exposure and presence of associated nearshore marine accumulates.

Along exposed coasts (east and north facing) of southern Biscayne Bay (Figure 7F, H and I, left side), bedrock lies only about one meter beneath the mangrove fringe shoreline. An exposed peat platform adjacent to the shore in some areas indicates erosion. In other areas red mangrove prop roots are spreading over the very shallow bedrock floor. Red mangroves line the several small creeks which penetrate landward far into the freshwater swamp.

Along western Card Sound, the narrow paralic mangrove swamp fringe is straight and nearly unbroken. Bedrock lies 2-3 m beneath the eastern edge of the swamp and is exposed offshore. A small rise, in the rock floor occurs under or just landward of the fringe (Figure 7 J, left side). The shore commonly has a narrow, erosional peat bank veneered with fine quartz sand.

The seaward edge of the paralic swamp fringe becomes irregular in southern Card Sound and Barnes Sound. A complex zone of mud keys, brackish bays and cuspate mud banks separates the Sound from the mainland mangrove swamp fringe (Figure 5).

Fibrous mangrove peats extend to or nearly to bedrock at the shoreline in Card Sound (Figure 7J, left side) and parts of southern Biscayne Bay (Figure 7H, left side). Landward is a sharp to gradational transition to freshwater derived calcitic muds. In several transects the mangrove peats expand (transgress) over the freshwater calcitic muds in the upper part of the sequence (Figure 7H, J, and K, left side). Along Barnes Sound and other parts of southern Biscayne Bay, the fibrous mangrove peat surface at the shoreline is underlain by freshwater calcitic mud (Figure 7I and K, left side). In southern Biscayne Bay this transgression leaves behind a totally eroded sequence except where preserved in bedrock pockets.

Swamp Accumulates in Local Protected Pockets

Narrow Channels and Pockets in the Bedrock Floor

The deep axis of the bedrock basin filled by Biscayne Bay is 4-7 m in depth and extends north-south along the eastern side. This deep axis and several subsidiary troughs in the rock floor appear to be relic dendritic drainage channels in the bedrock surface. Buried mangrove peat accumulates are preserved in or along the margins of these bedrock troughs (Figure 7D and G, center). These peats formed when marine waters were first entering the Biscayne Bay basin and have been preserved there because of the protection of the bedrock irregularity.

Hammocks (tree islands) Dotting Freshwater Swamps

Peat producing hammocks commonly overlie karst solution holes and other bedrock irregularities in the freshwater swamps. Hardwood forests dominate the hammocks far inland (or pine and palmetto where subjected to fire). Mangrove may dominate the hammocks near the coast. Some mangrove forested hammocks adjacent to Barnes Sound are underlain by a mangrove peat sequence extending to bedrock (Figure 7I and L, left side). Others are underlain by calcitic muds, but these may have migrated seaward by downcurrent seedling propagation (Figure 7J).

Throughout Biscayne Bay, Card Sound, Barnes Sound and Florida Bay, coring has revealed mangrove and freshwater peats preserved in small to large karst solution pockets in the underlying limestone bedrock demonstrating that paralic and freshwater swamps have been present throughout the Holocene rise of sea level.

However, as sea level rose, the bedrock setting became less restrictive to water movements into and within the bays. Increased wave and current energy eroded most of these early sealevel-associated swamp accumulates leaving little more than scattered pockets of peat as evidence of the transgression.

Discussion

The patterns and geometries of swamp accumulation described are related to the complex pre-existing and evolving co-existing topographic influence on wave and current patterns, detrital sediment movement, and freshwater drainage. Coastal mangrove swamps are a passive sedimentary environment, offering some resistance to erosion, in which peat accumulates predominate if the area is protected from strong physical agitation and detrital sediment influx. Paralic mangrove peats adjacent to marginal freshwater influx are commonly narrow, continuous barriers fringing a calcitic-mud dominated freshwater swamp deposit. Where there is no adjacent freshwater influx, the mangrove peat accumulate is narrow to broad and may either extend to the emergent topography or yield inland to a freshwater peat accumulate.

Mangrove swamps and resultant peats, although largely passive in their occurence, are, once formed, an important influence on adjacent sedimentary environments. The narrow mangrove fringe along the mainland shore of Card Sound provides effective physical separation of wave energies and to some extent water exchange between the Sound and the freshwater swamp behind. Mangrove forested shorelines throughout South Florida absorb much for the wave energy from winter storms and hurricanes. Mangrove fringes thus provide physical protection to environments behind, even though the shoreline itself may be seriously damaged.

OPEN BAY SEDIMENTS

The open portions of Biscayne Bay, Card Sound and Barnes Sound are striking in the extensive lack of sediment accumulation. Away from the marginal sediment buildups, over 50 percent of the Biscayne Bay Basin and the Card-Barnes Sound Basin has less than 15 cm (6 inches) sediment cover over limestone bedrock (Figure 4). Sediment accumulation that has occurred is confined primarily to the deep bedrock axes of Biscayne Bay and Barnes Sound. Two basic sedimentary environments are recognized -- sandy areas of non-accumulation and areas of lime mud accumulation (Figure 3). Depth of the bedrock surface, exposure to wave energy and seagrass stabilization appear to control the distribution of these environments.

Sandy Areas of Non-Accumulation

Bay bottom having less than 15 cm of sediment cover over bedrock is considered an environment of non-accumulation (Figures 3 and 7E-L). Bedrock is generally exposed in these areas with sediment filling irregularities in the bedrock surface. Seagrasses are sparce or absent except where sand has filled isolated bedrock depressions.

Surface environments are typical of semi-protected marine rock bottom communities found throughout South Florida and the Bahamas (Ginsburg, 1956, pp. 2398, 2402; Newell, *et al*., 1959, pp. 19-21; Cloud, 1962, p. 33; Purdy and Imbrie, 1964, p. 21). Calcareous sand producing algae *Halimeda incrassata* and *Halimeda monile* occur throughout this environment. Carbonate mud producing algae (*Penicillus*, *Rhipocephalus*, *Udotea*, and *Acetabularia*) sponges, alcyonarians and corals (mainly *Porites furcata* and *Solenastrea haydes*) occur only in Biscayne Bay and Card Sound away from the mainland.

The sediment veneer is a quartzose calcareous sand. Subangular quartz is medium to fine grained and comparable to that elsewhere *within* the Bay. Quartz constitutes 40-80 percent of the sand in Biscayne Bay decreasing to the south and east; 30-40 percent in Card Sound and 10-20 percent in Barnes sound.

Calcareous sand fraction is dominated by molluscs and benthic foraminifera.

In Biscayne Bay the arenaceous Foraminifera *Quinqueloculina agglutinans*, *Valvulina oviediana*, and *Triloculina carnata* characterize the sandy areas of non-accumulation. In Card Sound the arenaceous forms are less abundant and *Archaias* and other Soritidae dominate. In Barnes sound *Elphidium* spp. and *Ammonia beccarii* dominate a foraminiferal assemblage also containing Sortidae and Miliolidae, suggesting that brackish conditions are present during a part of the year.

Distinct mollusc communities are not evident. The common genera observed are *Laevicardium*, *Nucula*, *Lucina*, *Tellina*, *Bittium*, *Chione*, *Codakia*, and *Modulus*. In Barnes Sound *Lucina* and *Caecum* dominate (see also McNutly, *et al*., 1962).

A large amount of the mollusc fragments and foraminiferal tests are blackened and are suggestive of reducing conditions within the sand pockets. The occurence of these blackened grains increases markedly to the south into Card Sound and Barnes Sound where more protected conditions prevail.

Plates of *Halimeda* are present but nowhere abundant. Ostracods are present throughout the areas of non-accumulation. Coral and echinoid fragments are present in the coarser sand fraction.

The mud fraction (less than 62 microns) constitutes less than 10 per cent of the sediment type. Low magnesium calcite forms greater than 50 per cent of the mud fraction and increases to the south. Aragonite shows a marked decrease in abundance into Card and Barnes Sounds, while quartz (less than 62 microns) becomes more abundant especially in these more protected areas.

A maximum sediment thickness of 15 cm was chosen as the lmiit for areas of non-accumulation for two reasons. First, the bedrock surface is highly irregular and throughout the Biscayne Bay area has a local relief of at least 10 to 15 cm and often much greater. Thus, even where persistent currents or wave energies are present, sediment will be present in the protection of depressions in the irregular bedrock surface. Second, Thalassia does not appear to establish extensive grass beds unless a sediment thickness of at least 20 to 30 cm is present. Where Thalassia beds are present, the sediment sequence is thicker and more muddy.

Lime Mud Accumulation

In the eastern part of Biscayne Bay north of Featherbed Bank and along the deep bedrock axis in southern Biscayne Bay and Barnes Sound, sandy to silty lime muds have accumulated, generally to a thickness of less than 2 meters (Figures 3 and 7E-H, K and L). Here the bedrock surface lies between 3 to 5 meters below sea level.

The surface environments in areas of lime mud accumulation in Biscayne Bay are characterized by a moderate to dense cover of Thalassia disrupted by excrement mounds of burrowing shrimp. During much of the year the blades are covered with growths of epiphytes which aid in the entrapment of suspended particles (Ginsburg and Lowenstam, 1958, p. 313). In addition numerous calcareous microorganisms grow attached to the Thalassia blades. In these deeper waters, the meshlike root system of Thalassia does not form so dense a network as is found on the Safety Valve. the Thalassia beds do, however, appear to bind and protect the sediment from severe erosion during storms. Aside from the winnowing of a few centimeters of the surface sediment, the areas of lime mud accumulation in Biscayne Bay appeared virtually unaffected by the passage of Hurricane "Inez" in October of 1966.

Calcareous green algae are present in the bottom lime mud communities and locally form dense populations. Halimeda incrassata, Halimeda monile, Penicillus spp., and Udotea spp. are abundant throughout central and southern Biscayne Bay. With the exception of Halimeda, the calcareous algae are absent from the sandy lime mud communities in Barnes Sound.

Coring and probing in the areas of lime mud accumulation. A basal unit of coarse sand, 10 to 20 cm thick overlies bedrock and is similar in composition to the sands presently found in adjacent areas of non-accumulation. Upwards, this sand grades into a sandy to silty lime mud.

To the north of Featherbed Bank, where 90 to 95 per cent of the sediment is finer than 62 microns, the sediment may be classified as a sandy carbonate mud. Here, the mud fraction is composed of nearly equal amounts of magnesian calcite and aragonite. Calcite is a minor constituent and quartz is present only in trace amounts. the sharp decrease in low Mg-calcite as compared with the adjacent areas of non-accumulation reflects the absence of bedrock as an immediate sediment source in the areas of lime-mud accumulation. The sand fraction is composed primarily of plates of Halimeda incrassata, molluscs, Foraminifera (principally miliolids) and ostracods. Quartz constitutes only about 3 per cent of the sediment.

Along the deep axis of Biscayne Bay south of Featherbed Bank and in Barnes Sound, less than 100 cm of sediment accumulation has taken place. Here, the sediment is much sandier with only about 50 per cent being finer than 62 microns. The mud fraction is similar to the adjacent area of non-accumulation, except quartz is absent. The fine fraction is dominated by calcite which may be derived either from erosion (by boring or browsing) of the bedrock or from calcitic mud of the fresh water swamps which has been washed into the Bay during storms. Magnesian calcite and aragonite are both present.

In areas of lime-mud accumulation in Barnes Sound, shell material dominates the sand fraction. Similarly, Ammonia and Elphidium dominate the foraminiferal assemblage, indicating brackish conditions. No blackened molluscs or Foraminifera were observed in areas of sandy mud accumulation suggesting aerobic conditions in the sediment.

The cores taken in the lime mud to the north of Featherbed Bank indicate that extensive burrowing and reworking of the sediment has taken place. Grass rootlets are present in section, but not to the extent found in the tidal bar belt. Sandier sediment is present filling some burrows and occasionally forms thin layers. The sandier nature of the surface sediment may reflect winnowing associated with the abnormal number of hurricanes (four) that have affected the Bay in the past three years (1964 to 1966).

Discussion

Why has no sediment accumulated throughout large areas of Biscayne Bay? These areas have been subjected to marine conditions for 2,000 to 4,000 years and presumably, during much or all of this time communities of sediment producing organisms similar to those of today have prevailed. The lower limit of non-accumulation

(15 cm) coincides closely with the 3 to 3.5 meter bedrock depth contour. In other words, where bedrock is shallower than 3 to 3.5 meters, open Bay lime mud and/or sand accumulation has not taken place. (Exceptions to this general rule are some of the localized build-ups of certain bars and shoals discussed in previous sections).

It is not resolved whether seagrass or purely physical processes limit the distribution of lime mud accumulation.

Wanless (1969 pp. 105-108) proposed that the 3 to 3.5 meter upper limit for lime mud accumulation represents the upper stability limit of the Thalassia rhizome "sod" system which protects the sediment beneath from winnowing and transport by wind-wave induced water movements. Recent work by Wanless (1975) shows (a) that moderate to dense seagrass cover does offer significant stability to sand substrates and (b) that if the cover is lost the finer sands will be rapidly lost from the area. It is not certain how this applies to mud bottoms of moderate to sparce seagrass cover.

It is also possible that fine sediment accumulation in Biscayne Bay may simply be largely controlled by physical processes, the observed accumulation being a balance between

$$\Sigma(\text{mud produced in the Bay + mud influx}) - \Sigma(\text{mud discharge from the Bay}).$$

NON-TIDAL MUD BANKS AND KEYS

Narrow arcuate mud banks, many of which are capped by mangrove island chains border western south Card Sound and Barnes Sound (Figures 3-5). These mud banks are not underlain by anomolous bedrock topography (Figures 7K and L). Limestone bedrock bottom is exposed or nearly exposed off the flanks of these mud banks. Mud banks have a core of shelly carbonate mud. Seagrasses cover the subtidal surface. Mangrove flats, shell beaches and algal flats form the surface environment where the banks extend above sea level. Fibrous mangrove peat and algal-laminated sediments extend less than one meter below sea level beneath the banks. Shell beaches are superimposed on the bayward side of more exposed banks in and above the tidal zone.

The mangrove peninsula separating Card and Barnes Sounds, though compatible with the anastomizing mud bank plan, appear not to be underlain by mud. Probing indicates that a woody peat comprises the 3-4 meter thick sediment sequence beneath it.

The mud banks and keys from Card Sound south into Florida Bay are mostly arcuate features defining and enclosing oval to sub-circular bays. Gorsline (1964, pp. 134, 139), utilizing the work of Fleece (1962) suggests that slow, counter-clockwise gyral circulation patterns may be responsible for the formation of the anastomizing mud banks of Florida Bay. Wanless (1969, pp. 116-118) attributes the mud bank dissection of the Card-Barnes Sound Basin to circulation cells similar to those responsible for the formation of cuspate spits. Sand bordered lagoons are commonly segmented into sub-circular bays by the joining of cuspate spits from the two sides of the lagoon (Zenkovitch, 1959). He observed that sand spits, being dependent on bedload movement of sand grains, grow by a combination of accretion and erosion of the shoreline. Mud banks, such as those in Card and Barnes sounds, in contrast, are composed of suspended transported sediment and may not be dependent on gradual spit accretion for growth. Rather, they may have grown in total response to circulation cells set up in the bay.

Price recognized that the size and interval of cuspate spits are determined partly by the original plan (dimensions) and partly by water depth of the lagoon. Similarly, the shape and size of the mud-bank bounded sub-circular bays are related to the pre-existing shape and depth of the Card-Barnes Sound Basin. Card and Barnes Sounds, along the Basin axis, are largest and deepest. To the west the sub-circular bays become smaller and smaller with decreasing depth.

Mud of the banks may be largely derived from storm scour and redistribution from the rocky bottom communities of the sub-circular bays. Sponge and alcyonarian spicules, produced only on rocky substrates, are important constituents of the bank muds.

How long the mud banks have been important sedimentary bodies segmenting the Card-Barnes Sound Basin is not certain. Core borings through island capped banks along the western side of Barnes Sound show that the banks are actively migrating. This is destroying the banks history prior to about 1,500 years ago (see Wanless, 1969, pp. 114-116).

RECOMMENDATIONS FOR FUTURE RESEARCH

Research to date provides an adequate general description of the geologic setting, sediments and depositional history of Biscayne Bay. Future research programs should focus on the bio-sedimentary dynamics of the Biscayne Bay system. The following gaps should be filled towards a goal of understanding both the short and long term processes, patterns and rates of (a) sediment production, dispersal and accumulation, and (b) sediment body erosion, accretion and migration.

1. Fine grained sediments:

   a) Description of fine-grained sediments and their distribution;

   b) Documentation of rates and patterns of fine-grained sediment transport and of flux between different sectors of the system.

   c) Documentation of specific biogenic influences on fine-grained sediments in different sedimentary environments.

2. Sediment regimes:

   a) Detailed mapping of bio-sedimentary environment distribution.

   b) Analysis of morphology and of historical changes in sediment bodies as a key to understanding the long term integrated circulation patterns of the region.

   c) Detailed examination of depositional history of certain sediment regimes to determine their specific influence on the Biscayne Bay system (especially Safety Valve-Featherbed Bank area).

3. Biogenic influence on sedimentation:

   a) Evaluate the specific role of seagrasses, benthic community sediment production, burrowing organisms and shore vegetation on the dynamics of each sediment regime.

This list reflects a two-fold approach to subsequent research. The first is to focus on sediment dynamics to gain a usable understanding of how the system works. The second is to use the integrated record of the resultant sediments and sediment bodies to reconstruct the controlling physical, chemical and biological processes of the system.

ACKNOWLEDGEMENTS

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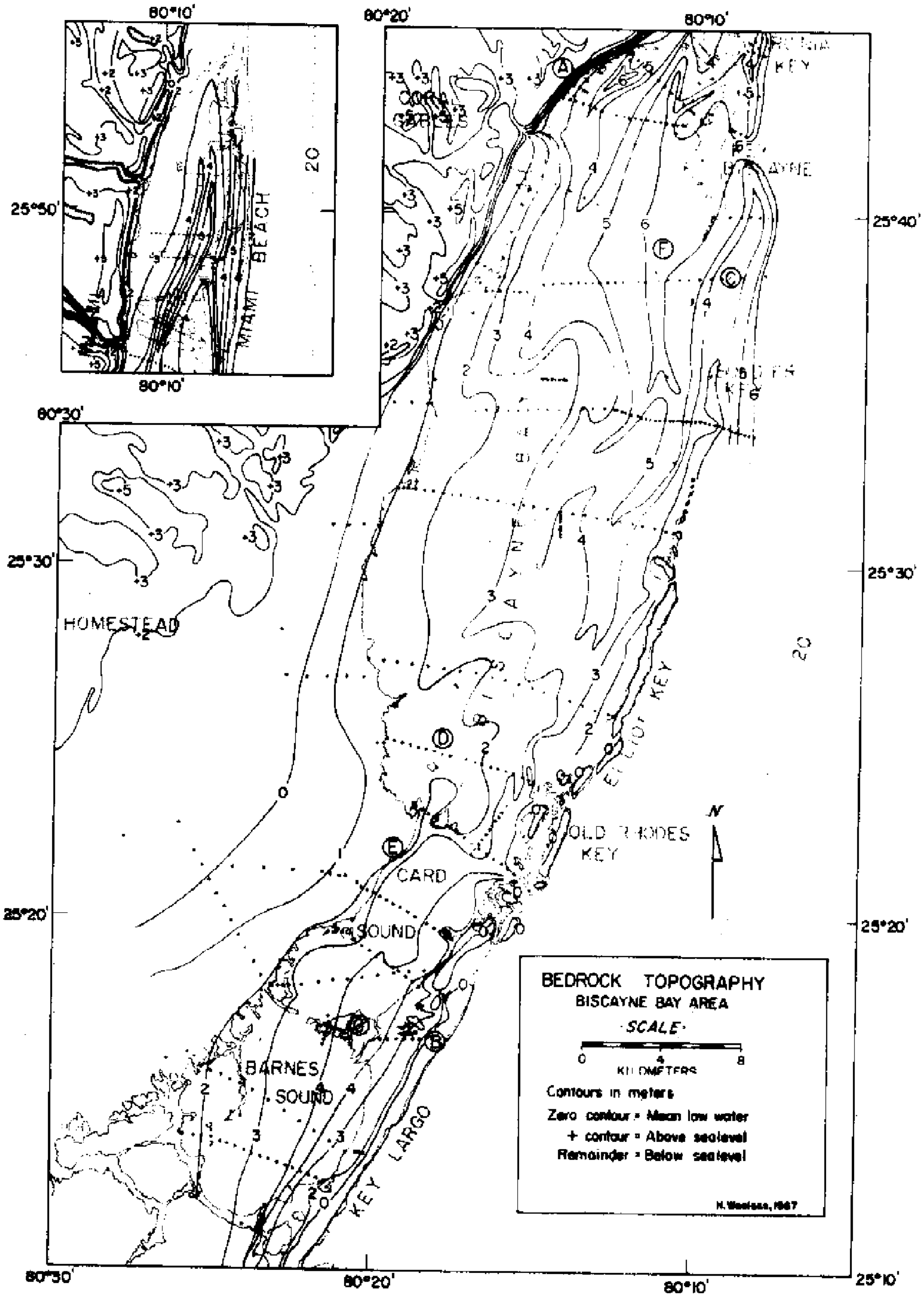


FIGURE 1. Map of Pleistocene "bedrock" topography in Biscayne Bay as determined by hand probing. Contours in meters relative to present sea level. Dots show probing locations. Lighter contour is present sea level. Letters on diagram indicate (A) Atlantic Coastal Ridge, (B) emergent Key Largo Limestone Ridge, (C) submerged Key Largo Limestone Ridge, (D) Arsenicker Keys Platform, (E) Everglades Rise, (F) Biscayne Bay Basin, and (G) Card-Barnes Sound Basin. From Wanless (1969).

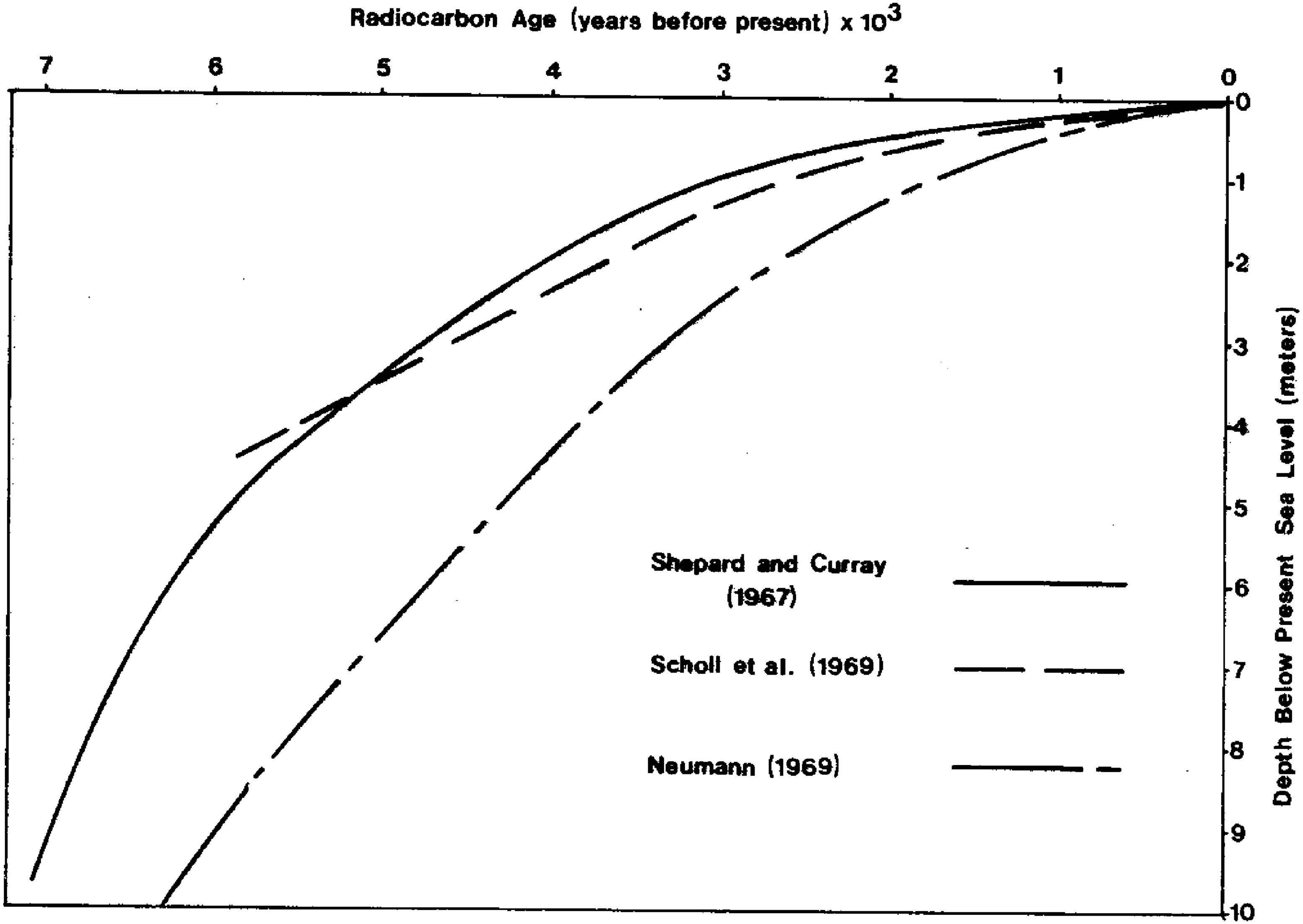


FIGURE [illegible]. Graph of post-glacial rise of sea level during the past 7,000 years as determined for south Florida (Scholl et al, 1969), Bermuda (Neumann, 1969) and (Shepard and Curray, 1967). From Warzeski (in preparation).

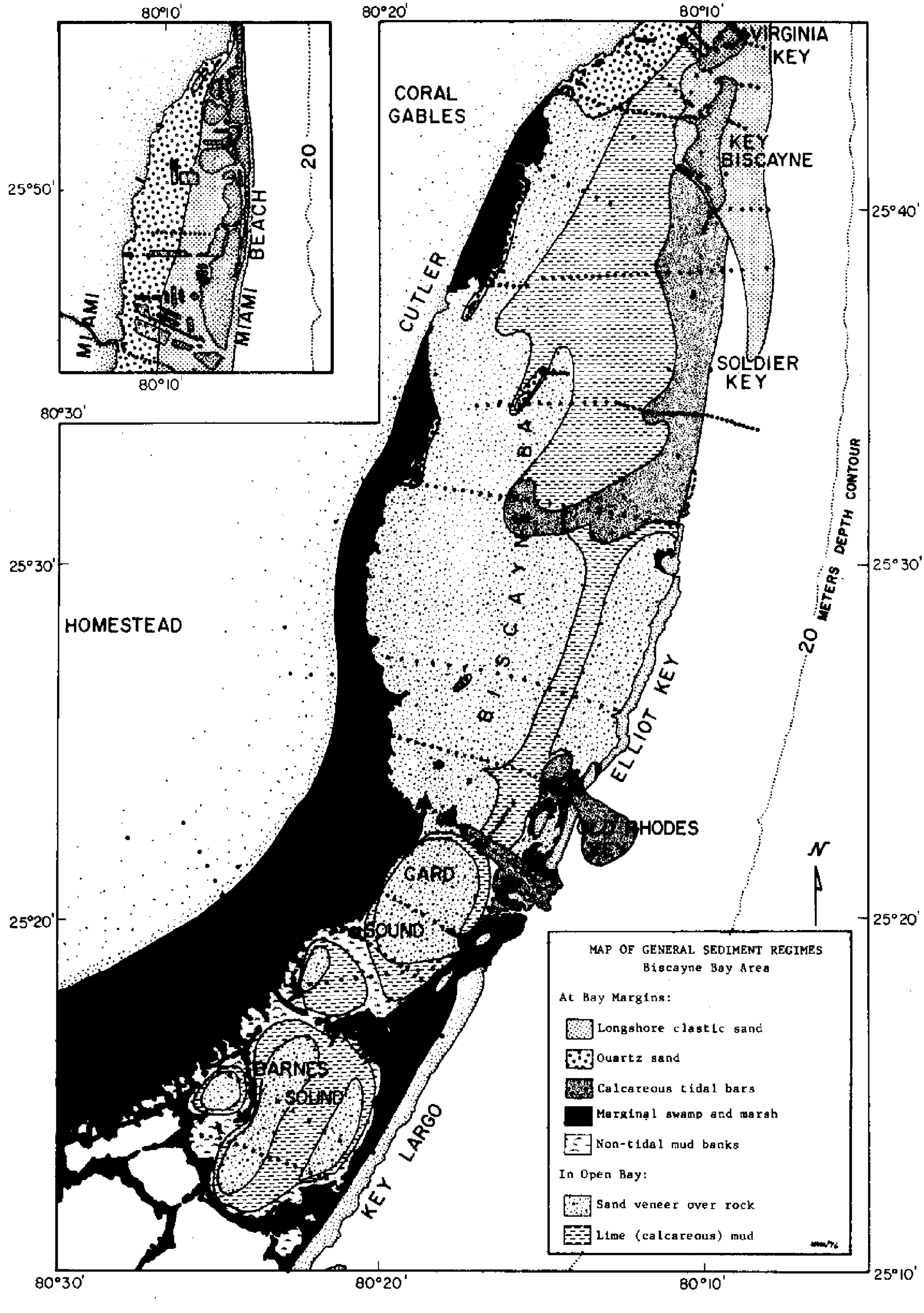


FIGURE 3. Map of general sediment regimes in the Biscayne Bay area.

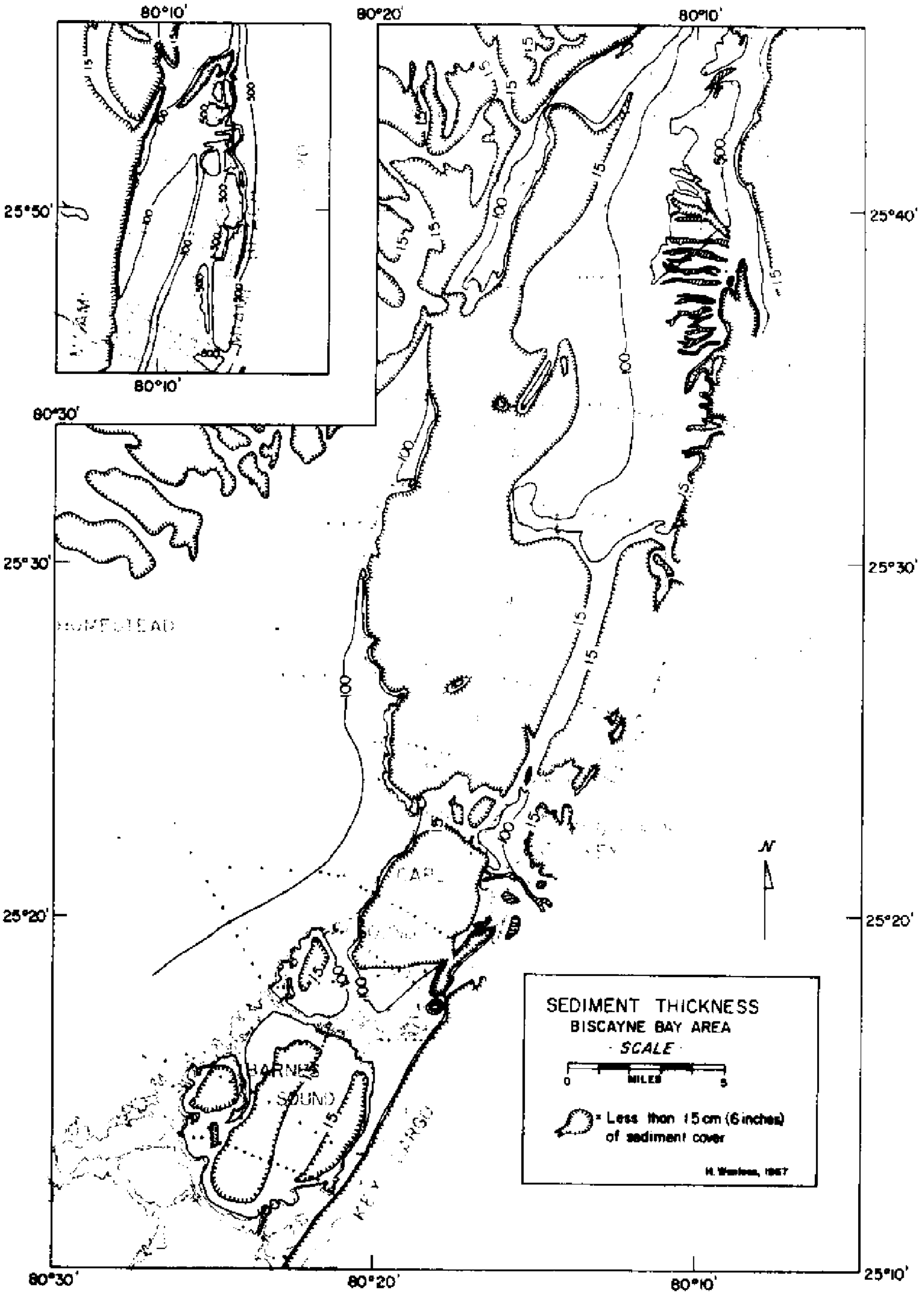


FIGURE 4 Map of Recent sediment thickness in over bedrock in Biscayne Bay as determined by hand probing. Contours in centimeters. Dots show probing locations. Lighter center is present shoreline. Twenty meter depth contour is shown to right.
From Wanless (1969)

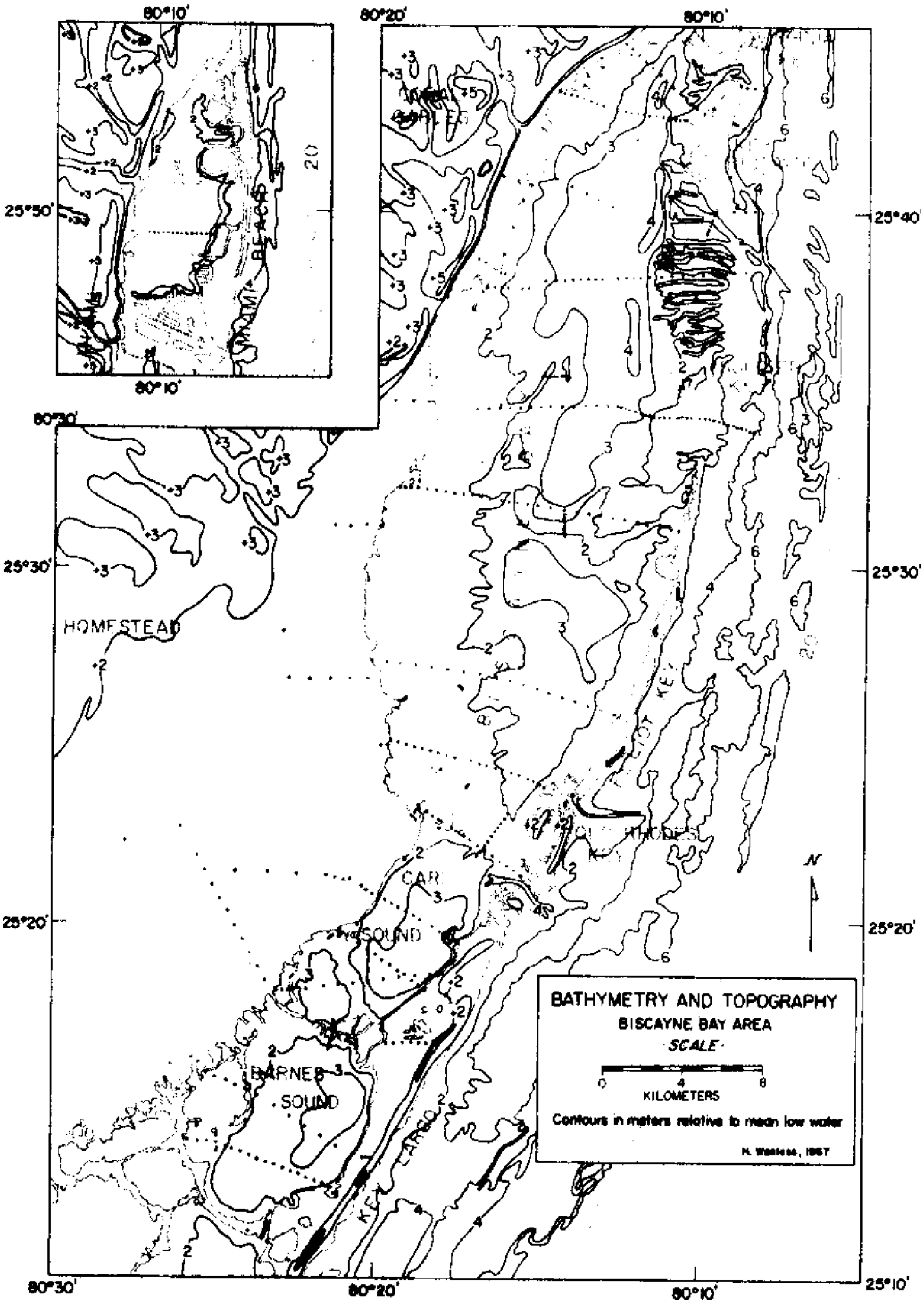


FIGURE 5. Map of present bathymetry and topography of the Biscayne Bay area. Lighter contour is present shoreline (mean low water). Dots show probing locations. Contours in meters are generalized from hydrographic charts and topographic maps. From Wanless (1969).

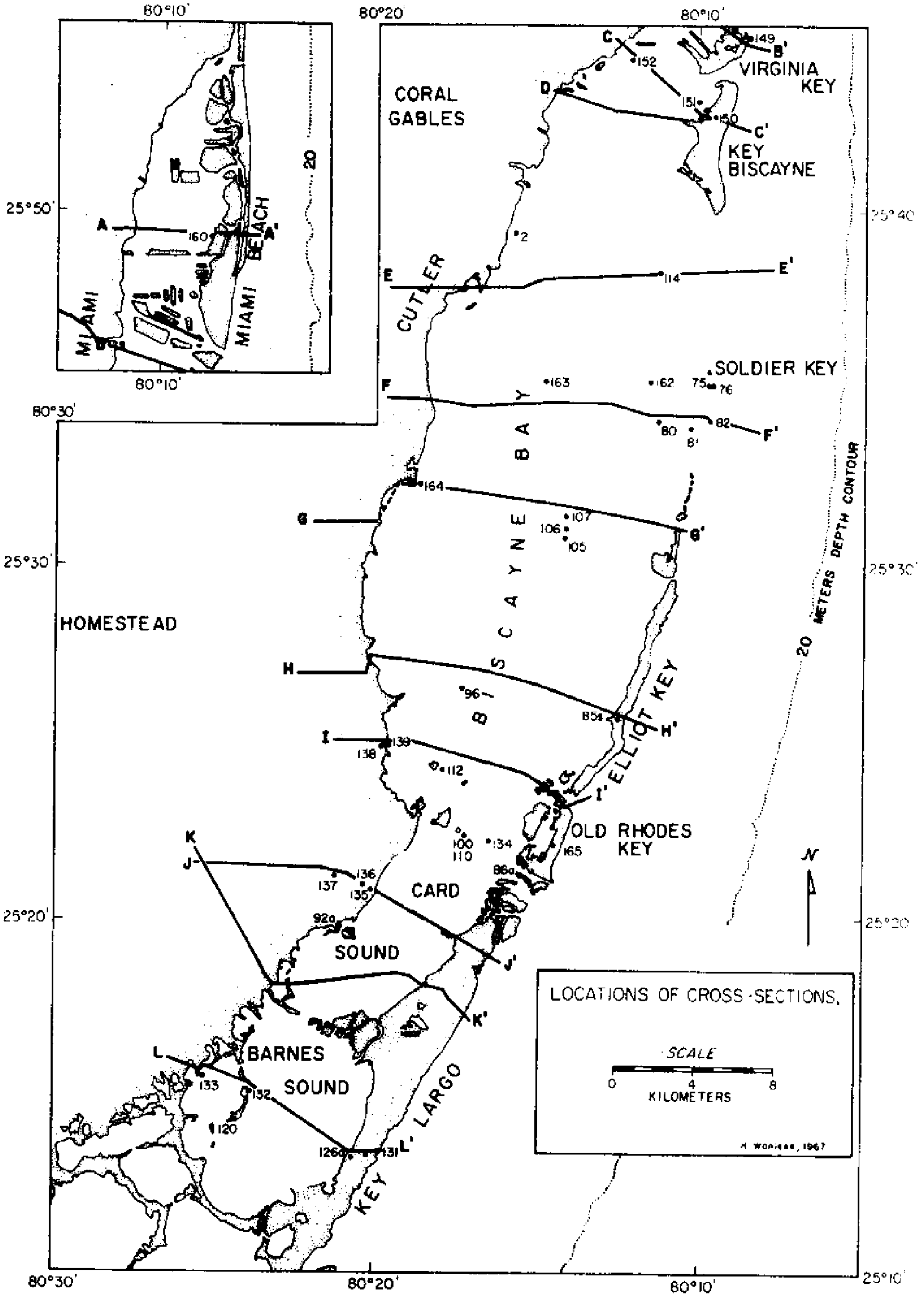


FIGURE 6 Locations of cross sections shown in Figure 7. Numbered dots indicate vertical core borings taken through Recent sediment accumulates.

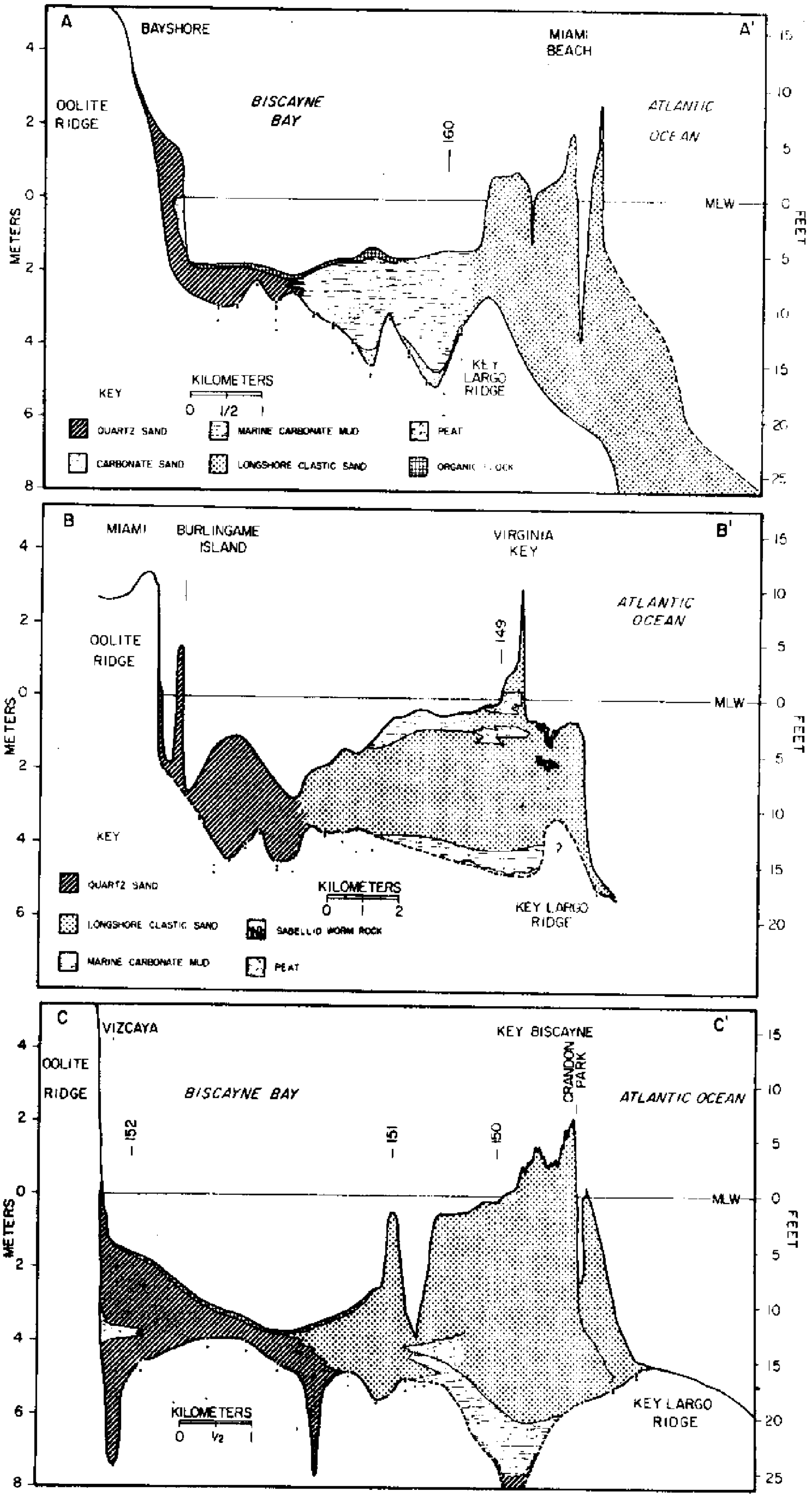
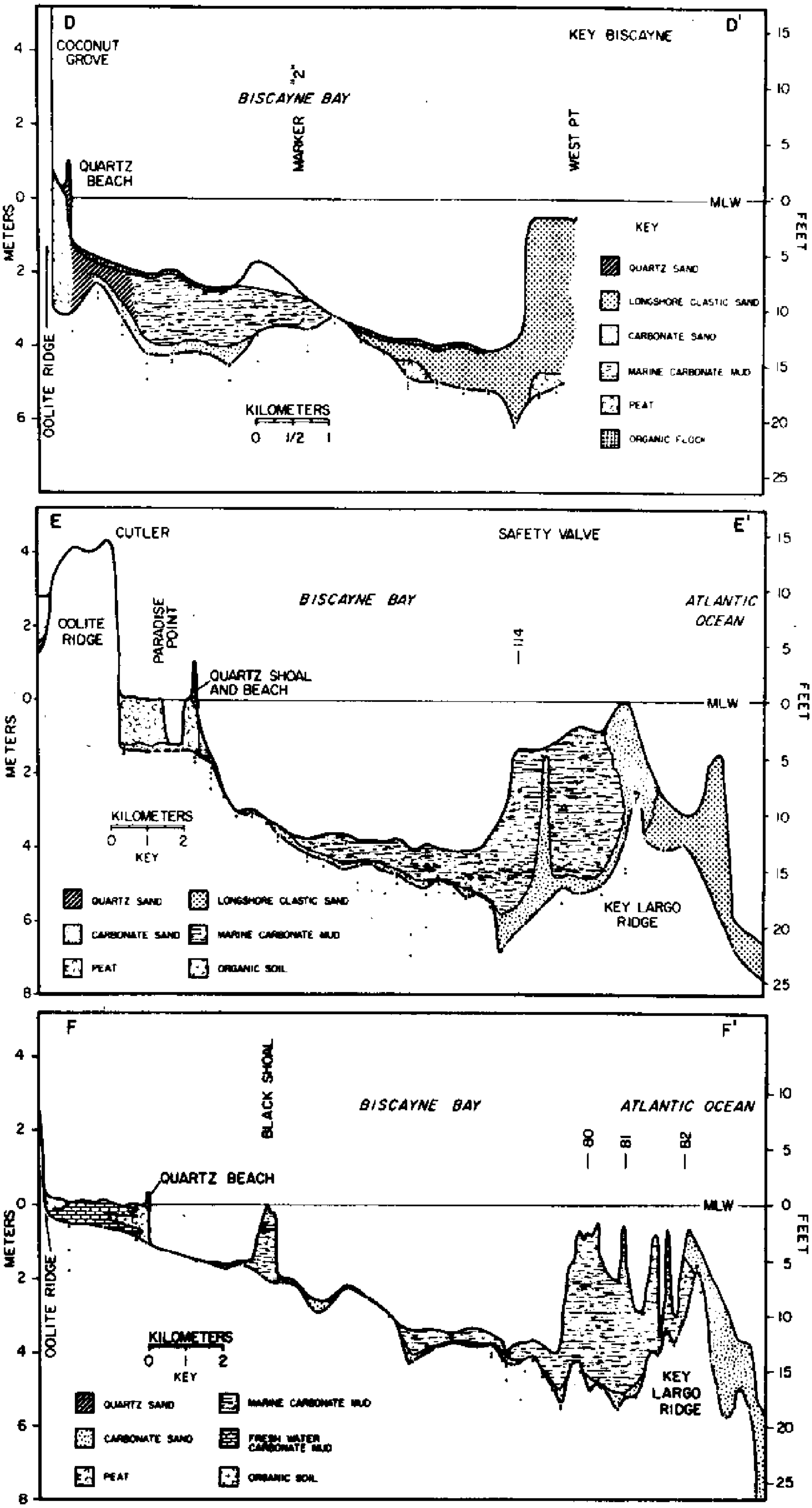
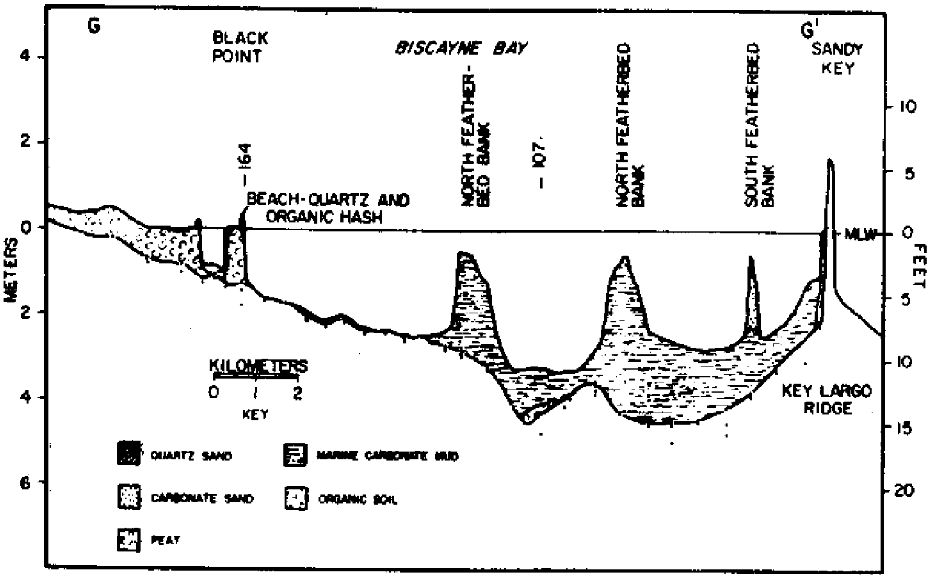
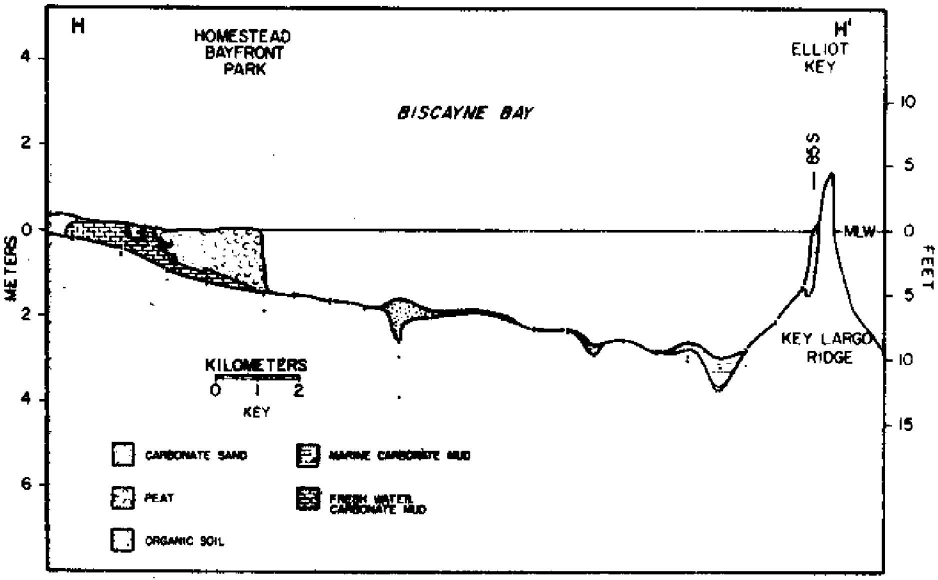
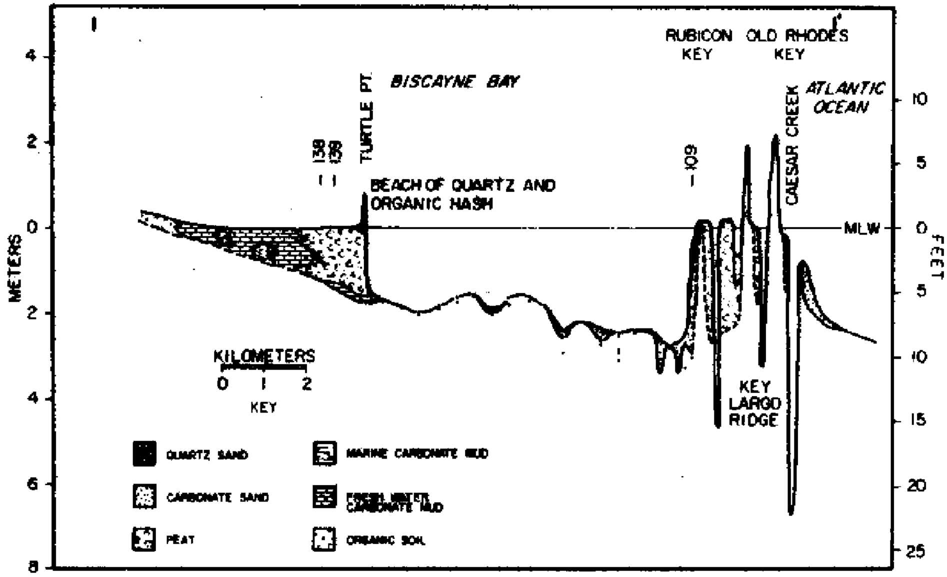


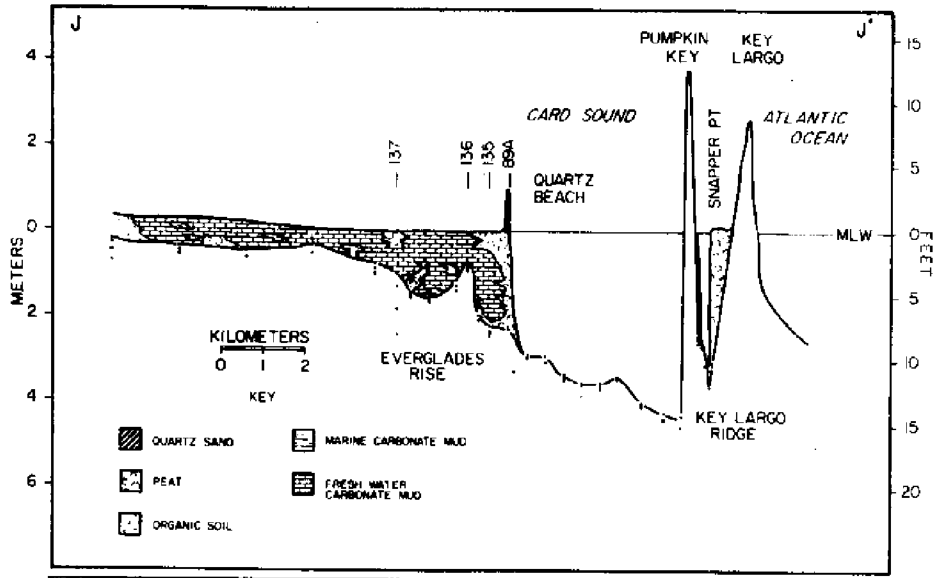
FIGURE 7. Cross-sections of Recent sediment accumulation from northern Biscayne Bay (A) south to Barnes Sound (C). Bottom line in each section is pre-existing bedrock surface. Dots interrupting line are probing stations. Variation in bedrock depth at each station is shown by vertical dots. Numbers refer to core boring localities. All data is relative to mean low water. Cross sections A-D have a vertical exaggeration of x500, E-L are x1000. See Figures 6 and 8 for locations. From Wanless (1969).

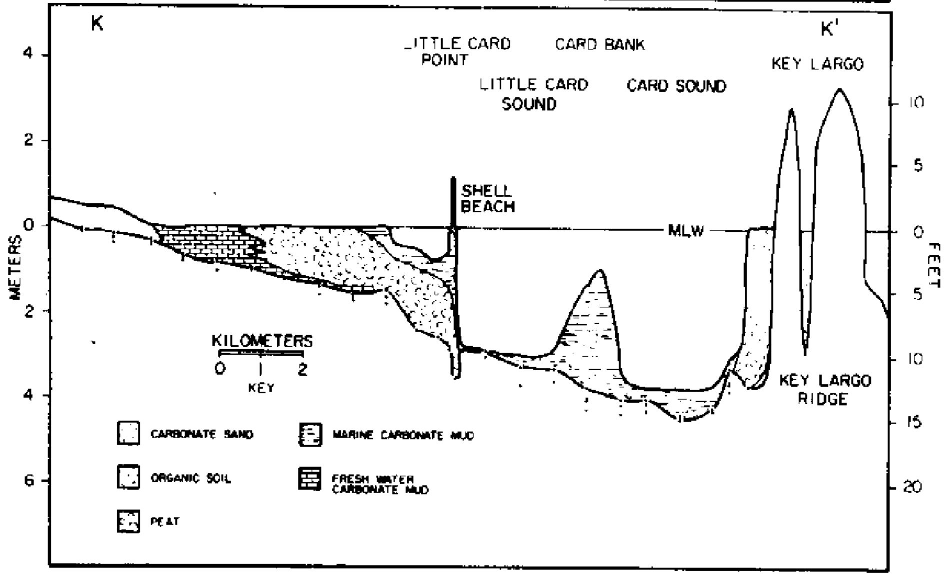

D
D'
COCONUT GROVE
KEY BISCAYNE
BISCAYNE BAY
MARKER "2"
WEST PT
QUARTZ BEACH
MLW
OOLITE RIDGE
METERS
FEET
KILOMETERS
0 1/2 1
KEY
QUARTZ SAND
LONGSHORE CLASTIC SAND
CARBONATE SAND
MARINE CARBONATE MUD
PEAT
ORGANIC FLOCK
E
E'
CUTLER
SAFETY VALVE
BISCAYNE BAY
ATLANTIC OCEAN
OOLITE RIDGE
PARADISE POINT
QUARTZ SHOAL AND BEACH
114
KEY LARGO RIDGE
KILOMETERS
0 1 2
KEY
QUARTZ SAND
LONGSHORE CLASTIC SAND
CARBONATE SAND
MARINE CARBONATE MUD
PEAT
ORGANIC SOIL
F
F'
BLACK SHOAL
BISCAYNE BAY
ATLANTIC OCEAN
80
81
82
QUARTZ BEACH
OOLITE RIDGE
KEY LARGO RIDGE
KILOMETERS
0 1 2
KEY
QUARTZ SAND
MARINE CARBONATE MUD
CARBONATE SAND
FRESH WATER CARBONATE MUD
PEAT
ORGANIC SOIL
4
2
0
2
4
6
8
15
10
5
0
5
10
15
20
25

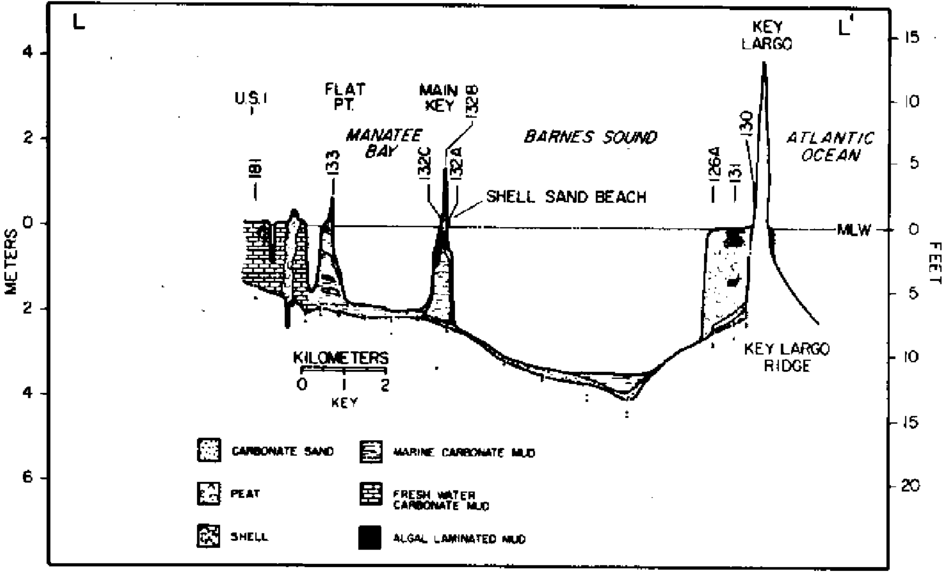

G
BLACK POINT
BISCAYNE BAY
G'
SANDY KEY
164
BEACH-QUARTZ AND ORGANIC HASH
NORTH FEATHER-BED BANK
107
NORTH FEATHERBED BANK
SOUTH FEATHERBED BANK
MLW
KEY LARGO RIDGE
KILOMETERS
0 1 2
KEY
QUARTZ SAND
MARINE CARBONATE MUD
CARBONATE SAND
ORGANIC SOIL
PEAT
METERS
4
2
0
2
4
6
FEET
10
5
0
5
10
15
20


H
HOMESTEAD BAYFRONT PARK
BISCAYNE BAY
H'
ELLIOT KEY
85S
MLW
KEY LARGO RIDGE
KILOMETERS
0 1 2
KEY
CARBONATE SAND
MARINE CARBONATE MUD
PEAT
FRESH WATER CARBONATE MUD
ORGANIC SOIL
METERS
4
2
0
2
4
6
FEET
10
5
0
5
10
15


I
I'
RUBICON KEY
OLD RHODES KEY
BISCAYNE BAY
ATLANTIC OCEAN
TURTLE PT.
138
139
BEACH OF QUARTZ AND ORGANIC HASH
109
CAESAR CREEK
MLW
KEY LARGO RIDGE
KILOMETERS
0 1 2
KEY
QUARTZ SAND
MARINE CARBONATE MUD
CARBONATE SAND
FRESH WATER CARBONATE MUD
PEAT
ORGANIC SOIL
METERS
4
2
0
2
4
6
8
FEET
10
5
0
5
10
15
20
25


J
J'
PUMPKIN KEY
KEY LARGO
CARD SOUND
SNAPPER PT
ATLANTIC OCEAN
137
136
135
89A
QUARTZ BEACH
MLW
METERS
FEET
4
2
0
2
4
6
15
10
5
0
5
10
15
20
KILOMETERS
0 1 2
EVERGLADES RISE
KEY LARGO RIDGE
KEY
QUARTZ SAND
PEAT
ORGANIC SOIL
MARINE CARBONATE MUD
FRESH WATER CARBONATE MUD


K
K'
LITTLE CARD POINT
CARD BANK
LITTLE CARD SOUND
CARD SOUND
KEY LARGO
SHELL BEACH
MLW
METERS
FEET
4
2
0
2
4
6
10
5
0
5
10
15
20
KILOMETERS
0 1 2
KEY
KEY LARGO RIDGE
CARBONATE SAND
ORGANIC SOIL
PEAT
MARINE CARBONATE MUD
FRESH WATER CARBONATE MUD


L
L'
KEY LARGO
U.S.1
FLAT PT.
MAIN KEY
132B
MANATEE BAY
BARNES SOUND
ATLANTIC OCEAN
181
133
132C
132A
SHELL SAND BEACH
126A
131
130
MLW
METERS
FEET
4
2
0
2
4
6
15
10
5
0
5
10
15
20
KILOMETERS
0 1 2
KEY
KEY LARGO RIDGE
CARBONATE SAND
PEAT
SHELL
MARINE CARBONATE MUD
FRESH WATER CARBONATE MUD
ALGAL LAMINATED MUD

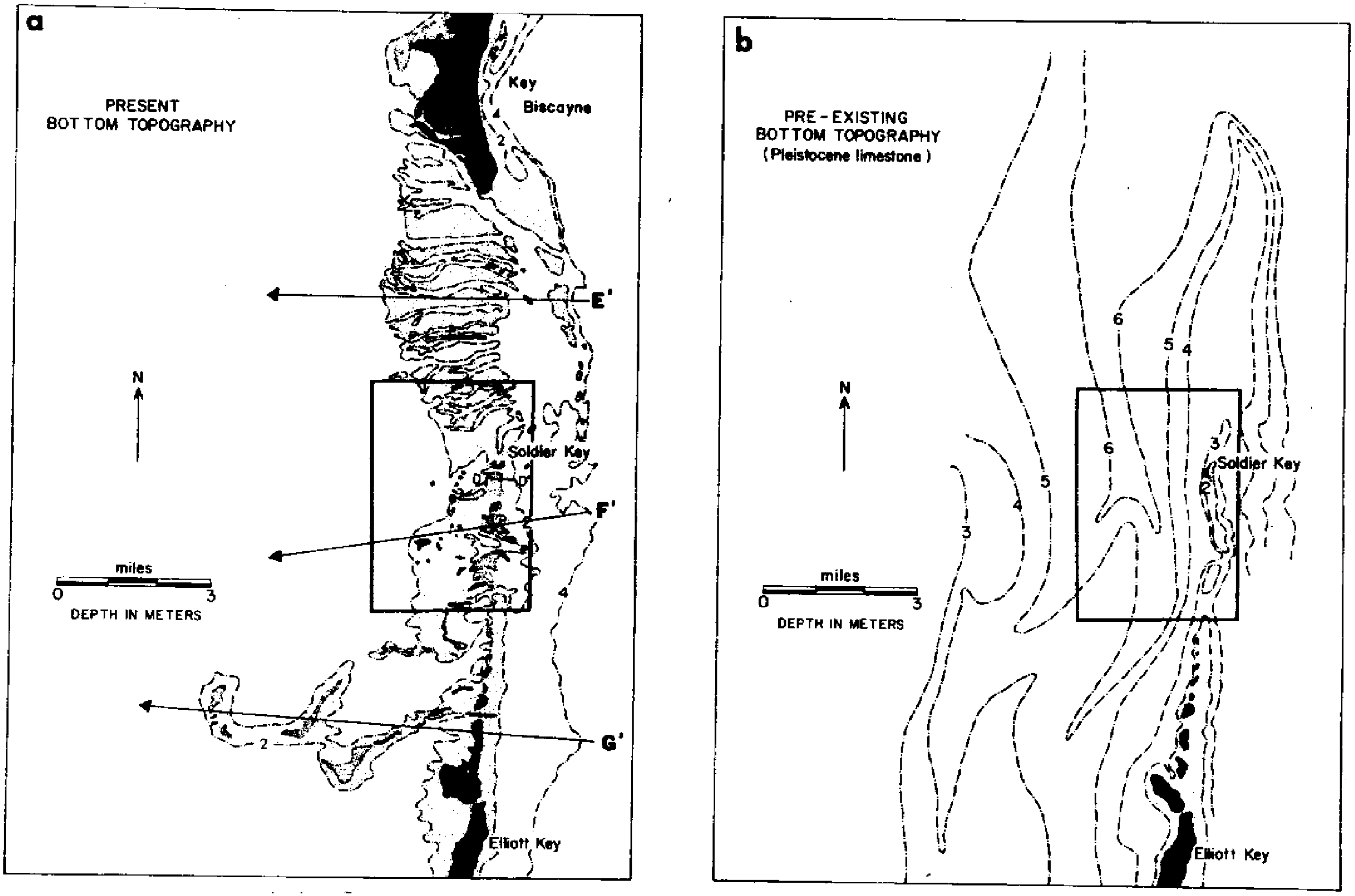


FIGURE 8. Maps of (a) present and (b) pre-existing bottom topography in the Safety Valve, Featherbed Bank area of east central Biscayne Bay. Lines are locations of cross sections E, F, and G (right sides). Dot is transition area discussed intext. From Wanless (1975a).

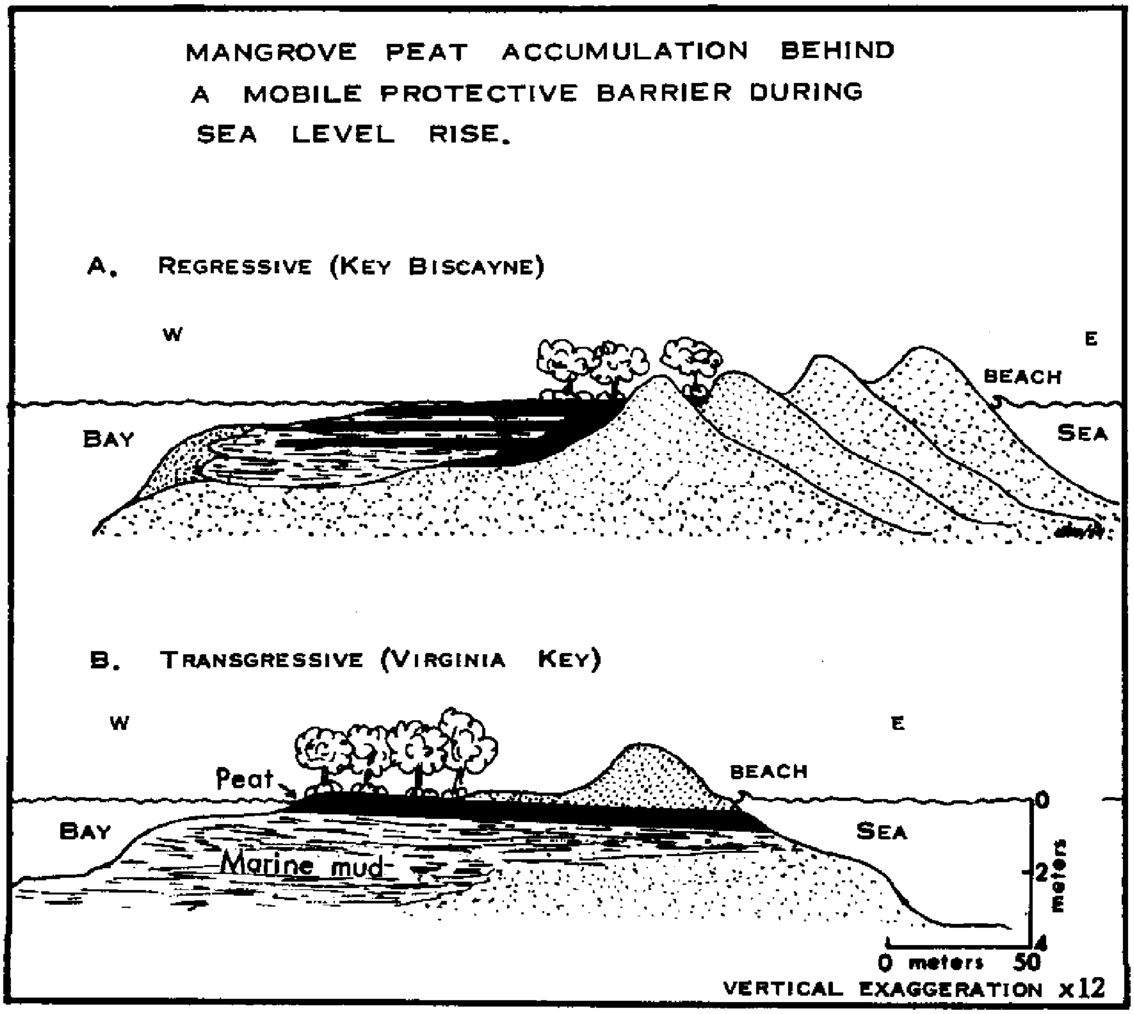


FIGURE 9. Cross-sections of mangrove peat accumulation behind (A) regressive and (B) transgressive mobile protective barriers during sealevel rise. From Wanless (1974b).

STORM SEDIMENTATION IN THE BISCAYNE BAY REGION

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ABSTRACT

The Biscayne Bay region is a low energy environment, characterized by mild climatic conditions during most of the year. Three climatic energy levels are recognized: 1) prevailing mild southeast and east winds, 2) winter cold fronts, 3) rare major storms (hurricanes). Sediment erosion and transport occurs almost entirely during 2) and 3).

Dominant northerly winds of cold fronts cause southward longshore drift of sand along beaches, and southward transport of unstabilized sands on the bay bottom. Muddy sediment stirred into suspension by wave agitation tends to be redistributed 1) from the bay bottom as a whole to seagrass beds, 2) to seagrass covered tidal deltas and tidal bar belts, and 3) out of the bay. Waves breaking along unprotected shorelines contribute to erosion and shoreline retreat.

Wave agitation and storm surge during hurricanes are the major agents which modify sediment bodies in south Florida. Hurricane waves both winnow huge amounts of sediment from the bay bottom and reef tract and erode exposed shorelines. Breaking storm waves can shatter coastal mangroves and damage buildings in flooded areas. Storm surges may cause erosion where channeled through tidal passes or other gaps in barriers. Surge takes the form of a tidal wave under certain circumstances, in which case it may devestate buildings and vegetation in low-lying coastal areas. Receding storm surge deposits silt layers up to 10 cm or more in thickness on flooded land areas. Suspended sediment is also deposited on tidal deltas and tidal bar belts, and carried offshore by storm discharge and subsequent tides.

Man-made land features are generally more vulnerable to storm damage than natural sediment accumulations, the latter having been conditioned by many hurricanes over centuries. Bridge abutments, causeways, and land-fill islands that constrict the flow of storm surge are commonly washed away. "Natural" shorelines, where man's influence has hampered natural systems which prevent or repair storm erosion, are also vulnerable to storm erosion.

INTRODUCTION

South Florida and The Bahamas are "low energy" environments experiencing a mild, sunny climate throughmost of the year. Careful examination of Biscayne Bay on a typical summer day makes it clear that very little physical sedimentation--erosion, transport, and redeposition of sediment--takes place under these conditions. The water is clear except in the northern bay where man's influence is felt most. Swift currents in tidal passes carry little suspended sediment and merely shift channel bottom sands back and forth as the tides change. Yet the bay has ample evidence of sediment movement: tidal deltas, channels cut in sediment banks, accretionary beach ridges on Key Biscayne, and eroding mangrove peat exposed beyond the present shoreline.

The purpose of the present paper is to bring together existing literature, primarily from the past 10 to 15 years, which bears on the dynamics of sediment movement in the Biscayne Bay region, and to tie the sedimentary processes to the atmospheric conditions which cause them. The Biscayne Bay region is taken here as the Bay itself, Card and Barnes Sounds, immediately adjacent low-lying land areas, and tidal passes connecting to the ocean. Much of this literature concerns specific areas other than the Biscayne Bay region but is relevant to sedimentary processes here.

Ball (1967) recognized that high energy events--storms--play a major role in physical sedimentation in south Florida and The Bahamas. Earley and Goodell (1968) and Wanless (1969) concluded that intermediate to high energy events, including cold fronts and hurricanes, are important in sediment transport and deposition throughout the Biscayne Bay region. Warzeski (1975, 1976) and Wanless (1969) found that this has been the case ever since the post-glacial rise of sea level first began to flood the bay between 6000 and 7000 years ago.* Ball et al. (1967), Craighead and Gilbert (1961), Perkins and Enos (1968) and Pray (1966) documented the major sedimentary significance of hurricanes. Ball et al. (1967) concluded that traces of these storms make up a disproportionately large part of the Holocene sedimentary record in south Florida when compared to the actual percentage of time that they affect the area.

Existing knowledge provides a good generalized picture of sedimentation within the Biscayne Bay region. A more detailed understanding which will allow prediction of the impact of man-made modifications awaits work on 1) water movements within the bay during storms, 2) concentration and composition of suspended sediments during storms, 3) rates and processes of shoreline erosion in different parts of the bay, and 4) natural systems which prevent or counteract shoreline erosion. Modeling techniques for predicting circulation within Biscayne Bay under various wind conditions have already been developed (Dean, this volume) and could be used to study effects of cold fronts. More complex models might conceivably predict movements during hurricanes of various strengths and paths. Turbidity studies await standardization of the technology for measuring turbidity, so as to allow comparison with results of other investigations as well as an actual research effort within the bay. Research which bears on 3) and 4) has been underway off Key Biscayne and Virginia Key for several years (Wanless and van de Kreeke, pers. comm.; 1973). An expanded effort encompassing other parts of the Biscayne Bay region is necessary, however, to produce information usable in setting bulkhead lines or predicting the results of development in the region as a whole.

DISCUSSION

CLIMATIC ENERGY LEVELS IN SOUTH FLORIDA

Climatic conditions in south Florida are divisible into three energy levels or intensities, each of which has a distinct sedimentological significance. These are 1) prevailing mild southeast and east winds, 2) winter cold fronts and 3) rare major storms (hurricanes). Sedimentation during prevailing low energy conditions is essentially limited to in situ production of carbonate sediment by benthic organisms, and biological reworking of sediment (bioturbation) by the infauna. Significant erosion and transport of sediment takes place only during intermediate and high energy events--primarily cold fronts and hurricanes. Because the frequency, wind patterns and strengths of these two types of disturbances are radically different, their effects upon the sediments of south Florida and the Biscayne Bay region are also distinctly different.

Cold Fronts

Winter cold fronts pass over Biscayne Bay an average of once a week during the period from November to April. The following description of an average cold front is based on Mooers and Fernandez-Partagas (in preparation). An average cold front affects wind patterns in the Biscayne Bay region for 4 to 5 days, involving a slow 360° clockwise rotation of wind direction (direction from which the wind is blowing). Winds rise above ambient throughout this period, reaching maxima roughly half a day before and after passage of the front itself. Maximum winds ahead of the front are from the southwest and reach 8 m/sec. Maximum winds behind the front are from the northwest and reach 10 to 15 m/sec. Northerly winds after frontal passage are of greater duration than southerly winds prior to passage. Maximum winds during an exceptional cold front can reach 20 to 26 m/sec (Fernandez-Partagas, pers. comm. 1976).

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* These ages are, by convention, in radiocarbon years and are uncorrected. They are roughly equivalent to 7500 to 8500 "earth years" before present.

Wave agitation winnows surface sediments throughout the Biscayne Bay region during passage of a cold front. Breaking waves on shorelines and bars transport longshore sands and cause shoreline erosion.

Winnowing is most effective on open, seagrass-free bottoms. Seagrasses, particularly the turtlegrass Thalassia testudinum, act as a baffle to currents and wave surge, partially shielding the bottom. Large quantities of mud (silt and clay-size carbonate and organic detritus) are stirred into suspension. Much of this sediment is removed from Biscayne Bay, Card Sound and Barnes Sound by ebbing tides over a period of several days. Trapping of suspended mud by seagrass carpets on tidal "deltas" and on the Safety Valve tidal bar belt contributes to the growth of these features.

Aerial photographs show that dominant northerly cold front winds cause a slow southward drift of turbid water within Biscayne Bay. Water is drawn in over the Safety Valve and through the northern tidal passes. In addition to noticeably raising the water level of Card and Barnes Sounds, this piling up of water to the south augments discharge of sediment-laden water from Caesars Creek, the southernmost tidal pass of Biscayne Bay. Partly as a result of this, the creek's ebb tidal "delta"--Caesars Creek Bank--is larger than any other in south Florida (Warzeski, 1975, 1976).

Sediment which remains within the Bay and sounds is preferentially redeposited on seagrass-covered bottoms due to lower turbulence within the mesh of Thalassia blades. Storms thus yield a net transfer of mud (silt and clay-size sediment) from the bay bottom as a whole to seagrass beds. This factor plus partial protection of the bottom from winnowing by Thalassia causes the higher percentages of mud found in seagrass stabilized substrates by Lynts (1966), Earley and Goodell (1968), and Wanless (1969).

Northerly winds from cold fronts also cause dominantly southward longshore drift of sand along beaches in the Biscayne Bay region and of unstabilized sand across the bay bottom. Southward longshore drift has caused southward accretion of barrier islands along the northern part of the Bay over the past several thousand years (Wanless, 1969; Shepard and Wanless, 1971). It provides a continuing supply of sand to nourish beaches except where natural processes are cut off by man. The distribution of fine quartz sand in loose bottom sediments of Biscayne Bay, Card Sound and Little Card Sound documents southward movement of sand within the bay and sounds (Vaughan, 1910; Earley and Goodell, 1968; Wanless, 1969).

Shoreline erosion during cold fronts is difficult to separate from that during hurricanes.

Hurricanes

Sedimentary effects of rare major storms--hurricanes and very rare, extremely powerful hurricanes (100 or 500 year storms)--are more profound due to the far greater energy of hurricane winds. As a result, hurricanes are disproportionately represented in the sedimentary record of south Florida (Ball et al., 1967). Hurricane force winds affect the Biscayne Bay region at highly irregular intervals, averaging once every 7 years (Dunn and Miller, 1960).

Hurricanes are characterized by extreme wind velocities, from 33 m/sec to over 100 m/sec. They exhibit a counterclockwise wind circulation about an eye several 10's of kilometers or more in diameter. Winds of 30 m/sec or more pound a section of coastline extending 75 kilometers or more away from the eye (Gentry, 1974). The sequence of wind directions experienced by the Biscayne Bay region during a hurricane will depend upon the path of the storm: its direction of approach and whether the eye passes the north, south or over the bay. Hurricanes striking south Florida usually approach from the southeast to east, or southwest resulting in initial north and east winds followed by south and west winds (Ball et al., 1967; Gentry, 1974). Storm surge and high energy wave action due to hurricane-force winds are important agents of sediment erosion, transport and redeposition.

Wave Action

Intense hurricane wave agitation reworks loose sediment throughout the Biscayne Bay region. Thalassia-stabilized muddy sediments are resistant to wave surge, and sustain only minor damage. Waves of Hurricanes Donna and Betsy, in 1960 and 1965 respectively, winnowed a few centimeters of sediment at most from seagrass beds in the inner reef tract, Florida Bay and Biscayne Bay (Pray, 1966; Ball et al., 1967; Wanless, 1969). Huge quantities of silt and clay-size sediment are stirred into suspension, to be carried landward by storm surge and seaward by ebbing storm discharge and tides.

More extensive damage may occur due to breaking of waves against the shoreline, and in flooded areas. Breaking storm waves generate short term, high velocity currents capable of shattering shoreline mangroves, damaging buildings, hurling large pieces of debris about, and eroding deeply into sediments along the shore (Craighead and Gilbert, 1962; Ball et al., 1967). Craighead and Gilbert (1962) attribute excavation of "moats" commonly observed around mangrove islands in Florida Bay and elsewhere to the latter process. Ball et al. (1967) found mangroves on the seaward side of Rodriguez Key, offshore from southern Key Largo, splintered and uprooted after Hurricane Donna.

Mangrove destruction during hurricanes and wave surge during both hurricanes and large cold fronts cause erosion of mangrove-stabilized shorelines in the Biscayne Bay region. Sediments overlying bedrock in the bay and sounds and along the present mainland shore record a history of shoreline retreat during the post-glacial rise of sea level (Wanless, 1969). Retreat has been greatest where protection from waves of onshore storm winds is least--central and southern Biscayne Bay. An exposed platform of mangrove peat along parts of the mangrove fringe bordering this section of the bay indicates that erosion is still taking place (Wanless, 1969).

Erosion in natural areas, however, is generally significant only on a time scale of centuries or more. This is not the case where man has hampered natural systems which prevent or counteract storm erosion. Beaches where the long shore sand supply has been cut off by jetties or groins are unable to recover from damage sustained during hurricanes and winter cold fronts. Shorelines from which protective shallow offshore seagrass beds have diminished may experience accelerated erosion. The northeast shore of Virginia Key is an example of both of these problems. The jetties of Government Cut shunt the zone of longshore and transport far offshore, preventing replenishment of the beach. Seagrass cover offshore from Virginia Key has decreased radically in area over the past decades (see Wanless, this volume). This seagrass bed loss may be related to cutoff of the long shore sediment supply. The net result of these factors has been substantial retreat of the northeast shore of the island. Mangrove peat originally deposited in the swamp behind the beach was exposed and eroding in places along the shore prior to the 1973 beach replenishment. In the absence of natural nourishment, future storms are likely to remove this beach as well.

Developed areas where bulkheads are placed too close to the shoreline are also vulnerable to shoreline erosion, particularly when combined with groins. Winter storms tend to erode beaches back, shifting sand to offshore bars. Where erosion reaches bulkheads, reflection of waves off the bulkhead excavates a "moat" along it. Groins, by keeping the zone of longshore drift offshore, prevent natural replenishment. Hurricane waves striking such an exposed bulkhead will undermine it. This occurred on parts of the beach on Key Biscayne during Hurricane Betsy in 1965 (Wanless, pers. comm., 1973).

Storm Surge

Storm tides and currents associated with them are the most damaging aspects of hurricanes in coastal areas. Hurricane winds generate mass flow of shallow coastal waters. Onshore winds pile storm tides of several meters or more against small sections of coastline, causing severe flooding in lowlying areas. Offshore winds tend to lower the coastal water level. Winds blowing along the axis of coastal bays may force water into or out of these water bodies. Storm tides of 2 to 3 meters have occurred within Biscayne Bay, Card and Barnes Sounds during Hurricanes Donna in 1960 and Betsy in 1965 (Perkins and Enos, 1968). The eyes of both of these storms skirted to the south of the Biscayne Bay region. Extreme tides of 4 meters or more were recorded within the bay during major hurricanes which passed directly over Biscayne Bay in 1926 and 1945 (Gentry, 1974).

Constriction of mass, wind-induced flow in narrow gaps between islands produces localized high energy currents. Currents are further enhanced if wind directions and coastal morphology combine to generate high storm tides on one side of the barrier while lowering the water level on the other. Hurricane Donna in 1960, provides an excellent example of this. Her effects are discussed in detail by Ball et al. (1967) and Craighead and Gilbert (1962) and are summarized below.

Hurricane Donna passed northwestward over Florida Bay and Cape Sable. Initial northeast winds flushed water out of Florida Bay into the Gulf of Mexico, dropping the water levels to 0.5 m below MLW in the southern part of the bay and much lower in the northern part. At the same time, a storm tide of up to 4 meters above MLW built up along the southern side of the Florida Keys. Extremely powerful currents flowed bayward through passes between the keys. This situation was reversed after the eye passed and winds shifted 180° (Ball et al., 1967). A 2 to 2.5 meter (6 to 8 feet) tidal wave swept over Cape Sable as water swept back into Florida Bay. The water reached 4 meters above MLW in the Bay, and subsided in the reef tract.

The location and magnitude of storm tides and the strength of associated currents in the Biscayne Bay region depend upon the path and strength of the hurricane. The greatest effects result from a powerful storm moving directly onshore over Biscayne Bay (Ball et al., 1967), as did the 1926 hurricane. Such a storm would generate a high storm tide in central and southern Biscayne Bay (4.0 meters at Dinner Key in the 1926 hurricane). Initial northerly winds and high water in the central bay would produce southward flow, raising the water level in southern Biscayne Bay, Card and Barnes Sounds as well. As the eye of the storm moves across the bay, offshore winds to the south of the eye would depress water levels in the reef tract to the south (Gentry, 1974), causing extremely high velocity discharge from Broad, Angelfish and Ceasars Creeks.

Powerful storm discharge is potentially an important agent of erosion. Natural sediment bodies have been conditioned by many hurricanes, but still may, rarely, be affected. Norris Cut appears to have been formed when the Great Hurricane of 1835 passed directly over the bay (Chardon, this volume). Wanless (1969) concluded that new channels in the Safety Valve tidal bar belt are cut during major storms. Warzeski (1975, 1976) found clear evidence of exceptionally powerful storm discharge from Caesars Creek within the past several hundred years. Cores through Caesars Creek Bank show that seagrass cover was ripped out and sediment eroded over much of the bank. A mud storm layer was deposited afterward, probably by waning currents of the same storm. This erosion is attributed to the 1926 and/or 1935 hurricanes on the basis of the storm layer's shallow burial, and aerial photographs showing incomplete recovery of seagrass beds by 1940.

Artificial obstructions to flow are not adapted to such currents and may experience severe erosion. Currents through tidal passes in the keys during Hurricane Donna removed hundreds of cubic meters of fill, undermining the overseas highway and nearby homes (Ball et al., 1967). Water flowing southward from Card and Barnes Sounds into Florida Bay washed out two section of U.S. 1 during Hurricane Betsy (Perkins and Enos, 1968). Portions of the Biscayne Bay region such as northern Biscayne Bay, where man-made features would severely obstruct the flow of storm waters, are particularly vulnerable to a direct strike by a major hurricane.

Hurricane "tidal waves" such as that which struck Cape Sable during Hurricane Donna can devestate developed areas along the coast. Greatest damage in the Biscayne Bay region would be inflicted on the keys and islands on the ocean-side of the bay. Low-lying parts of the mainland coast would be hard hit as well. Waves of this type would result primarily from a 180° wind shift after initial winds had blown water away from the shore. A storm would have to approach from an odd direction, such as the north or northeast, in order to produce a mainland "tidal wave" in the Biscayne Bay region.

Much sediment stirred into suspension or eroded during a hurricane is redeposited on land by high storm tides or tidal waves. Hurricane Donna left a silt layer 0 to 13 cm in thickness extending up to 8 km into the Everglades and silt layers up to 6 cm in thickness on various keys in Florida Bay (Ball et al., 1967). Hurricane Betsy generally deposited thinner and less extensive layers in the Florida Bay region (Pray, 1966; Perkins and Enos, 1968), but left up to 5 cm of silt on Key Biscayne (Wanless, 1969). Similar layers have been found in core borings through Key Biscayne, indicating a history of sporadic hurricane deposition over the last 3000 to 4000 years.

Storm silt deposits are an expensive and annoying side effect in developed areas, but are important geologically. Supratidal storm deposition is an important process of land-building in south Florida (Ball et al., 1967; Craighead and Gilbert, 1962).

Silt layers are deposited on submerged tidal deltas and tidal bar belts as well. Deposition is due to a combination of (a) waning current energy as the storm passes, (b) decrease in velocity (and therefore sediment carrying capacity) of currents beyond narrow tidal passes, and (c) trapping of suspended sediment by seagrasses. Layers are rarely preserved in the manner of that found near the sediment surface in Caesars Creek Bank (Warzeski, 1975, 1976). Deposition in intact seagrass beds and subsequent burrowing of benthic organisms prevent formation or preservation of discrete layers. Despite this lack of preservation of direct evidence, the growth history of Caesars Creek Bank, (Warzeski, 1975, 1976) and inclusions of storm transported fine quartz sand in the Safety Valve tidal bar belt (Wanless, 1969) indicate that storms, including hurricanes, are a major source of fine sediment for those sediment bodies.

SUMMARY

Sedimentation in the Biscayne Bay region occurs in discrete "events" associated with passage of cold fronts and hurricanes. Little or no erosion or transport of sediment occurs during prevailing mild climatic conditions.

Cold fronts, by virtue of the consistency of their wind patterns and their frequency (30 to 40 times per winter--November-April) have a major role in surface sediment movement. Dominantly southward longshore drift of beach sands, and southward movement of sands on grass-free parts of the bay bottom are products of strong northerly winds after passage of a cold front. In addition, there is a net transfer of mud stirred into suspension by cold front winds 1) from the bay bottom as a whole to seagrass beds, 2) to seagrass-covered tidal "deltas" and tidal bar belts and 3) out of the bay. Wave surge of hurricanes and cold fronts combine to erode exposed parts of natural mangrove shorelines, and may cause serious erosion of shorelines created or affected by man.

Hurricanes, through wind-induced large-scale flow and wave surge, are the agents of major modifications of sediment bodies, such as cutting of channels, rapid sediment accretion and erosion. Hurricane erosion occurs as a result of 1) high energy storm discharge through tidal passes and other gaps in barriers, 2) wave surge, and 3) "tidal waves". Storm discharge is a threat chiefly to artificial constrictions of flow such as causeways, artificial islands, and bridge abutments. In extreme cases, it may wash away or undermine buildings. Wave surge is a threat (a) to natural shorelines which lack bars, seagrass beds or nearby islands to protect them, (b) to seawalls and bulkheads placed too close to the shore, and (c) to boats, buildings and vegetation near the shoreline. "Tidal waves" would tend to occur where water was first blown away from shore and then blown back after the 180° shift in wind direction as the storm passes. The Biscayne Bay region could be subjected to such a wave only if a strong hurricane approached from an odd direction, such as the northeast. The chief effects of a tidal wave from the east would be 1) destruction of vegetation and homes on the barrier islands and bedrock keys along the bay's ocean side and on the unprotected mainland shoreline of central Biscayne Bay, 2) landward transport of loose sediment--beach sand, vegetation and man-made debris.

Sediment deposition during hurricanes occurs 1) as surging waters lose energy and retreat, 2) as storm waters enter a much broader and/or deeper body of water. Deposits are rarely preserved except on land where they are not subject to subsequent biologic reworking. Silt layers left by retreating storm waters are usually 5 cm or less in thickness, and rarely exceed 10 cm. They are generally restricted to areas near the shoreline, but may reach several kilometers inland in low-lying areas such as southern Dade County.

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BIOGEOCHEMISTRY OF TRACE ELEMENTS IN CARD SOUND, FLORIDA INVENTORY AND ANNUAL TURNOVER

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ABSTRACT

The concentrations of vanadium, iron, copper, cadmium, zinc, and lead have been determined in organisms, water, and sediments of Card Sound, Florida. Multiplication of these specific concentrations bv the amount of organisms, water, and sediment has led to an inventory of Card Sound for these elements. Highest amounts of each element are found in sediments, followed by water and then living organisms. The trace element inventory of turtle grass (Thalassia testudinum) was highest for all elements, followed closely by sponges, with large rooted algae approximately an order of magnitude (ten times) lower. Phytoplankton, epiphytes, and invertebrates constitute a minor part of the biological trace element inventory.

The significance of the living organisms of Card Sound, Florida as well as South Biscayne Bay is due to their ability to concentrate trace elements as they grow and die. In the biological process of photosynthesis, the plants of Card Sound and Biscayne Bay incorporate more trace elements in a year than contained in the biomass at any given time. For all of Card Sound, the minimum uptakes by photosynthesis are the following: iron, 1.8×10^4; zinc, 3.5×10^3; vanadium, 1.3×10^3; copper, 3.7×10^2; lead, 3.5×10^1; and cadmium, 1.0×10^1 Kg yr^{-1}. The turtle grass after death and decay accounts for most of the movement of iron, lead, and cadmium from the sediments into the water. There is a strong possibility, yet to be proven, that turtle grass pumps more trace elements into the water directly than has been accounted for by our methods. If this process is true, then turtle grass assumes even greater importance in the cycle of trace elements than these results indicate. Our preliminary data indicate that phytoplankton and epiphytes (small plants which coat turtle grass) produces about one-third of the photosynthesis of turtle grass even though they are present in very small amounts compared with marine grass. These two biological groups cycle most of the vanadium, copper, and zinc of Card Sound. The least well known of the biological groups identified as important to trace element cycling in Card Sound, the phytoplankton and epiphytes, are in need of intensive work on abundance, rate of photosynthesis, and trace element concentrations.

Tidal flows transport more trace elements/day (between 2.5 times more iron and 110 times more copper) into and out of Card Sound than biological incorporation. Much of this water, however, only exchanges directly with a small part of Card Sound, so that biological flow of trace elements remains important. In South Biscayne Bay, there is a greater tidal volume exchange so that water movements may be more important than biological activity. Preliminary results over three continuous days of intensive analysis indicate that there is a net outflow of zinc and cadmium through the tidal exchanges of Card Sound and a net inflow of iron, copper, and lead. Most of the above information for Card Sound is probably true for the adjacent and very similar South Biscayne Bay, except as indicated.

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INTRODUCTION

The estuarine zones of the world are the essential geochemical link between the continental land masses and the oceans. It is through these zones that almost all the products of continental weathering must pass before being introduced to the deep oceans. The alternate pathway, aerial transport, plays a minor role in comparison with water transport. It is important to determine the nature of the processes which control the transport of continentally derived material as it passes into and through these zones.

The estuarine zones serve as vital links in both coastal and open ocean fisheries by providing a rapid growth area for young fish and crustaceans. These zones also accommodate such diverse functions as water recreation and waste disposal. The potentially dangerous impact of man's activities on these zones is increasingly obvious in many areas, especially those associated with coastal metropolitan centers. It is of vital economic and public health concern that the continually accelerating degradation of certain estuarine zones be assessed (Lippson, 1973). Equally important is that baseline studies of estuarine areas near expanding urban centers be initiated before substantial changes occur.

The extent of our ignorance about estuarine biogeochemistry is indicated by the recent suggestion that at least some estuaries may have a net input of trace elements from both rivers and the ocean (Turekian, 1971). This implies that chemical and biological processes within the estuary leading to deposition of the elements are more efficient than their removal to the deep ocean. This has obvious implications in regard to dumping certain elements in estuarine zones.

The current state of knowledge of trace element biogeochemical cycles in estuarine zones is limited to a few isolated studies (Duke et al., 1966; Parker et al., 1963; Parker, 1966; Cross et al., 1970; Wolfe et al., 1972). Identification of major reservoirs in the above studies has indicated that the complex interactions which must be correlated to understand the dynamics of the system are currently beyond our capabilities. The recent review of Wolfe and Rice (1972) only indicates the type of information and procedures needed to develop trackable solutions to understand the very complex nature of cycles in estuarine zones. Clearly, then, one of the most important requirements of estuarine trace metal research is a first approximation assessment of the qualitative and quantitative dynamics of their transport between the water, sediment, and biota of an ecosystem.

In this work, a sequence of procedures has been developed as a necessary first step in the estimation of major biogeochemical processes which occur in a small bay, Card Sound, Florida. The procedure (Segar and Gilio, 1972, Gilio and Segar, 1972, and Gilio and Pellenbarg, 1972) adopted is similar to the simultaneously developed approach of Wolfe and Rice, 1972, and Wolfe et al., 1972. A water-sediment-biota compartment model was constructed combining chemical analysis data, and both species biomass, and net production data to estimate net trace element flux between compartments. A number of assumptions have been based upon the best available knowledge.

Trace Elements

The elements selected for study were vanadium, iron, copper, cadmium, zinc, and lead. They were chosen primarily for their analytical trackability and the wide spectrum of chemical species they exhibit in the Card Sound system. The chemical speciation of these elements within the water, sediment, and biota compartment of Card Sound is a problem which is not solvable at present. Although the elements in this study were not chosen primarily for their importance in current pollution problems or for geochemical balance considerations, most of them fall into one or both of these categories. Cadmium and lead are frequently significant contaminants in industrial and urban activities and are known to be toxic to aquatic organisms at fairly low levels (Eisler, 1971). Zn and Fe are found as radioisotope releases in our nuclear technology. Virtually no reliable data exist for V in aquatic ecosystems, yet current pollution control devices remove particulates of V_2O_5 from fossil fuel power plant stacks. Most of the V_2O_5 generated in power plants adjacent to estuarine zones passes quickly into the adjacent waters (Segar and Pellenbarg, 1973).

Card Sound, Florida

The location of Card Sound as a visibly unpolluted shallow embayment south of a rapidly growing urban development provides a baseline to judge the progressive changes in biota, sediment, and water interactions so clearly evident in the waters adjacent to the developed area (McNulty, 1970). Card Sound may currently be characterized as containing diverse biota of high biological production (Bader and Roessler, 1971, 1972; Thorhaug and Roessler, 1975), and low trace element content in the sediments (Segar and Pellenbarg, 1973), thus amplifying the role of biota as a conveyor of trace elements within the system. The normal water residence time is estimated at 1-2 months (Lee and Rooth, this volume), thus providing a possible steady state aquatic system. These factors combine to provide an ideal location for a first approximation study to determine the major processes of trace element biogeochemical cycles in an apparently unpolluted estuary.

Card Sound is a shallow subtropical estuarine embayment located on the southeast coast of Florida some 50 km to the south of Miami (Fig. 1). The Sound is about 9 km long and 5 km wide and is linked with two similar bodies of water, Biscayne Bay to the north and Barnes Sound to the south. The three basins are separated by shallow (less than 1 m in depth) flats so that water exchange between the basins is limited. Card Sound has a relatively uniform depth averaging 3 m, with the deepest areas reaching about 5 m. An extensive shallow bank, Card Bank, comprised of loose sediments and covered with turtle grass (Thalassia testidinum) divides the Sound itself into a major basin to the north and a smaller section to the south, known as little Card Sound. The only direct connections between the Sound and the ocean are located at the north end of Key Largo, which forms the eastern boundary of the Sound. A series of tidal channels are cut through the barrier islands at this point, principally Broad Creek and Angelfish Creek. Key Largo is a low lying carbonate oolite rock platform covered with vegetation consisting mainly of mangrove swamp (principally Rhizophora mangle, Laguncularia racemosa, and Avicinea nitida) with extensive stands of marsh grass (Juncus sp.) farther inland. This area drains into Card Sound and in addition a drainage canal, The Model Land Company Canal enters the Sound in the center of the western shore. The Florida Power and Light Discharge Canal was constructed just north of the Model Land Company Canal and operated on an interim basis between 7/72 and 3/73, until permanently closed off from its connection with Card Sound upon completion of an enclosed cooling canal system. Almost all the samples and the biological data used in the present study were gathered prior to the opening or after the closure of the canal.

North of Card Bank the sediments are only a few centimeters thick while south of the Bank, on the Bank itself, and along the eastern shore of the Sound, the sediments are deeper and more flocculent. The maximum sediment depth found on Card Bank is about 3 m (Wanless, 1969; and in this volume). The sediments in the Sound are different from those of the adjacent oceanic shelf in that they contain appreciable quantities of fine grained quartz thought to be wave-induced and water-transported through the bays from the Pamlico formation to the north of Miami (Early & Goodall, 1968). Although there is considerable variation in composition, all of the sediments of the Sound consist of variable proportions of calcium carbonate materials such as shell and coral fragments and Halimeda plates, organic detritus and quartz. Clay minerals are not present in detectable concentrations in the Sound sediments.

The biota of the embayment is dominated by a turtle grass (Thalassia testudinum) community occurring throughout the Sound. Dense standing stocks are found in thick organic-rich sediment areas with lower stocks in sediment-thin areas. The macrobiota in the turtle grass community include the marine grasses Thalassia testudinum and Halodule wrightii, and the marine calcareous algae Penicillus capitatus, Halimeda incrassata, and Laurencia poitei. Various sessile animals such as sponges, Chondrilla nucula, Ircinia fasciculata, and Speciospongia vesparia, and the seawhip Pterogorgia anceps are concentrated in the shallow sediment area in the north central and northeastern part of the Sound. This sessile and attached biota is somewhat depleted in the turbid, high sedimentation rate area to the south of Card Bank and the deep eastern basins.

The mobile animal populations in Card Sound are extremely diverse, including such crustaceans as Thor floridanus, Neanope packardii, Pagurus benairensis, and Panulirus argus. Fish such as Acanthostracion quadricornis, Micrognathus crinigerus, Opsanus beta and Sphyraena barracuda, Mugil spp., and various molluscs, echinoderms, coelenterates, and polychaetes are also found. However, only the porifera are of quantitive importance to the total biomass with the fish, molluscs, and crustacea being of smaller biomass and the coelentrates, echionoderms and polychaetes having essentially the least biomass.

Salinities in the Sound can vary considerably in response to local rainfall and evaporation. During the South Florida rainy periods of early summer and fall, inshore salinities may be near zero while those a few tens of meters offshore can fall as low as 15 ppt. During late spring, intensive evaporation coupled with low rainfall can produce salinities of up to 45 ppt in the eastern half of the Sound. However, the normal salinity range is from about 32 to 38 ppt. The interior water of the Sound exchanges predominantly with Barnes Sound and lower Biscayne Bay. The circulation within the Sound is controlled by tide and wind action. Tidal exchange with the ocean takes place in a limited area in the northeast corner of the Sound through Broad and Angelfish Creeks. The interior body of water in the Sound normally exchanges only slowly with the ocean. Some of the interior water is exchanged with the water from the similar bays to the north and south. Estimates of the flushing time of the Sound by the ocean vary considerably, but apparently this flushing is slow, taking approximately 1-2 mo. under normal wind conditions. Infrequent large storm systems may flush the Sound effectively and the strong northerly winds associated with the several winter cold fronts which occur every year, may lead to increased exchange and the flushing of Card Sound water south into Barnes Sound. In this situation, however, the Sound is refilled mainly with water from lower Biscayne Bay and not the ocean.

During the sampling phase of this investigation, 1971 and 1972, the Card Sound ecosystem was largely undisturbed by man. A limited residential development on Upper Key Largo with a boat basin, the Intracoastal waterway and the Model Land Company Canal, comprised the major part of man's influence on the Sound. The residential community on Key Largo consists of approximately 1,000 dwellings with 2,500 people and their sewage disposal is handled by a treatment plant. In addition to these influences, small commercial sponge and lobster fisheries are operated in the Sound.

METHODS

Sample Collections

Samples of biota, detritus, water, and sediments were collected within the framework of the Card Sound stations indicated in Figure 1.

All field collections were made to prevent trace element contamination. Plastic collecting pails and polyethylene trowels were used to collect, wash, and store the samples. Field workers wore polyethylene gloves throughout sample handling. Sub-samples were collected from three different areas about 15 m distant from each station. The sub-samples were combined upon collection and washed with clear sea water to free roots and rhizomes of attached sediment, sealed in labelled whirlpacks and put under ice. Certain sub-samples were not combined but treated in an identical manner to composites. Water samples were collected by either of two methods. In deep water, the first diver swam at a constant rate to the bottom with a freshly acid-washed opened polyethylene bottle. In shallow water, an acid-washed bottle attached by a pole was put overboard at the bow with a forward boat movement sufficient to eliminate boat and motor contamination.

Sample Preparation and Analysis

The general outline of the analytical method used is from Segar and Gilio (1973). Several significant differences from the published procedure were used in this research. More specific details in the chemical and biological analysis of Card Sound samples will be available (Gilio et al., in prep). A pure ammonium pyrrolidine dithiocarbamate (APDC) was synthesized from redistilled A.C.S. grade pyrrolidine and carbon disulfide. Flame atomic absorption spectrophotometry (dual beam) was used for most iron analysis but concentrations of all other elements required an atom reservoir atomic absorption mode initially incorporating a Perkin Elmer (HGA-70) heated graphite atomizer with a deuterium arc background corrector and a variable ashing temperature. Slurry sample analysis of microbiota in a HGA-2100 atomizer was undertaken. Only a matrix interference on the iron absorption peak in the flame mode was observed as a function of low pH. This problem was corrected by 11-fold dilution with double silica distilled water.

Phytoplankton samples were collected in 8ℓ acid-washed polyethylene bottles, and stored on board the vessel in a shaded area; the water samples were HA Millipore® filtered by positive pressure between 6 and 11 hours after collection. Particulate green-yellow matter retained on the filter was washed with double silica distilled water in acid-washed polyethylene jars, freeze dried and saved for analysis. Microscopic examination of parts of the unwashed filter revealed some diatoms, many microflagellates and almost no detritus. Epiphytes were collected after heavily encrusted Thalassia blades were freeze dried in whirlpacs. The epiphytic constituents dislodged easily from the intact Thalassia blades and collected on the bottom of the containers as a coarse-grained powder.

Accuracy and Precision

The accuracy of trace elements in one type of biological tissue (SRM 1571-NBS Orchard Leaves) has been certified for Fe, Cu, Zn, Cd, and Pb by several analytical methods (Cali, 1971). Comparison of the analysis of NBS certified results with the chemical analytical procedures utilized here are given in both Table 1 and in Segar and Gilio (1973). The results indicate that the method used here is accurate for Fe, Cu, Zn, Cd, and Pb analysis from an organic matrix with about the same imprecision as the certified values. A data workup error in Cd in the referenced paper was corrected in all data of this work. Recovery from an inorganic matrix yielded 102% for Fe, Cu, Zn, and Cd, well within the imprecision error of analytical procedure.

The error of imprecision in the analysis of the environmental samples is reported as the relative standard deviation (R.S.D.) defined as ((Sx/X)100%). The imprecision for all six elements in the analysis of major components of the Card Sound ecosystem averaged less than 10%. Specifically, the error in Thalassia was 7.6% for 45 samples. Corresponding values for Penicillus and water were 9.6% (21)and 9.6% (37) respectively.

Biological Standing Stocks and Productivities

In general, standing stock and net production data for Card Sound biota for 1972 were taken from Bader and Roessler (1971 and 1972). We acknowledge and thank the following investigators who kindly permitted use of then unpublished data in 1973 when the biological analysis was performed: A. Thorhaug (Thalassia), R. Smith (sponges), S. Bach (calcareous macroalgae) and Wanless (sediment depths). Only those taxa deemed important to the present biogeochemical investigations have been discussed here. Zooplankton, detrital consumers and carnivores, although extremely important as part of functional life units of the Card Sound ecosystem, will be discussed in a future publication.

Thalassia

Extensive field work determined Thalassia testudinum blade abundance and net blade growth in Card Sound for 1971 and 1972 (Thorhaug, 1973; Thorhaug and Stearns, 1973 and in this volume). The referred data only concerns the western half of Card Sound. Since the inventory developed here is based on the entire Card Sound ecosystem, an extrapolation of the relevant data for the eastern half was made. The results of the extrapolation are summarized in Table 2.

A conversion of blade abundance to total Thalassia plant stock may be made using the conversion factor of total dry weight/blade dry weight. The data of Jones (1968) shows that the combination of green blade shoots and non-green blades constitutes approximately 46% (34-58%) of the total dry weight of the plant and that the roots and rhizomes average 54%. The roots only grow by apical growth (Tomlinson & Vargo, 1966) and the rhizome does not appear to grow continuously (Stearns and Thorhaug, personal communications). Thus, the root and rhizome system has been assumed constant in biomass with little net production on an annual basis. The mean rhizome and root biomass/m^2 may be calculated and assumed constant for the maximum and minimum standing stocks.

The mean standing stock of Thalassia blades for the entire Card Sound ecosystem was calculated from the following equation:

$$\frac{\text{weighted mean number of blades (2400)}}{m^2} \times \frac{0.032\text{g dry weight}}{\text{blade}} = \frac{\text{g dry weight of blade}}{m^2}$$

The value calculated was 77g dry weight of blades/m^2. The total *Thalassia* plant biomass/m^2 is 77/.46 = 167 g/m^2 or 90 g/m^2 of rhizome tissue. This value of 90 g/m^2 has been added to the blade standing stock numbers to obtain the entire plant biomass in Table 4.

Calcareous Macroalgae

Bach (1975) has recently conducted an extensive field study of six calcareous macroalgae in Card Sound. The total mean standing crop of 11.12g dry weight m^{-2} consisted of *Halimeda incrassata*, *H. monile*, *H. opuntia*, *Penicillus capitatus*, *Rhipocephalus phoenix*, and *Udotea flabellum*. This standing stock was converted to biomass m^{-2} by adding a 15% weight factor for the rhizoids neglected in standing stock calculation. The calcareous macroalgae biomass as reported in Tables 4,5, and 6 are grouped into the three *Halimeda* species and *P. capitatus*, *R. phoenix*, and *U. flabellus* at 9.7 and 3.1g dry weight m^{-2}, respectively.

The net primary production of these same species was calculated from Bach's 1975 data and equalled 13 g m^{-2}yr^{-1}. Direct harvest data were selected as being most consistent for all the species. Field estimation of net primary production by the life-span standing crop method and density growth methods were well within an order of magnitude of the direct harvest data (Bach, 1975). The annual net production of 8.6 g m^{-2}yr^{-1} was estimated for the *Halimeda* species collectively and 4.3 g m^{-2}yr^{-1} for the *Penicillus* group.

Sponges

Standing stock was determined by two distinct methods in Card Sound. Analysis of the trawling data of Roessler et al. (1972) gave a sponge density range of 48-162 g wet weight/m^2. The second, possibly more reliable method employed scuba divers to make visual counting along permanent transects (Smith, 1973). A significant difference in sponge biomass measurements was found by Smith to be correlated with substrate. Hard substrates had substantially higher numbers of the very large *Spheciospongia vesparia* and corresponding higher biomass.

The trawl data and visual transect data were treated in identical manner for converting species sponge number/m^2 into g dry wt/m^2 sponge biomass. The number of predominant sponges by species was multiplied by respective mean wet weights to obtain a wet weighted average of sponge/m^2. In the use of Smith's data two extreme situations were calculated, a high sponge density area, station 0504 at 0.291 sponges/m^2 and the low density area 0207 at 0.089 sponges m/^{2}. The high sponge density averaged 690 g wet weight/m^2 and the low density was 190 g wet weight/m^2. Weight differences between the two areas is due to the higher weighted number of *Spheciospongia vesparia*. Averaging sponge standing stock for hard and soft bottom distributions gave 530 g wet weight/m^2.

The net growth of *Spongia graminea* averaged 1.3 cc/wet sponge/day as determined for 16 monthly periods in Card Sound. No significant variation was found as a function of size from 100 to 2,700 g wet weight of this species (Smith, 1973). Also, no clear trend in growth with time of year was evident nor was temporal variation more than twofold. Assuming that the measured *S. graminea* growth is a valid estimate of the sponge community of different species in Card Sound and that growth is constant for all size ranges, the following formula may be applied to yield growth per unit sponge per day:

$$\frac{\text{wet weight}}{\text{cc}} \times \frac{\text{cc sponge}}{\text{day}} \times \frac{\text{dry}}{\text{wet}} = \text{g dry weight sponge/day}$$

where: wet weight cc values are from Roessler (1972). Dry/wet ratios for sponges from Card Sound were determined in this study and will be reported in future publications. The area weighted net sponge growth for Card Sound was determined to be 0.06g dry weight m^{-2}d^{-1}.

Epiphytes

Epiphytes on *Thalassia* blades in the south Florida area are primarily Rhodophytes, some Phaeophytes, and lesser numbers and biomass of Chlorophytes and Cyanophytes (Humm, 1964). Two types of epiphytes on *Thalassia* blades are those which are exclusively found there (calcareous disc-shaped Rhodophytes) and those small forms which may spend their entire life history as *Thalassia* epiphytes. The former species are constant members of the ecosystem while the latter are seasonal, reaching greatest biomass and production in early spring (Humm, 1964). *Melobesia membranacea* and the similar *Fosliella farinos* and *F. lepolisi* form calcareous discs about .5 cm in diameter. These forms are very low in biomass in Card Sound but increase greatly in the Caribbean area. The high wave energy and shallow water environment of Barbados contained 10.4 mg carbonate/cm^2 of blade and a production of 2800 g m^{-2}yr^{-1}(Patriquin, 1972). However, such high energy areas are restricted in Card Sound to a small percent of the total system. A more characteristic value for Card Sound would be closer to the 180 g m^{-2}yr^{-1}of carbonate estimated for Jamaican waters (Land, 1970). Pomeroy (1960) estimates that the *Thalassia* epiphyte production is negligible in Boca Ciega Bay, Florida.

The best estimates of epiphyte stock and production for Card Sound are provided by extensive differential manometer experiments of Jones (1968) for Bear Cut, Florida. However, this area is in a higher tidal energy system than Card Sound with resulting higher biomass and production of *Thalassia* and its epiphytes. Calculations from Jones' data gave an average value of 0.36 (range .26-.45) g dry wt m^{-2}day^{-1} and 10 g dry wt/m^2 stock. These are very rough estimates and as such represent the least well known bio-

Table 1. Comparison of APDC - IMBK (ketone) treated SRM - 1571 (NBS Orchard Leaves) with NBS certified results. The indicated limits on certified values are equal to the entire range of observed results or 2 standard deviation (95% confidence), whichever is larger. For the work reported here, the Fe, Cu, Zn, Cd and Pb limits are at 90% confidence. The numbers in parenthesis are the number of samples.

NBS	SRM - 1571	NBS Certified ug/g
Fe	260 ± 20 (2)	300 ± 20
Cu	11 ± 1.0 (9)	12 ± 2
Zn	24 ± 2 (9)	25 ± 3
Cd	0.11 ± 0.03 (9)	0.11 ± 0.02
Pb	44 ± 5 (2)	45 ± 3

Table 2. Estimates of blade production in all of Card Sound as extrapolated (1) and calculated (2) from Thorhaug's data for the Western half. Values taken from Thorhaug (1973) (Tables 7, 9, 10). Thermal effluent stations not considered in either blade abundance or blade growth for 1972.

	DATES	ABUNDANCE BLADES/m^2(1)	X	SEASONAL MEAN BLADE GROWTH (g/blade/day)(2)	=	THALASSIA BLADE PRODUCTION g/m/day ± Sx
1971	11/23-12/31	1600		0.00039		0.62
	5/20-6/16	3200		0.00078		2.50
	annual mean	2400		0.00068		1.63 ± .36
1972	1/26-12/24	1600		0.00055		0.88
	5/22-6/24	3200		0.00083		2.66
	annual mean	2400		0.00071		1.70 ± .39

two year mean = 1.67 g/m^2/day

Table 3. Trace element concentrations for marine organisms of Card Sound, Florida as determined in this work. Numbers in parenthesis are the number of samples.

	Elements (ug/g dry weight) ± Standard Error of the Mean					
Macrophyta	V	Fe	Cu	Zn	Cd	Pb
Thalassia testudinum (46)	8.5 ± 1.2	320 ± 46	1.6 ± 0.33(a)	18 ± 1.3	0.20 ± 0.021	0.72 ± 0.16
Laurencia poitei (14)	96.0 ± 58	420 ± 75	12 ± 2.4	34 ± 5.1	0.20 ± 0.047	0.59 ± 0.16
Penicillus capitatus (34)	4.8 ± 0.72	560 ± 77	1.2 ± 0.17	12 ± 3.5	0.11 ± 0.012	1.1 ± 0.21
Halimeda incrassata (4)	2.4 ± 0.78	230 ± 75	0.70 ± 0.26	3.7 ± 1.2	0.16 ± 0.12	1.2 ± 0.56
Rhizophora mangle (7)						
Leaves (b)	.43 ± .29	100 ± 76	1.3 ± .67	3.1 ± .88	.044 ± .028	.39 ± .11
(c)	.52 ± .22	71 ± 20	5.8 ± 4.6	2.3 ± .52	.24 ± .11	.79 ± .23
Seedlings in water (3)	.48 ± .41	12 ± 5.6	0.81 ± 0.79	2.2 ± .58	.017 ± .0059	.23 ± .17
Decaying stems in water (2)	.056 ± .055	140 ± 0	0.52 ± 0.46	8.1 ± 5.9	.056 ± .055	.099 ± .0072
Microphyta						
Phytoplankton (d)	0.33	730	12 ± 8.0	180 ± 80	.20	.33
Epiphytes on Thalassia blades (e)	96	420	21 ± 9.4	150 ± 59	.20	0.59
Macrofauna						
Detritivores and Carnivores (4)	0.77 ± 0.07	41 ± 8.9	7.4 ± 0.67	28 ± 20	0.19 ± 0.08	0.39 ± 0.15
Sponges (7)	2.8 ± 1.5	530 ± 150	3.7 ± 1.5	24 ± 9.8	.44 ± .18	.36 ± .15

Notes: (a) Possible error due to a high Cu blank; (b) Live leaves; (c) Dead leaves; (d) Values for V, Fe, Cd, and Pb, 15-fold lower than Bowen's 1966 data. Cu and Zn values determined in this study as 15-fold lower than Bowen's values; (e) Values same as Laurencia poitei.

logical parameters of production and standing stock of the Card Sound system, with the exception of the benthic microalgae. From Jones (1968, Figure 18), the gross minus respiration values gave .45 g dry wt m^{-2} day^{-1} assuming 17% epiphytes and a lower *Thalassia* production, hence biomass in Bear Cut exceeded that of Card Sound. A similar calculation from Jones (1968, Figure 17), gave 0.26 g m^{-2} day^{-1}. He also concluded that maximum production of epiphytes in Bear Cut was one-third to one-fourth that of *Thalassia*, or 0.57 to 0.43 as applied to Card Sound.

The standing stock estimate of epiphytes on Thalassia blades was calculated from the following formula:

$$\frac{0.028 \text{ g wet wt}}{\text{cm}} \times \frac{10 \text{ cm}}{\text{blade}} \times \frac{800 \text{ blades}}{m^2} \times \frac{\text{dry (1)}}{\text{wet (11)}} = \frac{20 \text{ g dry wt}}{m^2}$$

where: 0.028 wet wt/cm is from Figure 1, Jones (1968). 10 cm/blades is estimated for Card Sound by our field observations. 800 blade/m^2 comes from 2,400 blades/m^2 (See *Thalassia* section) ÷ by 3 blades/stem only one which was covered with epiphytes, dry/wet ratio for *Laurencia*. Since much of the material at Bear Cut is restirred carbonate mud, a factor of 1/2 was applied for the lower energy Card Sound system. Thus, the epibionts on *Thalassia* are estimated at 10 ± 5 g/m^2.

Phytoplankton

The standing stock of phytoplankton in Card Sound was determined in two separate investigations (Bunt et al., 1972; Reeve and Cosper, 1973). The similarity in both results lends confidence to the reliability of these measurements even though in the opinion of many workers in the field, phytoplankton measurements of biomass and primary productivity may be crude estimates accurate to only ± 50% (Riley, 1972). Nevertheless, this important parameter must be integrated into the entire system. Reeve and Cosper (1973) employed GF/A glass filters to collect phytoplankton and determine chlorophyll a by the trichromatic method of Strickland and Parsons (1968) on samples frozen for up to 3 months. This time delay is the maximum allowable time to get reliable chlorophyll determination (SCOR/UNESCO, 1966).

A mean chlorophyll a value of 0.56 mg/m^3 and a range of 0.06 - 0.75 was obtained in bimonthly sampling of four pooled Card Sound stations from 1/06/71 to 12/15/71 (Reeve and Cosper, 1973). Bunt et al. (1972) averaged three Card Sound stations for 1 m depth intervals (3 m depth) for 8 sampling periods from 12/70 to 11/71 for an annual mean of 0.27 mg chlorophyll a/m^3. Conversion of mg chlorophyll a/m^3 into dry weight phytoplankton was made by multiplication of 60 mgC/mg chlorophyll a (Strickland, 1965) and 2.7 total weight/mg C (Jørgensen, 1966). Averaged over 3 m depths, the two annual estimates of phytoplankton standing stock are (0.14-0.28) g/m^2. The higher estimate 0.28 is preferred because of a change in filter types to an unspecified pore size during field sampling in the lower estimation. Even 0.28 g/m^2 may be low because of the possible initial loss of the high nannoplankton biomass on GF/A glass fiber filters (Gilio, 1966).

The monthly primary production of the phytoplankton has been determined by the C-14 method (Strickland, 1968) for Card Sound from 2/71 to 11/71 (Bunt et al., 1972, Table X). The mean primary production of 0.34 g m^{-2} d^{-1} was averaged for day length and converted from organic C to dry weight. This C-14 method estimates primary production somewhat closer to net than the gross productivity. Comparison of this value with the standing stock gives a regeneration time of 1 day. Similar determination in estuarine and coastal waters of Georgia gave regeneration times also of about 1 day (Jørgensen, 1966). Thus, these measurements in Card Sound, although subject to much systematic error, are comparable to other such measurements.

Benthic Microalgae

The methodology for the determination of biomass and primary productivity in the benthic microalgae has not been adequately worked out. However, recent field data partially substantiate a low primary productivity for the Card Sound benthic microalgae (Carpenter, personal communication). Extensive work in other mostly sandy environments have shown that in general the benthic inflora and fauna are a closed system (McIntyre et al., 1970; Fenchel and Riedl, 1970; Fenchel 1968, 1969). Thus, the benthic microbiota are not considered significant contributors to the cycle of trace elements as they have been assumed to be cycling elements completely within the sediments. The role of the benthic microalgae and bacteria needs considerable work before their role is properly identified in biogeochemical cycles of coastal marine ecosystems.

RESULTS

Trace element concentrations

A summary of the trace element concentrations for the major and minor biomass organisms of Card Sound is given in Table 3. In general, the various taxonomic groups concentrate trace elements in the decreasing order of iron, zinc, vanadium, copper, lead, and cadmium. Single element differences among the various inhabitants of Card Sound were significantly different ($\pm 2 \cdot S\bar{x}$) in only a few species specific cases. The macrophytes, *Thalassia testudinum*, *Laurencia poitei*, *Penicillus capitatus*, and *Halimeda incrassata*, are all relatively similar to one another in trace element concentrations and variances. The trace element content of *Rhizophora mangle* leaves and seedlings is significantly lower in vanadium, iron, and zinc than in the marine macorphytes, but similar to them in copper, cadmium, and lead. These results were found for (b) live leaves, (c) decaying leaves in the littoral zone, and both newly released seedlings and rotting stems in the water. Phytoplankton and epiphytes from Card Sound have presented analytical difficulties which are currently being solved by a direct analysis of the organisms in an acid slurry following the method of Segar and Cantillo (1975). To date only copper and zinc have been accurately determined for these groups from Card Sound. Concentrations for the other elements of Card Sound phytoplankton were estimated at the same 15-fold lower factor that copper and zinc were found to be compared with the phytoplankton compilation of Bowen (1966). Epiphyte concentrations for vanadium, iron, cadmium, and lead were taken as those for the phytogenetically closest relative in Card Sound for which data exist, namely, *Laurencia poitei*. Detritivores and carnivore were represented by juvenile carangids, a *Lagodon rhomboides* and *Panulinus argus* (muscle only). In the fish and crustacea, the data suggest a well developed regulatory mechanism(s) for iron, copper, and vanadium. Both iron and vanadium are found in very low concentrations compared with all the other marine organisms analyzed from Card Sound. Zinc and copper are higher than in the macrophytes and sponges, consistent with the findings of Bryan (1964, 1966) for bioregulation of these elements in decapods. Cadmium and lead values are, however, similar to the marine macrophytes and mangroves. The *demospongia*, *Spheciospongia vesparia*, *Dysidea etheria*, *Haliclona viridis*, *H. molbidta*, *Chondrilla nucula*, and *Spongia sp*. were similar in range to the higher value of the marine macrophytes for each element. A rather surprising result is that all the marine organisms of Card Sound concentrate each element to a similar degree indicating the existence of similar mechanisms for uptake or removal, the noted exception being the fish and crustacea with well developed removal mechanisms for some of these elements.

Card Sound Inventory

The inventory of trace elements in Card Sound is given in Table 4, as the product of the standing stock of each compartment and the specific concentrations of Table 3. The high organic carbonate sediment contains most of the trace elements of the ecosystem while the water content is about an order of magnitude less for copper, zinc, cadmium, and lead, and roughly three orders of magnitude less for iron and vanadium. The biota collectively contain the smallest inventory of any of the trace elements considered in this work (see Table 5). The vanadium and iron biota inventories are similar to the total water inventory, whereas the zinc and cadmium are one order of magnitude lower and two orders of magnitude lower for copper and lead. For all elements, an obvious correlation exists between the inventory of the water or sediments and the biota which inhabit that environment. The biota reflect to a high degree the trace element aerial concentration of their environment.

The inventory of trace elements in the living biomass of Card Sound is seen to be in many cases a function of the standing stock of that biomass, as a result of the similar trace element concentrations among the biota. *Thalassia* is the dominant organism of Card Sound and this is reflected in the inventory of this species compared with all the other species. A notable exception is the higher iron aerial concentration of the sponges. Zinc, cadmium, and lead aerial concentrations for sponges rank second to *Thalassia* but are exceeded by epiphytes for vanadium and copper. Epiphytes rank third in the trace element biota inventory. Current work may result in modifications of the importance of epiphytes to the ecosystem since both epiphyte biomass and trace element concentrations are the least accurately known of the items of Table 4. The calcareous macrophytes are similar to the macro-epiphytic *Laurencia poitei*, in the inventory of iron, cadmium, and lead and about an order of magnitude lower in vanadium, copper, and zinc. Phytoplankton and detritivores combined with carnivores are the least important contributors of trace elements to the biological inventory of Card Sound. Macrodetritus consisting of *Thalassia* blades and minor amounts of calcareous macroalgae is not considered in this inventory since preliminary observations indicate that the bulk of the macrodetritus leaves the ecosystem as wind-driven blades which concentrate along the mangrove shoreline in the supralittoral zone. In summary, the similar concentrations of trace elements contained within turtle grass and sponges, combined with the preferred different habitats of deep peripheral sediment areas and the central, shallow sediment area, respectively, result in a rather homogeneous biological inventory in Card Sound.

Internal Cycling by Biota

The metabolic cycles of the biota in Card Sound cause a dynamic recycling within the ecosystem. Assuming for the present a steady state condition in the water, sediment and biota compartments, then biological interaction with the two other components results in transfers of trace elements from the sediment into *Thalassia* or from the water into the other biota directly or through the established detrital based food webs of Card Sound (Thorhaug and Roessler, 1975). The magnitude of the processes of internal cycling of trace elements along the three major components of the Card Sound ecosystem is clearly recognized as a function of biological net production (Table 6). The processes of primary production are of higher magnitude than secondary production by macro and micro fauna, such that these groups are of minor importance to internal cycling of Card Sound trace elements. The dominant role of *Thalassia* in internal cycling is consistent with its rank as the highest net primary producer of the Card Sound ecosystem. The microphytes of Card Sound, although the least accurately quantified of the groups identified as significant recycling agents within the ecosystem, have been estimated at roughly one-half the net primary production of turtle grass. If this estimate proves reasonably accurate in future research, the internal cycling of vanadium, copper, and zinc are primarily regulated on an annual basis by microphytes whereas *Thalassia* blade growth, death, and decay to detritus account for the highest internal fluxes of iron, cadmium and lead. The demospongia of Card Sound, although of high trace element inventory, are minor factors of net trace element recycling as a consequence of slow net growth rate. The calcareous macroalgae and the macro-epiphytic *Laurencia*, as well as the higher tropich levels of the food web, appear to have little influence on the net internal cycling of trace elements in Card Sound.

Net primary production in Card Sound produces a total trace element flux (mg $m^{-2}yr^{-1}$) of iron, 310; zinc, 61; vanadium, 23; copper, 6.4; lead, 0.61; and cadmium, 0.18 (Table 7). The annual transport of

Table 4. Biological Trace element inventory for Card Sound, Florida.

Compartment	Biomass- g dry wt/m'	Elements (mg/m^2)					
		V	Fe	Cu	Zn	Cd-	Pb
Sediment (1)	3.4 x 10^5	8.0 x 10^3	6.3 x 10^5	6.7 x 10^2	1.4 x 10^3	23	3. 4 x 10^2
Water (g wet wt/m^2)	3.0 x 10^6	2.6	5.2 x 10^1	1.2 x 10^1	2.6 x 10^1	0.21	1. 5
Biota							
Macrophyta							
Thalassia testudinum	1.67 x 10^2	1.4	53	0.27	3.0	0 .033	0.12
Laurencia poitei	6.1 (2)	0.23	2.6	0.073	0.21	0 .0012	0.0036
Halimeda group	8.7 (3)	0.023	2.2	0.0068	0.036	0 .0016	0.012
Penicillus group	3.1 (4)	0.015	1.7	0.0037	0.037	0 .00034	0.0034
Microphyta							
epiphytes	10	0.96	4.2	0.21	1.5	0.002	0.0059
phytoplankton	0.28	0.0092 x10^{-2}	0.064	0.0034	0.050	0.0076 x10^{-3}	0.92 x10^{-4}
Macrofauna							
sponges	1.1 x 10^2	0.032	89	0.19	2.1	0.030	0.014
Detritivores & Carnivores	0.18 (5)	0.021 x 10^{-2}	0.011	0.002	0.075	0.055 x10^{-3}	0.11 x10^{-3}
Biota Total	**3.1 x 10^2**	**2.7**	**150**	**0.76**	**7.0**	**0.068**	**0.16**

Notes: (1) Calculated from concentration data of trace elements in Card Sound, Florida from Pellenbarg (1973). Includes total sediment depth and total element concentrations

(2) Josselyn (1975).

(3) Calculated from Bach (1975). Includes Halimeda incrassata (5.5), H. monile (1.5), and H. opuntia (1.4).

(4) Calculated from Bach (1975). Includes Penicillus capitatus (1.7), Rhipocephalus phoenix and Udotea flabellum (0.48).

(5) Gilio, . In prep.

Table 5. Three compartment model of trace elements in Card Sound, Florida. All values are total element concentrations of the whole organisms summed for all biomass, entire water column and entire sediment and entrained pore water. The average sediment thickness of sediment in the Sound is 46 cm.

	Elements (mg/m^2)					
Compartment	V	Fe	Cu	Zn	Cd	Pb
Sediment	8.0 X 10^3	6.3 X 10^5	6.7 X 10^2	1.4 X 10^3	23.	3.4 X 10^2
Water	2.6	5.2 X 10^1	1.2 X 10^1	2.6 X 10^1	0.21	1.5
Biota	2.7	1.5 X 10^2	0.76	7.0	0.068	0.16

Table 6. Trace transition element net mass transfer to sediment or water components from direct death and decay, floatation and decay and/or faunal consumption and fecal production . Table was derived as the product of the annual net production data for Card Sound and the mean trace transition element concentrations both derived in this work.

Trace Element Minimal Net Biological Incorporation ($mg/m^2/yr$)

Compartment	Annual Net Production $g/m^2/yr$	V	Fe	Cu	Zn	Cd	Pb
Macrophyta							
Thalassia blades	609.	5.2	200.	0.97	11.	0.12	0.44
Laurencia poetei	11.	1.1	4.6	0.13	0.37	0.0022	0.0065
Penicillus group	4.3 (1)	0.021	2.4	0.0052	0.052	0.00047	0.0047
Halimeda group	8.6 (2)	0.021	2.0	0.0060	0.032	0.00014	0.010
Σ Sub-comp	630	6.3	210	1.1	13.	0.12	0.46
Microphyta							
Epiphytes	180.	17.	76.	3.8	27.	0.036	0.11
phytoplankton	120.	0.040	28.	1.4	22.	0.024	0.040
Σ Sub-comp	300	17.	100	5.2	49.	0.060	0.15
Macrofauna							
Sponges	21.	0.059	11.	0.078	0.50	0.0092	0.0076
Detritivores & Carnivores	6.6 (3)	0.0051	0.27	0.049	0.18	0.0043	0.0026
Σ Sub-comp	28.	0.12	11.	0.13	0.68	0.14	0.010
Total (4)	960.	24.	320.	6.4	61.	0.19	0.62

Notes: (1) Calculated from Bach (975) as Penicillus capitatus (56%), Rhipocephalus phoenix (37 %), and Udotea flabellum (7 %

(2) Calculated from Bach (1975) as H. incrassata (94%) , and H. monile (6%)

(3) Assumed ingestion of 0.18 g dry wt /m^2/day since most members of this group are juveniles which ingest their own body weight / day (Jorgensen, 1966) of which 10 % is net production.

(4) Excludes detritivore and carnivore group as only initial uptake via primary production from water or sediment is relevant to net transfer.

trace elements through the identified biological processes into biota account for less than 1% of the total inventory of all of the elements. This indicates a very slow turnover time for the sedimentary trace elements, which is predicted upon total average depth of 46 cm and a homogeneous physiochemical form of each element. The same assumptions applied to the water component represent a much more rapid turnover for all elements. In all cases, the magnitude and turnover times of trace element transport between the sediment, water and biota of Card Sound are minimal values.

DISCUSSION

Uncertainty of Model

Two series of interconnected biogeochemical cycles of trace elements in Card Sound have been identified in this work. The exact nature of these interrelationships is being resolved. *Thalassia* blade abscission does result in trace element transfers from sediment to water. The predominant east-southeasterly winds pile up floating, decaying blades in the supralittoral zone of the mangrove fringe along the western shore. No significant differences in a limited number of analyses have been found as *Thalassia* decays in the water, but the absolute decrease in detrital weight argues for some release of trace elements to the water. Such a process interconnects the sediment-biota cycle with the water-biota cycle. Ongoing work indicates an active decay zone for both *Thalassia* blades and *Rhizophora mangle* blades in the intertidal and adjacent sublittoral zones along the mangrove fringe. The production of small detrital particles of high nutritional value occurs there. Return of trace elements proceeds through small detrital particles circulating within the Sound by way of wind and advective processes to the more open parts of the ecosystem. An undetermined fraction of this organic detritus settles out directly into the sediments and the rest returns to the aqueous phase to attain some dynamic equilibrium with the various physicochemical forms of the water (Martell, 1971; Siegel, 1971; Millero, 1975). The water phase is also influenced to some degree by mixture with tidal water exchanges.

The magnitude of the biogeochemical cycles of Card Sound are subject to much uncertainty. There is high variance in the trace element concentration data and higher variance in the biological data. Since much of the biological data is based on direct methods of counting, this variance reflects the natural heterogeneity of the existing Card Sound ecosystem. The annual mean calculated fluxes may not be found true on any given day in situ, if such measurements could indeed be currently undertaken with any accuracy and precision in this system.

Two factors indicate that the calculated trace element fluxes are too low compared with the real ecosystem. McRoy et al. (1972) found that *Zostera marina* "pumps" phosphate out of sediments and into the water. Similar findings are expected for *Thalassia* and it is not inconceivable that trace elements will be "pumped" from the sediments into the water. The functional anatomy of osmoregulatory cells in *Thalassia* blades (Jagels, 1973), and its high transpiration rate (Gessner, 1971) argues for a gross trace element flux through *Thalassia* blades much higher than that given by net primary production values. The second underestimation of the calculated biogeochemical fluxes concerns the secondary production of heterotrophs. Consideration of ecological efficiencies at 10% (Steele, 1975) negates most of the egested and/or excreted trace elements flows. Current calculations based on fragmentary literature data indicate that gross elemental flows through the heterotrophs of Card Sound will not significantly alter the present concepts; but "pumping" by *Thalassia*, if found, may be of great significance.

The degree to which the Card Sound ecosystem is open to tidal flushing and mangrove litter inputs is an important factor in determining the accuracy of the three-compartment, biogeochemical model of Card Sound trace elements. Preliminary work determined the total trace element content of the water for three successive days in 1972, sampling both high and low tides. These results (Table 8) indicate that under predominate wind and sea conditions in Card Sound, there are net outflows of zinc, cadmium, and lead and net inflows of iron and copper. These data, coupled with similar mangrove data, indicates that the Card Sound ecosystem is acting as a sink for iron and copper and either a source for zinc, cadmium, and lead to the open sea or a conduit for these elements from the land to the sea. The turnover times correlate with physical oceanographic data (Lee and Rooth, in this volume), indicating an approximate closed water component of the ecosystem except the tidally flushed northeast portion, for all these trace elements when compared with rapid biological uptake rates via primary production. The water to biota cycles are thus conceived to operate under rather uniform trace element water concentrations, reducing concentration dependent incorporation phenomena (Riley and Roth, 1971).

Perhaps the largest error in our flux estimates arises from not being able to define and subsequently analyze those physiocochemical forms of the water and sediments which are biologically incorporated in photosynthetic processes. Since our calculations are based on total trace element concentrations of the water and sediment system, our results are lower estimates of the real system's biogeochemical cycling rates.

As commonly conceived, the sediments and biota of Card Sound are sinks of trace element while the water acts as a source. However, from a dynamic point of view, a sink may be defined as having a time dependent net input ranging from positive to zero, whereas a source would range from zero to negative. Only at steady state could zero net fluxes be found, which implies complete internal cycling and a net production/community respiration equal to one. Brock (1967) considers an ecosystem as both open and at steady state. Only mature systems in this context are true ecosystems and successional changes in ecosystem are considered embryological stages of their development. Such successional systems are open and not at a steady state. The *Thalassia*-dominated ecosystem of Card Sound represents a climax ecosystem in Florida estuarine environments. The water budget data indicates that this ecosystem is open to trace

Table 7. Annual potential biological – sediment-water interaction in Card Sound , Florida. Two major internal cycles are indicated as occurring through biological net primary production. A major net movement of iron, cadmium and lead transfers from sediment into Thalassia blades . Most of the vanadium, copper and zinc cycle from the water into epiphytes, phytoplankton and macroalgae The potential turnover of the water is much greater than that of the sediment. Note – Columns 8 + 9 = 100% of biotic flux.

	1 ∑ sediment	2 Flux sediment to biota	3 influx biota % sediment (2/1)	4 ∑ water content	5 Flux water to biota	6 Flux biota as % of water (7/5)	7 Flux ∑ biota uptake (2+5)	8 Flux sed to biota as % ∑ biota flux (2/7)	9 Flux water to biota as % ∑ biota flux (5/7)
_Element	mg/m^2	$mg/m^2/yr$	%	mg/m^2	$mg/m^2/yr$	%	$mg/m^2/yr$	%	%
V	8.0×10^3	5.2	0.065	2.6	18.	130.	23.	22.	78.
Fe	6.3×10^5	200.	0.032	52.	110.	280.	310.	65.	36.
Cu	6.7×10^2	0.97	0.15	120.	5.4	120 .	6.4	15.	85.
Zn	1.4×10^3	11.	0.78	260.	50.	120.	61.	18.	82.
Cd	2.3×10^1	0.12	0.52	2.1	0.063	290.	0.18	66.	35.
Pb	3.4×10^2	0.44	0.13	1.5	0.17	360.	0.61	72.	28.

Table 8. Short term - 3 continuous days- water budget of Card Sound, Florida. Trace element inputs from the Florida Power and Light discharge canal have been canceled out of these results.

Element	Inflow (kg / day)	outflow (kg/ day)	Net water flux (kg/ day)	Σ water content ($X10^3$ kg	turnover time (days)	net biota fixed (kg/day)	net water flux net biota fixed
Fe	+ 180.	- 120.	+60	3.0	50	49	1.2
Zn	+110.	- 170.	- 60	1.5	25	9.5	6.3
Cu	+ 79.	- 26.	+53	0.67	13	1.0	53
Pb	+2.1	-0.1	+2.0	0.088	44	0.096	21
Cd	+1.5	- 1.7	-0.2	0.012	60	0.027	7.4

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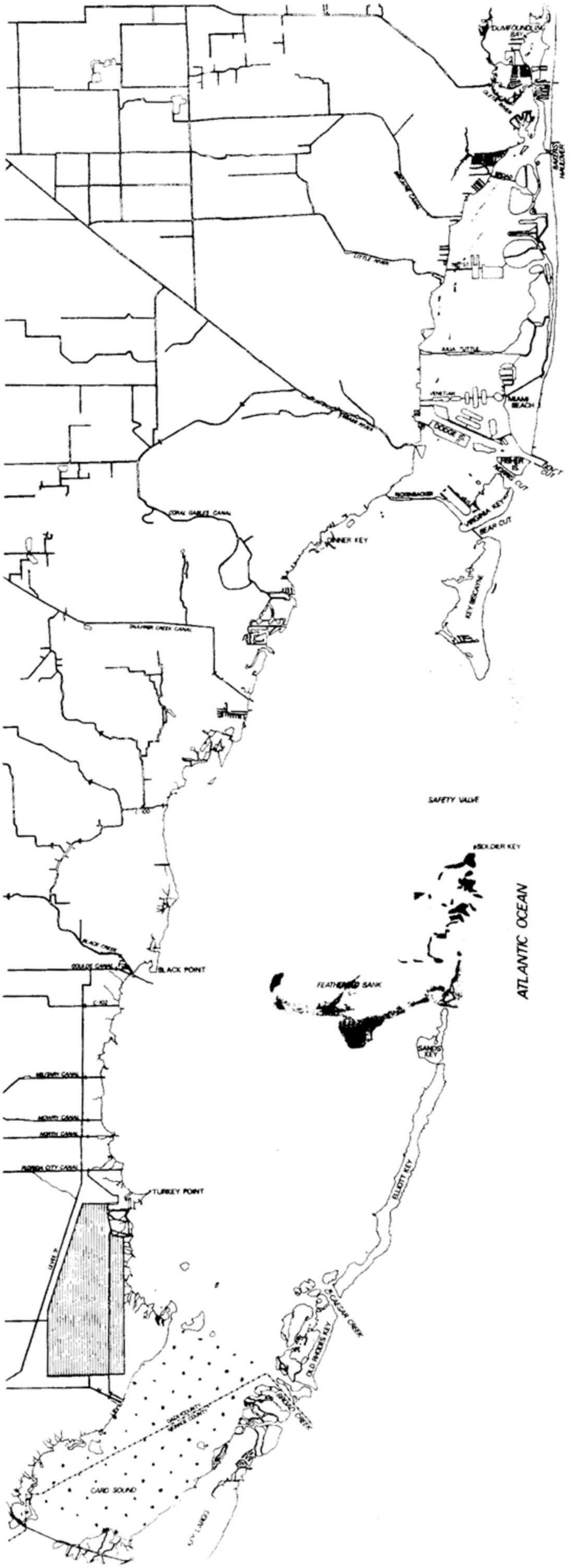

Figure 1. Map of study area and locations of Card Sound Stations.

TIDES IN BISCAYNE BAY

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ABSTRACT

The importance of the tide in Biscayne Bay derives from its function as a mechanism to renew the waters in the bay. The tidal amplitudes and the current velocities are determined by the ocean tide, the geometry of the bay and, in particular, the flow conveying characteristics of the inlets, shallow banks and causeways. Tidal amplitudes decrease and phase lags increase going from north to south. As a first approximation water levels in each of the basins, North, Central, and South Biscayne Bay and Card Sound fluctuate uniformly; the major changes in amplitude and phase occur across the shallows and causeways separating the basins. Information on currents is scarce and limited to North Biscayne Bay, Card Sound and the inlets Government Cut, Bear Cut, Angelfish Creek and Broad Creek. As a first step to improve our understanding of the tides in Biscayne Bay it is suggested to 1) determine the order of magnitude of the tidal velocities in Central and South Biscayne Bay. 2) develop a simple model making use of the observed uniform rise and fall of the water levels in the various basins.

INTRODUCTION

For the purpose of this paper Biscayne Bay is defined as the system of inter-connected basins: North Biscayne Bay, Central Biscayne Bay, South Biscayne Bay, and Card Sound; see Fig. 1. Typical dimensions for these bay areas are: length 50,000 ft, width 25,000 ft, and depth 10 ft. The boundaries between the various bays are formed by either causeways or shallow banks, both restricting the flow and exchange of water between the respective basins. Exchange with the ocean takes place via a number of inlets of which the most prominent are Baker's Haulover, Government Cut, Norris Cut, Bear Cut, Caesar Creek, Broad Creek, and a complex of channels referred to as the Safety Valve. Following is a description of existing data sets of water levels and currents. For the location and period of operation of the measuring stations referred to in this section see Fig. 2 and Table I respectively.

The tidal motion in a semi-enclosed basin such as Biscayne Bay is forced by the ocean tide at the open boundaries. A typical record of the ocean tide as measured by the master tide gauge T1 at the Miami harbor entrance is presented in Fig. 3. The NOAA-NOS tide table lists the average mean and spring tidal range for this station as respectively 2.5 ft and 3 ft. In addition to the tide information at Miami harbor entrance, water levels at the ocean station Ocean Reef (N7) are available. Predicted times and heights of high and low waters for the bay area stations $T_2 - T_{15}$, may be found in the NOAA-NOS tide tables. Values of mean and spring tidal ranges are listed in the same volume. A number of continuous recording tide gages, designated U1-U6, are maintained by the U. S. Geological Survey.

During the period July 1, 1967 through June 20, 1968 the United States Geological Survey measured water elevations in the bay at ten stations designated S2-S7. Information on tidal ranges and phase lags for the various stations as presented by Schneider (1969) are listed in Table II. The relatively small differences between the mean tidal range and time lags within each basin suggest that as a first approximation the water levels in each basin may be assumed to fluctuate uniformly and differences in tidal ranges and time lags in the Biscayne Bay system are primarily a result of the shallows and causeways separating the various basins.

A similar measurement program was carried out by NOAA-NOS as part of the Florida-NOAA Coastal Boundary Mapping Program during the period April 1970 - April 1972. Waterlevels were measured every 6 minutes at the stations N1-N8. The major objective of these measurements was to determine tidal datums. The previously mentioned ocean station, Ocean Reef, was part of the same program. The data is complemented by a three-day series (March 1-3, 1973) of water levels measured at 10 stations along the western shore of Biscayne Bay (Thurlow, 1973).

Information on tidal currents is restricted to North Biscayne Bay, Card Sound and some of the inlets. Results of current measurements in North Biscayne Bay extending over one tidal period are reported by Hela et. al. (1957). Generally, velocities in the bay are less than 1.5 ft/sec. Velocities are minimum near the 79th Street Causeway, marking the areas of influence of Bakers Haulover Inlet and Government Cut. Maximum current velocities in the inlets are 8 ft/sec for Baker's Haulover Inlet, 6.2 ft/sec for Government Cut and 3.3 ft/sec for Bear Cut. Although not explicitly stated these values probably refer to maximum surface velocities. Daily predictions of times and magnitudes of maximum currents in Government Cut may be found in the NOAA-NOS Tidal Current Tables. The only current records having a length considerably larger than the tidal period are those measured in Card Sound during the period March 5, 1971 - April 14, 1971 by Lee and Rooth (1972). These results for Station A and Angelfish Creek and Broad Creek, together with information on wind are reproduced in Fig. 4. Results of current measurements carried out in Bear Cut during the same period are not presented here but are available from the University of Miami, RSMAS, Division of Physical Oceanography. It is obvious from the velocity records that tidal modulations in the interior of Card Sound are greatly affected by variable wind-induced currents. The order of magnitude of the tidal currents at Sta. A is 0.5 ft/sec. Currents in the inlets are clearly tide-induced with maximum velocities on the order of 3 ft/sec. At the time of the current measurements several tide recorders were operational in Biscayne Bay (see Table I). Velocity and waterlevel measurements carried out with the specific purpose of determining the hydraulic characteristics of Broad Creek and associated channels are reported by Taylor (1971). Similar experiments were carried out for Card Bank and Cutter Bank by Riege (1974).

On March 10, 1973 vertical velocity profiles were measured in four stations across Bear Cut. The measurements extended over a full tidal cycle. The flow rate computed from the velocity data, together with the water levels in Bear Cut, are presented in Fig. 5. The maximum cross-sectional mean velocities for ebb and flood are respectively 2 ft/sec and 1.5 ft/sec. The corresponding flood and ebb volumes are 5.97×10^8 cu ft and 9.80×10^8 cu ft, resulting in a net outflow of 3.83×10^8 cu ft per tidal cycle. For comparison the tidal prism and low water volume of Central Biscayne Bay are respectively 6×10^9 cu ft and 2.4×10^{10} cu ft. Examples of surface flow patterns in Bear Cut are presented in Fig. 6.

DISCUSSION

The importance of the tide and associated currents derives from their function as a transport mechanism. The oscillatory nature of the tidal shear flow combined with vertical and transverse mixing leads to a horizontal constituent transport. In the presence of gravity circulation the tide through vertical mixing generates the energy to maintain the circulation cells described by Pritchard (1955). Furthermore, the relatively large values of the ratio of tidal amplitude to depth suggest the presence of residual currents; i.e., superimposed on the oscillatory motion there exists a mean current.

As an initial step in the investigation of the hydraulic characteristics of the inlets, causeway openings and shallows, it is suggested to develop a simple model making use of the observed uniform rise and fall of the water levels in each basin; Keulegan (1951). For a complete description of the tide-induced velocity field it will be necessary to use the vertically integrated equations of motion and continuity. Velocity measurements with a recording current meter in a number of stations are suggested to gather data for a proper scale-analysis of these equations. In addition these measurements together with measured water levels will provide information on the magnitude and direction of the Lagrangian mean current.

ACKNOWLEDGMENT

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TABLE I

WATER LEVEL STATIONS IN BISCAYNE BAY

Symbol	Agency	Name of Station	Period of Operation
T1	NOAA-NOS	Miami Harbor Entrance	Since June 1931
T2		Miami Beach	Oct 10, 1934 - Nov 2, 1934
T3		Miami 79th St. Cswy.	Feb 1, 1935 - Feb 18, 1935
T4		Miami City Yacht Basin	?
T5		Miami Causeway, (East end)	Oct 10, 1934 - Nov 2, 1934
T6		Dinner Key Marina	?
T7		Cape Florida (W. side)	?
T8		Cutler Biscayne Bay	?
T9		Soldier Key	Feb 1, 1934 - June 25, 1934
T10		Fowey Rocks	?
T11		Ragged Keys Biscayne Bay	?
T12		Turkey Pt. Biscayne Bay	?
T13		Adams Key Biscayne Bay	?
T14		Angelfish Key	June 14, 1934 - Sept 12, 1934
T15		Pumpkin Key (Card Sound)	Feb 6, 1934 - Feb 8, 1934
S1	USGS Schneider (1969)	Miami Beach Primary Tide Station	July 1, 1967 - June 30, 1968
S2		Biscayne Bay @ Coconut Grove	"
S3		Biscayne Bay @ Key Biscayne	"
S4		Cutler Drain @ Structure 123	"
S5		Biscayne Bay near Homestead	"
S6		Biscayne Bay near Elliott Key	"
S7		Card Sound @ Model Land Canal	"
S8		Barnes Sound @ Card Sound Road	"
N1	NOAA-NOS (Florida - NOAA Coastal Boundary Mapping Program)	Biscayne Creek	April 2, 1970 - June 2, 1971
N2		Miami Biscayne Bay	April 21, 1970 - Oct 27, 1971
N3		Miami Harbor Entrance	See T1
N4		Cutler	April 22, 1970 - April 4, 1972
N5		Ragged Keys	Nov 18, 1970 - June 29, 1971
N6		Turkey Point	April 23, 1970 - June 25, 1971
N7		Ocean Reef	Nov 19, 1970 - June 9, 1972
N8		Card Sound Bridge	April 28, 1970 - Aug 27, 1971
U1	USGS	Dinner Key	Since Feb 1959
U2		Bayfront Park	" Feb 1946
U3		North Miami	" May 1947
U4		Card Sound at Model Land Canal	" Feb 1967
U5		Miami Canal at NW 27th Ave	" Oct 1945
U6		Golden Beach on Intracoastal Waterway	" Nov 1969

TABLE II

TIDAL RANGES AND PHASE LAGS (SCHNEIDER (1969))

Basin	Tide Station	Mean Tidal Range (FT)	Mean Time Lag	
			High Tide (HR)	Low Tide (HR)
Ocean	T1	2.44	-	-
Central Biscayne Bay	S2	2.02	1.33	1.66
	S3	1.94	1.00	1.33
	S4	1.92	1.50	2.00
South Biscayne Bay	S5	1.65	2.33	2.83
	S6	1.54	2.16	2.66
Card Sound	S7	0.74	3.00	3.33

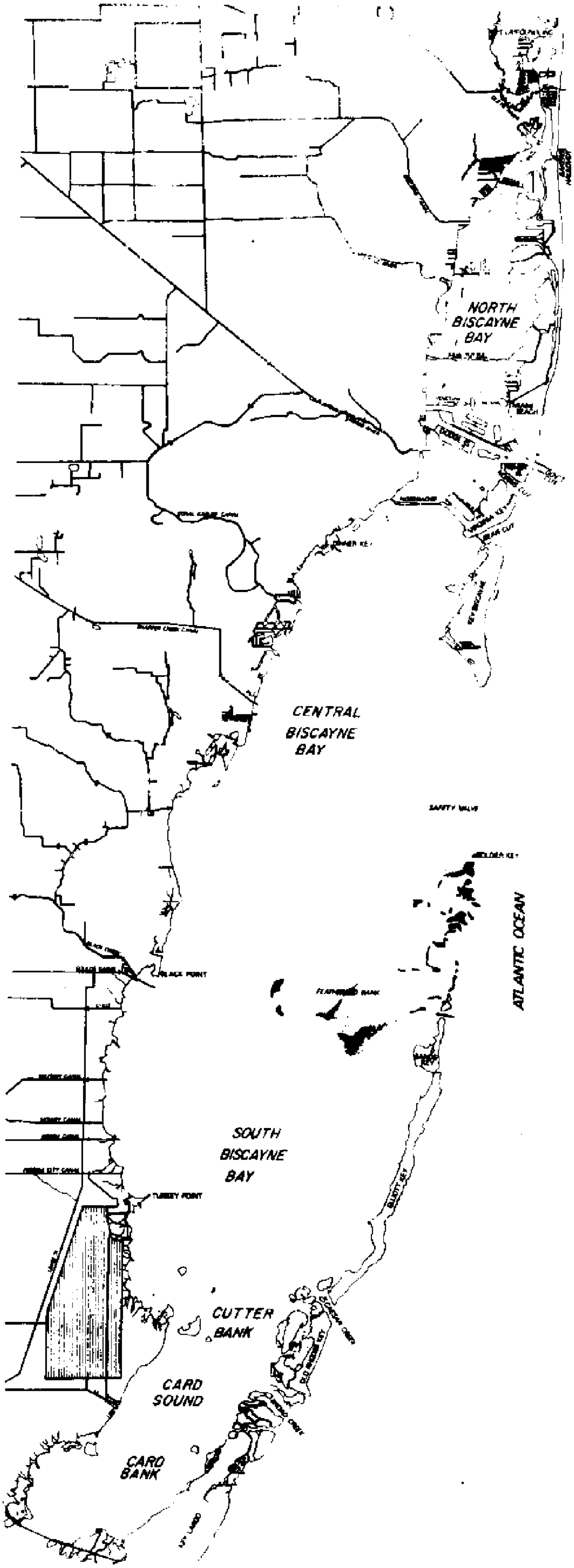


Figure 1. Biscayne Bay.

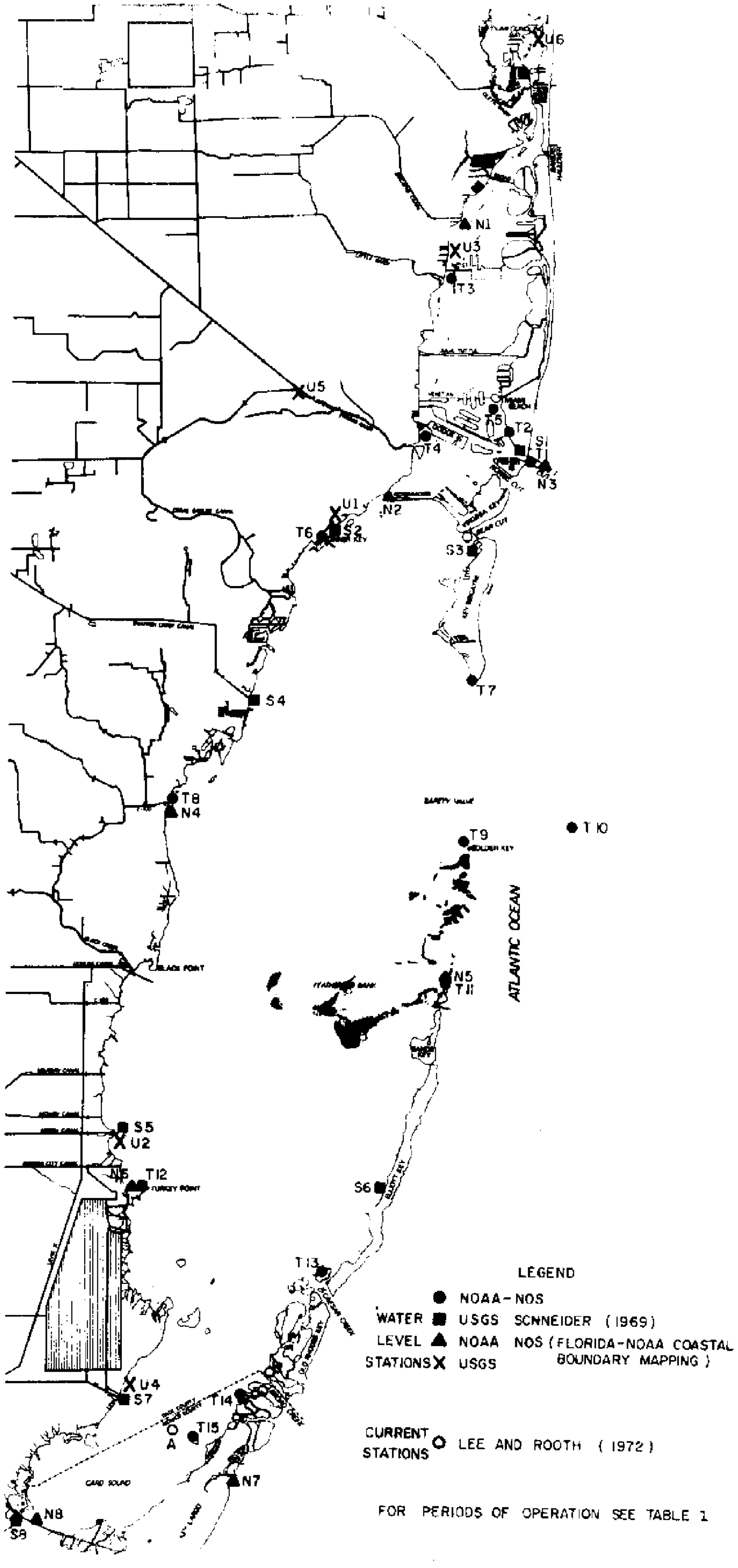


Figure 2. Location of water level and current stations.

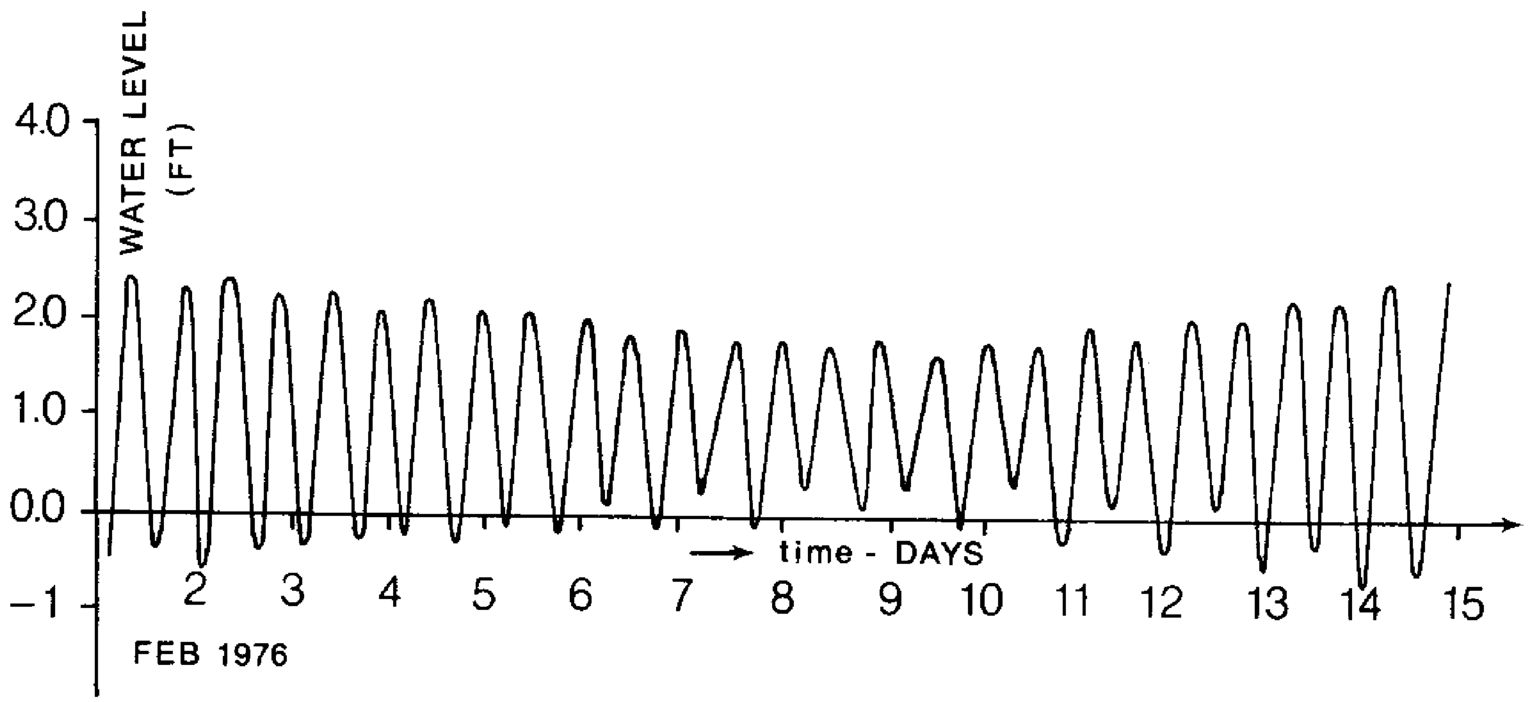


Fig. 3 - Typical Tide Curve for Miami Harbor Entrance

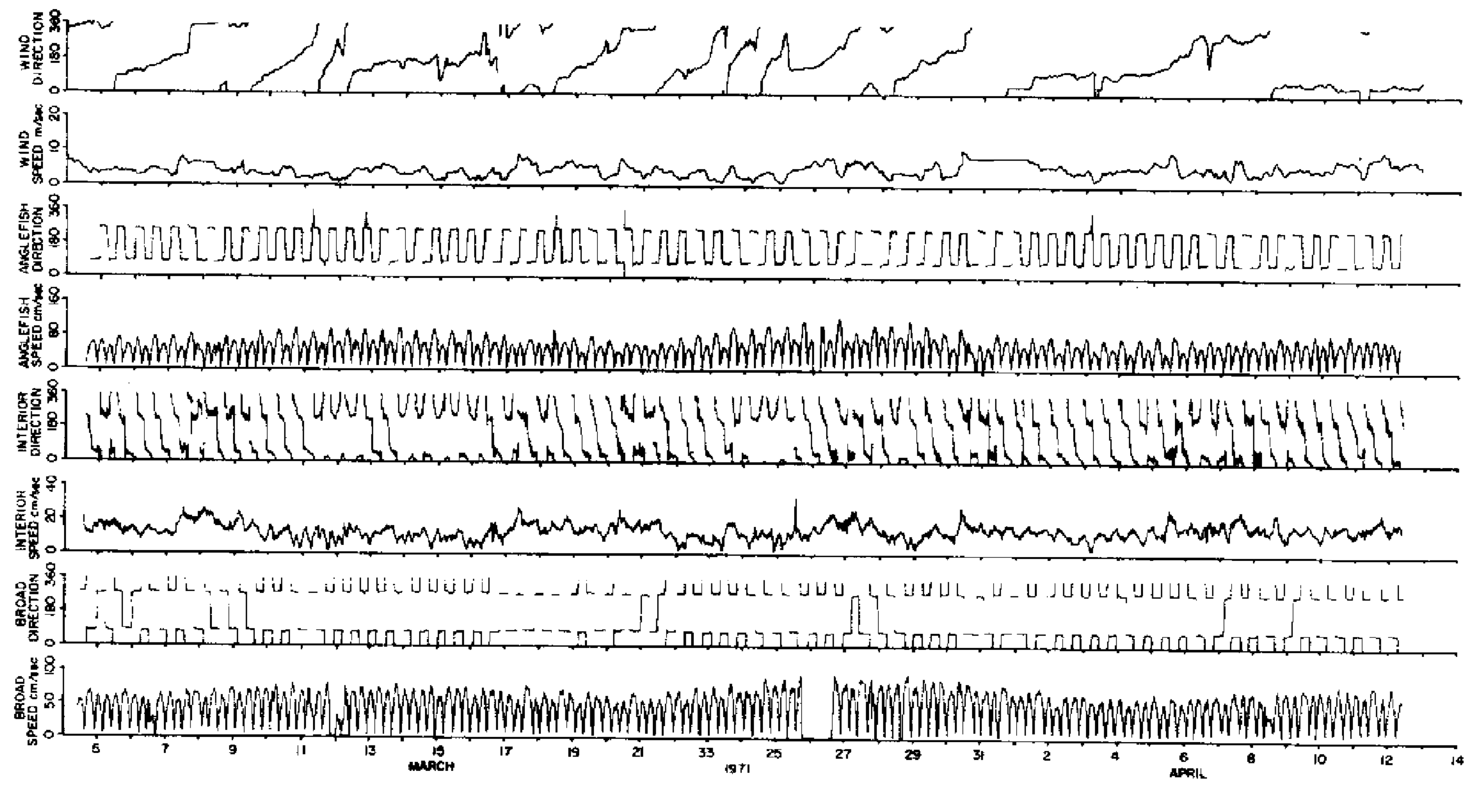


Figure 4. Time series of currents and wind for Card Sound.

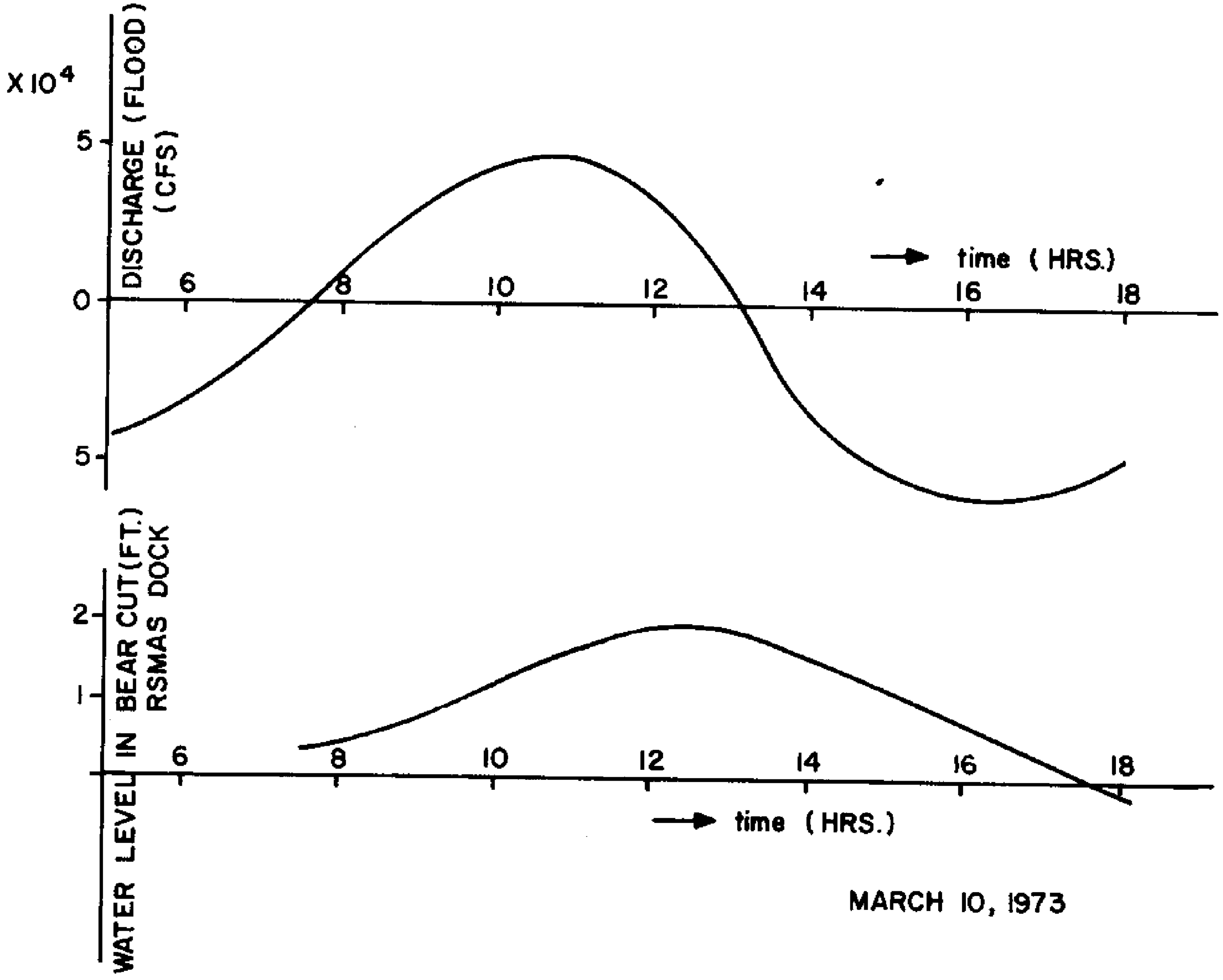
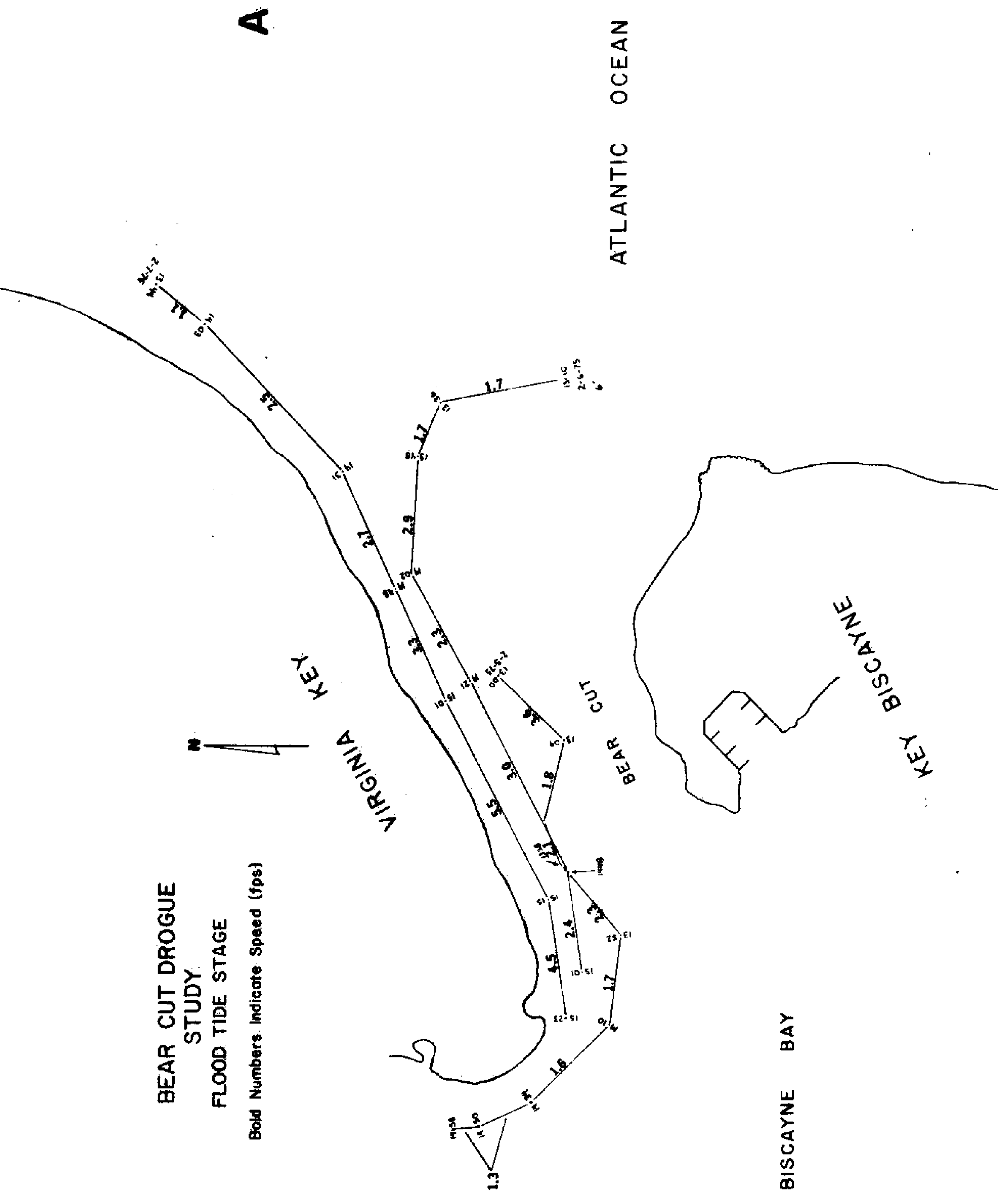


Figure 5. Water level and discharge for Bear Cut.



BEAR CUT DROGUE STUDY
FLOOD TIDE STAGE
Bold Numbers Indicate Speed (fps)

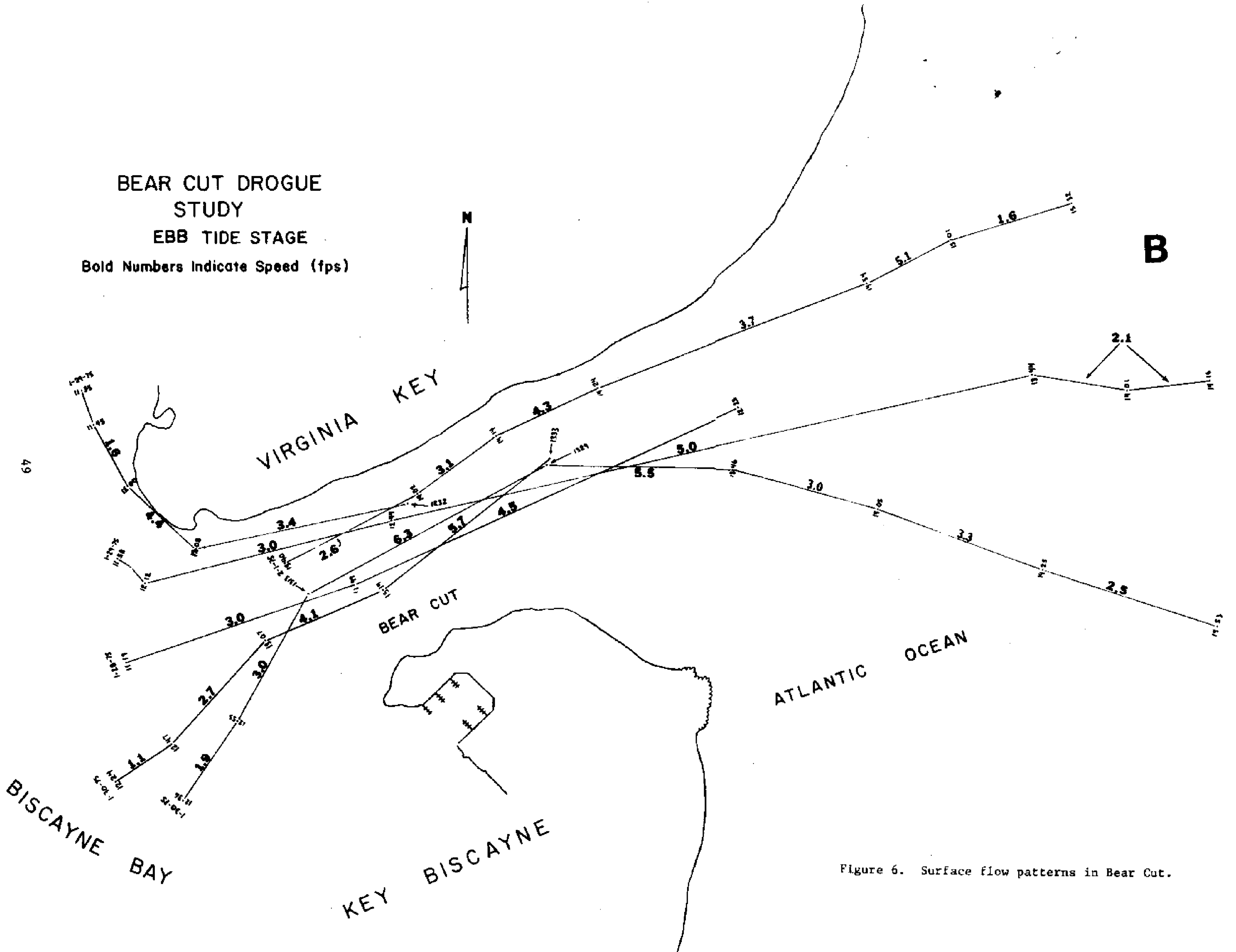


Figure 6. Surface flow patterns in Bear Cut.

CIRCULATION AND EXCHANGE PROCESSES IN SOUTHEAST FLORIDA'S COASTAL LAGOONS

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ABSTRACT

A series of field experiments and analytical studies geared toward identifying important circulation- and exchange-inducing processes and understanding their role in flushing shallow coastal lagoons, such as Biscayne Bay, were conducted over a five-year period beginning June 1970. We show that wind-induced circulation coupled with tides in the inlets is the dominant exchange mechanism in these shallow lagoons and produces mean renewal times ranging from 1 to 3 months. Tidal exchange of interior waters is weak and essentially concentrated in the direction of tidal flow which is aligned with the basin axis. Density gradient generated exchange was also found to be weak, due to the shallowness of the lagoons and to the vertical mixing generated by tidal bottom friction effects.

INTRODUCTION

The water quality of coastal bays and estuaries is controlled by a balance between the rates of influx and removal of pollutants. The supply rate and quality of the effluent entering the estuary is the only element subject to our planning and water management. To execute these functions intelligently, with respect to their impact on our inshore environment, community planners and enforcement agencies must be supplied with reliable estimates as to a particular water body's ability to remove pollutants. A precise quantitative determination of the removal rate is extremely complicated due to the dependence on many chemical, biological, and physical processes which vary in both time and space. However, the problem can be simplified if one considers the removal rate to be primarily a physical process and therefore dependent on the flushing rate or residence time of the receiving water body, with biological and chemical processes considered as secondary effects.

The Biscayne Bay system of embayments (Fig. 1) consists of a series of interconnecting lagoons which interact across shallow shoals and through dredged navigation channels. The major axis of the system is oriented generally in a north-south direction, approximately 90 km in length, with widths ranging from 6 to 16 km. Water depths in the interior of the basins vary from 2 to 4m. Exchange with coastal waters takes place through a complicated network of tidal inlets and across a broad shoal (Safety Valve), honeycombed with narrow flow channels.

Semidiurnal tidal forcing at the seaward entrances to the embayments is approximately in phase, because the length of the major axis is small in comparison with the tidal wave length. The semidiurnal progressive tidal wave entering Biscayne Bay through the tidal passes travels to the south through the lagoon system with decreasing amplitude and increasing lag due to frictional dampening and reflection by the shallow shoals (Schneider, 1969). The mean tidal range in Biscayne Bay is approximately 60 cm (1.98 ft.) and lags the ocean tide at Government Cut by about 1.5 hours. In Card Sound the mean range is 22 cm (0.74 ft.) and lags Government Cut by approximately 3 hours; in Barnes Sound the mean tidal range is 12 cm (0.40 ft.) and the lag is 5.5 hours.

Excepting hurricanes, the major wind forcing events occur in the winter with the passage of cold fronts, which produce a clockwise rotation in wind direction and a sharp increase in wind speed lasting 1 to 3 days. For the remainder of the time the winds are primarily out of the east and southeast with moderate speeds.

The salinity of the lagoons is controlled by the pronounced wet-dry seasons of southeast Florida. The rainy season occurs in the summer, primarily from late May to September, when the bays are freshened by the combination of local rainfall and runoff, directed through a system of flood control canals along the western borders. Dry conditions prevail during the winter months of November through April.

METHODS

Salinity is a very useful tracer for investigations of mixing and exchange properties in lagoons where large contrasts develop due to seasonal climatic forcing and weak oceanic exchange. In July of 1971, a standard salinity mapping procedure was established for Card Sound. This procedure consisted of running a series of traverses across the bay with a small boat equipped with a Bissett-Berman, continuously recording, flow-through thermosalinograph. The traverses were run at constant speed between known objects. In October 1972, the salinity mapping procedure was expanded to include Biscayne Bay. The experiments were conducted at approximately monthly intervals. After a 7-month delay due to equipment break down, the mapping experiments were begun again in May 1974, and were further expanded to include Barnes Sound. Maps of surface salinity patterns were then produced and used as a basis for analysis of mean conditions and patterns of variability.

In addition to the surface mapping, vertical profiles of temperature and salinity were made in each basin by stopping the boat and lowering a marked hose. Each experiment was conducted during a time span of two consecutive days. The Biscayne Bay survey typically lasted about 6 hours, as did the following day's Card Sound and Barnes Sound survey. The observations are aliased somewhat by tides, but the effect can be shown to be minor, except near the tidal inlets, due to the relatively small tidal excursions ($\simeq$ 2 km) in the interior of the lagoons.

In April 1975, a cooperative dye experiment was conducted in Card Sound with Dr. J. Carpenter, in an attempt to measure the renewal rate of the interior waters directly. On April 10, 60 pounds of rhodamine WT dye in 20% solution, i.e., 300 pounds of dye solution, was released in a 2-mile line along the western side of Card Sound. Dye was pumped continuously over the transom of a 22 ft. outboard traveling at 2 knots. The horizontal and vertical distribution of dye in the elongated patch was then mapped repeatedly until it disappeared about April 29. Dye concentrations were determined with a continuous recording Turner Model 10 flow-through fluorometer. The sensitivity of this instrument is ±0.01 parts per billion (ppb). A series of traverses were run perpendicular to the major axis of the dye. Vertical profiles were made at stations along the traverses by stopping the boat and lowering a marked hose. All positioning was determined by starting at known locations and running a constant heading and speed. The speed was held steady within ±0.1 knots by trailing a General Oceanics flow meter, and direction was known to ±5 degrees with a hand-held compass. The error in these two measurements produced an overall positioning error of approximately ±0.1 km. A detailed description of the data and analysis techniques resulting from the above experiments can be found in a Technical Report by Lee (1976).

RESULTS

Salinity Mapping

A four-year time series of Card Sound mean salinities is shown in Fig. 2, along with the total monthly rainfall measured at Homestead Air Force Base, which is approximately 8 km from Card Sound. To obtain the basins' mean salinity, the surface maps were spatially averaged with a planimeter. The solid dots represent mean salinities from the mapping technique, and the crosses are mean salinities obtained by averaging station data from a biological sampling grid during a period when the thermosalinograph was being repaired. The seasonal salinity fluctuations are clearly in response to the wet-dry periods of southeast Florida. The minimum (maximum) salinity usually lags maximum (minimum) rainfall by about one to two months which indicates that the basins' exchange time is long compared with the rainfall and runoff time scales.

A typical salinity map and vertical profile are shown in Figs. 3 and 4, respectively. A number of consistent features pertaining to the lagoons' mixing and circulation properties can be seen by inspection of these Figures:

1) In Biscayne Bay and, at times, in Card Sound and Barnes Sound, the salinity contours are generally aligned with the major axis of the basins. This feature was previously explained by Lee and Rootn (1972) as the result of reversing tidal currents in the interior of the lagoons being aligned with the major axes, which enhances mixing in the downstream direction.

2) Seasonal forcing due to the wet-dry periods of southeast Florida is strongly evident in the sign reversals of the horizontal salinity gradients. Negative salinity gradients develop during the dry period from November through April, when precipitation and runoff from the network of drainage canals along the western border of the bays are weak, causing salinities of the interior waters to increase faster than water on the eastern side where evaporation losses are buffered by oceanic exchange. Positive salinity gradients occur shortly after the onset of the rainy season in May, due to canal discharge along the western boundaries. During this stage, salinity maxima develop in the central regions of the lagoons, especially in Biscayne Bay where runoff is greatest.

3) A region of homogenous salinity is frequently present on the east side of Biscayne Bay adjacent to the "Safety Valve." This region is believed to define the area of direct tidal exchange with the coastal waters. On many occasions, the homogenous region extends across Featherbed Bank to the south, which suggests a phase delayed interaction of the tidal flow through the inlets north and south of the bank, similar to that observed between Caesar's and Broad Creeks across Cutter Bank (Lee and Rooth, 1972).

4) The Miami River discharge into north Biscayne Bay appears to be generally contained within the region between Rickenbacker Causeway and the Government Cut ship channel, which is in agreement with earlier observations by Hela _et al._, (1957). Rapid exchange of this discharge with coastal waters takes place through Government Cut and Norris Cut inlets.

5) Card Sound appears to have the most complex mixing patterns. Reversing tidal currents in the basin are aligned with the major axis (Lee and Rooth, 1972); however, on many occasions, the isohalines are perpendicular to the axis or at a significant angle. These complexities arise because Card Sound is interacting with Biscayne Bay, Barnes Sound, and the coastal waters, in addition to receiving low salinity runoff from Model Land Company canal and higher salinity waters from exchange with the bordering wet mangrove regions. The cross-basin orientation of salinity contours is believed to result during the periods when Barnes Sound behaves as a high salinity source, as do the broad shallow regions of fringing mangroves; whereas, downstream alignment of salinity contours tends to occur when runoff is strong.

6) The vertical profiles show that the interiors of the shallow lagoons are vertically homogenous on almost all occasions. The significance of the vertical uniformity occurring simultaneously with horizontal gradients will be discussed in a later section (Johnson and Lee, 1976). Stratification does appear along the western boundaries of the lagoons during periods of heavy runoff. Also, a salty bottom layer appears on occasions in Card Sound and Barnes Sound, which is probably due to exchange with the fringing mangrove regions, where the shallow depths and mangrove evapotranspiration produce high salinities.

The spatial average salinity of each lagoon is plotted as a time series in Fig. 5 along with the total monthly rainfall, evaporation, and canal discharge. The rainfall data was obtained from Homestead Air Force Base. Canal discharge data was acquired from the United States Geological Survey (U.S.G.S., 1972, 1973, 1974); however, this data has not been available since September 1974 and there is no discharge data available for Card Sound. Monthly evaporation, E, was computed by the bulk transfer method (Roll, 1965), using surface temperatures from Card Sound and meteorological data recorded at Turkey Point by Florida

Power and Light Company. Due to the scarcity of climate data, it was only possible to compute evaporation for six-month periods in 1973 and 1974. However, the seasonal fluctuation is still apparent, showing a maximum of about 17 cm/mo. in the summer when water temperatures are greatest and a minimum of approximately 4 cm/mo. in the winter.

Figure 5 clearly shows the seasonal response of each lagoon to the wet-dry climatic conditions. During dry periods, the mean salinities of Biscayne Bay and Card Sound increase at a rate varying from 1 to $2^{o}/oo$/mo., becoming greater than the shelf salinities and showing no signs of leveling off until the rainy season begins. Barnes Sound follows the same trend except that mean salinities are always higher than the shelf and lagoons to the north. This tendency for the basins' salinity to become greater than that of the coastal waters suggests poor exchange and long residence times. Of the three lagoons, Card Sound appears to have the most rapid exchange since the mean salinities are lowest during the dry periods. The weakest exchange is indicated to occur in Barnes Sound where the salinities are highest. This is not surprising since Barnes Sound has no openings to the coastal waters and must exchange through Card Sound. The greatest salinity fluctuations occur in Biscayne Bay, which receives the largest amount of canal discharge. The smallest fluctuations are in the shelf waters which are a mixture of water from the lagoons and the Florida Current.

Salt Balance Estimates of Lagoon Residence Times

Monthly estimates of the residence times of each lagoon were computed with a salt balance model similar to that developed by Pritchard (1960). This is an integrated approach, giving estimates of mean flushing times due to the combined effects of exchange mechanisms. Using the data displayed in Figure 5, the mean residence time of Barnes Sound was found to be 3.4 months; Biscayne Bay was estimated at 2.4 months; and, as anticipated, the most rapid exchange was indicated for Card Sound at 1.3 months. The salt balance model was found to be too great a simplification of a complex system, and as a result, negative values occurred. However, the estimates appear to be reasonable if the obvious erroneous values are neglected. Due to the many uncertainties in this technique, the residence times should be considered reliable within a factor of 2 to 3.

Card Sound Dye Experiment

The renewal rate of the interior waters of Card Sound was measured directly in a dye experiment which monitored the material balance. Repeated mappings of the dye line released along the western side of Card Sound confirmed that wind is the dominant exchange producing mechanism at the time of these experiments.

The total amount of dye present during each experiment was determined by measuring the areas within dye contours with a planimeter and multiplying by the mean depth of the area and density of sea water. These values are plotted as a time series (Fig. 6) along with water level measured at Model Land Company Canal by the U.S. Geological Survey and wind vectors computed from an anemometer located at Miami Beach. The error bounds represent the estimated experimental error in determining the total amount of dye. This error stems from four sources: mapping ≈±1%; fluorometer ≈±1%; contouring ≈±2%; and planimetering ≈±4%; giving a total error of ≈±8%. The wind vectors are computed from a 3-hour low-pass, filtered time series of the U (east-west) and V (north-south) components of the Miami Beach wind data. Since local winds are coherent over hundreds of kilometers, the Miami Beach winds are representative of the actual winds at Card Sound.

Figure 6 reveals that the major reductions of dye were wind-induced. There was a 50% dye reduction in 2 days after experiment #1, when the winds were out of the southeast, south, and southwest at about 8 m/sec. This occurred when the dye line was still very concentrated so there was a large dye loss, but the tagged water volume removed from the lagoon was only about 2% of the mean volume of Card and Little Card Sounds (Lee, 1976). If the winds were to continue from the south at the same speed, then a water volume equivalent to the mean volume of Card and Little Card Sounds ($1.65 \times 10^{14}cm^3$) would be transported into south Biscayne Bay in approximately 100 days. After experiment #4, a 33% dye loss occurred in 4 days during which time the winds were out of the southeast at speeds ranging from 6 to 10 m/sec. Since the dye line had become considerably wider than on experiment #1, this dye reduction represents an 11% removal rate of the mean volume. Thus, it is anticipated that the mean volume of Card and Little Card Sounds would be flushed into south Biscayne Bay in approximately 36 days if the winds were to remain constant. A transport of water to the north during these south wind conditions suggests that there should be some compensatory inflow to Card Sound, either through the tidal inlets (Broad and Angelfish Creeks) or the channel connecting Barnes Sound to Florida Bay (Jewfish Creek). A numerical model of the flow in Biscayne Bay and Card Sound, developed by Dean (1971), also indicates that a wind-forced inflow should occur through Broad and Angelfish Creeks during southerly winds. In addition, personal communications with marina operators at Jewfish Creek indicates that continuous inflow to Barnes Sound occurs during periods of strong winds from the south; whereas, normally, the current reverses with the semidiurnal tide. On April 22, a strong wind event began which lasted about 4 days with speeds, occasionally, over 10 m/sec out of the northeast, shifting to east, then east-southeast. This event transported almost all of the remaining dye in Card Sound to Little Card

Sound and Barnes Sound. Thus, Card Sound can be flushed by the passage of a single event if it has sufficient strength and duration and the wind direction has a component along the major axis. However, most of the exchange is taking place between lagoons so that a contaminant, once introduced, would remain in the total lagoon system for an extremely long period. This is especially true of strong winds out of the north. A contaminant injected into Card Sound during north winds should be transported to Barnes Sound, which behaves as a cul-de-sac and, thus, results in a very long containment period within the lagoon system.

Winds from the south appear to be the most favorable for lagoon-ocean exchange. Southerly winds transport Card Sound waters north into south Biscayne Bay, and Biscayne Bay waters are believed to be advected into the coastal waters through the Safety Valve and inlets to the north. This was also shown by Dean (1971) in his numerical model. Southerly winds normally precede the passage of cold fronts, which are the dominant winter forcing. Inspection of the 1973 wind records from the Miami International Airport indicate that cold fronts occur in the months of December through April on the average of one per week. If we assume that approximately 10% of the mean volume of Card Sound is exchanged during the passage of each cold front, then it would take an average of about 2.5 months to flush. However, as was shown previously, lagoon exchange is very much event dependent. Cold fronts with wind speeds greater than 10 m/sec, aligned with the major axis and lasting several days, can flush the lagoon within the passage time of the front. Wind records reveal that fronts with this intensity occur approximately every 1 to 2 months during the winter.

DISCUSSION

Tidal Exchange in the Interior of Estuaries

Tidal currents in the interior regions of estuaries will normally show a simple longitudinal reversing pattern aligned with the major axis of the basins. Theoretical tidal analysis suggests that this simple along-basin tidal flow should result in substantial anisotropic mixing conditions, with mixing being enhanced in the direction of the flow.

It is well known from studies of exchange in the atmospheric boundary layer, as well as in shallow estuaries, that the combination of vertical shear in the mean velocity field and vertical turbulent diffusion leads to a horizontal dispersion effect, which can be described as an anisotropic diffusion process. As shown in a detailed treatise by Bowden (1965), this induced diffusivity is dependent on the velocity shear and on the vertical diffusion time scale in such a way that a stable stratification enhances the effect. If a diffusing property (pollutant being discharged into an estuary) has little effect on density, then asymmetric diffusion will result in a distribution of the property which resembles a simple advective outflow. In an embayment such as Biscayne Bay, which has an intermittent freshwater source along the western boundary, this process will result in salinity patterns aligned with the main direction of tidal flow, as shown in Figure 3.

The diffusion in the crosscurrent direction is given solely by the turbulence in the stream. In the neutral case, symmetry between vertical and cross-stream mixing is to be expected, but stable stratification will lead to enhancement of the lateral mixing due to the horizontal spreading of decaying eddies. Bowden estimates the cross-stream diffusivity, at most, to be a few percent of the streamwise diffusivity as long as stratification is subcritical.

It follows from an extension of Bowden's analysis (Lee and Rooth, 1972) that a simple rule of thumb can be applied to tidal-induced mixing in the interior, which states that the equivalent diffusivity is approximately one tidal prism per tidal cycle. It can be shown from this that an estuary with a central basin 9 km long and 3 m deep (Card Sound), and with a maximum tidal current of 25 cm/sec, would take on the order of one year to exchange its water by tidal mechanisms alone.

If an estuary consists of several interconnected basins, such as Biscayne Bay, then due to the preferred direction in tidal mixing, exchange of interior water will be predominantly between the different basins. Direct exchange with the ocean will be restricted to the regions in the vicinity of the tidal inlets.

Tidal Exchange in the Vicinity of Inlets

The regions of direct coastal-estuarine interaction are confined to the near vicinity of the seaward openings, coupling the estuary to the sea. Flow through these passages will normally be dominated by tidal forces. The astronomical tidal wave progressing through the coastal waters produces a slope in the water surface through the inlet. The magnitude of the resulting flow will be directly dependent upon the height of the slope. The volume of fluid that can be exchanged through a passage depends also on its width and depth. The shapes of openings can vary from narrow inlets to broad shallow flats.

The region of the estuary which undergoes direct exchange with the ocean will depend upon the shape of the seaward opening. In the vicinity of inlets narrow enough to produce noticeable fluid jetting, an induced mixing due to inertial effects on the flow will arise. The incoming tide may give rise to a jet-like motion into the estuary, while on the falling tide, the flow towards the inlet is similar to an ideal potential flow toward a sink. The net result, when averaged over a complete tidal cycle, is a mean circulation corresponding to a double vortex sheet along the edge of a widening jet. Using the standard type linear entrainment law, which has been found experimentally to work in most cases of turbulent jets, a first order estimate of the jet's penetration distance into the basin can be found. This penetration distance was determined to correspond to a semicircle with a radius approximately 500 times the mean depth of the inlet (Lee and Rooth, 1972), or roughly about 1.5 to 2.0 km for the non-dredged tidal inlets opening into Biscayne Bay and Card Sound.

Circulation Induced by Horizontal Density Gradients

In the shallow lagoons of southeast Florida, tide and wind mixing are of sufficient strength to maintain vertical near-homogeneity in the water column. However, due to freshwater runoff from drainage canals along the western side of the lagoons and exchange with the ocean through tidal inlets on the eastern side, a horizontal density gradient is usually present. This density gradient takes the form of a horizontal salinity gradient with fresher (lighter) water on the mainland side and saltier (heavier) water on the ocean side of the lagoons. The long term maintenance of the horizontal density gradient is enhanced by the anisotropic tidal mixing in the interior of the lagoons discussed previously, which tends to align the density gradient along the major axis of the basin. The existence of a horizontal density gradient in the presence of gravitation induces a circulation which attempts to stratify the basin by moving the lighter water seaward along the surface and the heavier water toward the mainland along the bottom. Thus, this density-induced circulation can produce an additional flushing mechanism which tends to reduce the residence time of the interior waters.

In order to estimate the significance of this flushing mechanism in the presence of tide mixing in shallow estuaries, we undertook an analytical study of a two-dimensional model system (Johnson and Lee, 1976). A perturbation analysis was made of the equations of fluid motion, scaled to fit conditions in the Biscayne Bay and Card Sound estuaries. Two cases were investigated: 1) the case of density-induced circulation in the presence of tidal mixing; and 2) the case of acceleration in the density-induced circulation during slack tide when tidal stirring vanishes.

The analysis provides the appropriate scaling relations to estimate, in general, the circulation induced by weak horizontal density gradients, and to establish its significance as a flushing mechanism. For the two cases investigated, it was found that the shallowness of the lagoons and the intense vertical mixing generated by bottom friction effects led to very weak density-induced flows, which were too small to be considered important in the renewal process.

Wind-Induced Exchange

Our previous qualitative analysis of the effects of wind-forcing on Biscayne Bay and Card Sound (Lee and Rooth, 1972) indicated that winds are the dominant exchange-producing mechanism. This was arrived at partly because of the striking nature of the observations taken before and after transient wind events, and partly because the other flushing mechanisms analyzed; tides and horizontal density gradients were shown to produce extremely long residence times. In southeast Florida, winds are primarily out of the southeast and east with moderate speeds during the summer months. During the winter, the normal easterly flow is repeatedly perturbed by the passage of cold fronts which produce a clockwise rotation in wind direction and an increase in speed. Our analysis indicated that the passage of a cold front could generate a mean circulation, due either to partial sheltering or to irregular bottom topography. This can advect interior water into the vicinity of tidal inlets where direct exchange with the ocean takes place. It was estimated that a typical cold front with wind speeds of 5 m/sec and a resulting circulation of 10% of the wind-induced drift velocity would reduce renewal times in a basin, with a length of 9 km and a depth of 3 m (Card Sound), to be on the order of one month. However, this estimate has not been verified by quantitative modeling. Our first attempt at modeling wind effects was to develop an analytical model for the simplest case; i.e., steady, spatially uniform winds and uniform bottom topography.

Winds which are spatially uniform across the shallow lagoons of Biscayne Bay and Card Sound and which are steady for a significant period of time will induce a "set up"; i.e., a counter-pressure gradient formed by piling up of water along the downwind boundary. When this occurs, the vertically averaged wind-driven currents are canceled. The time necessary to establish this case is essentially the time it takes for a barotropic wave to propagate across the lagoon, which is given by $T = \frac{L}{\sqrt{gh}}$, where h is the mean depth and g is the acceleration of gravity. For winds blowing in the x direction (east) this is about 20 minutes, and in the y direction, i.e. north (with L ~ O(50km)), about 4 hours.

The analysis consisted of solving the equations of motion and density equation for the steady state wind case scaled to the Biscayne Bay and Card Sound estuaries. Solutions for the resulting velocity and density anomalies were obtained for the interior portions of the lagoons so that horizontal friction was neglected. For simplicity, the wind stress and horizontal density gradient were defined to be in the cross-basin direction only and tidal stirring was neglected. We then computed the time necessary to eliminate the horizontal density gradient, which is equivalent to the residence time. This was found to be extremely long, indicating that uniform winds over a shallow uniform basin are not significant as a flushing mechanism. However, since it was shown that wind forcing is dominant in regulating renewal rates, then it is reasonable to assume that non-uniform conditions, such as those created by the transient occurrence of locally intense storms, are driving the interior water renewal.

On the basis of field experiments and theoretical analysis of various mechanisms for generating water exchange effects, we have come to the following conclusions regarding the flushing of the Biscayne Bay system of shallow lagoons. Tide- and density-induced motions are ineffective in renewing interior lagoon waters. Winds appear to be the dominant flushing mechanism however, a quantitative understanding of this process is still lacking. We believe that the wind exchange is dominated by events of unusually strong wind conditions which create an intensive transient mean circulation. This conclusion still needs to be verified by analytical or numerical models. It appears that for quantitative understanding of the variability expected in pollution effects on this system, the most significant present need is to acquire data on wind variability, with emphasis on extreme event statistics.

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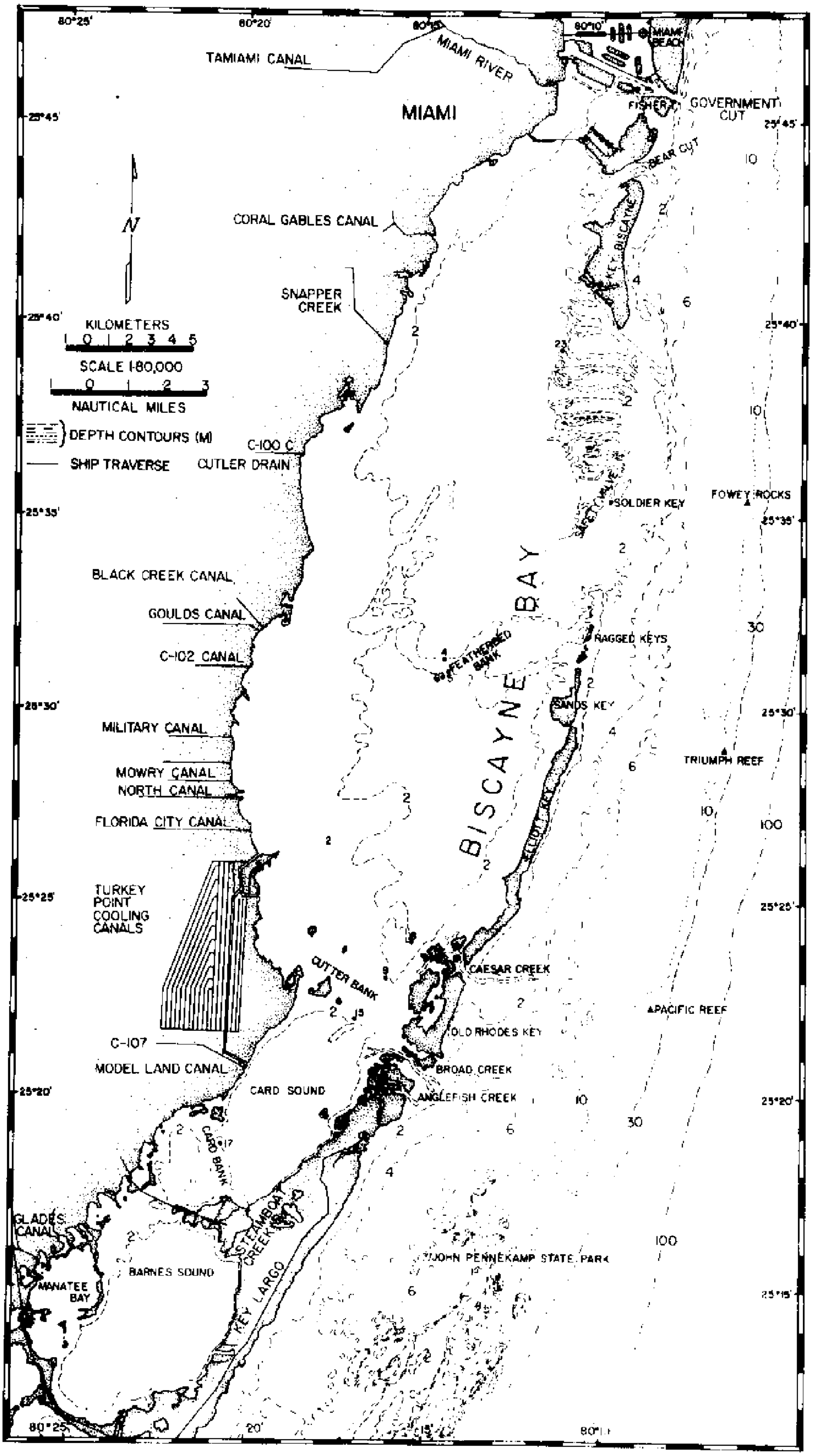


Figure 1. Location map of Biscayne Bay and connecting lagoons.

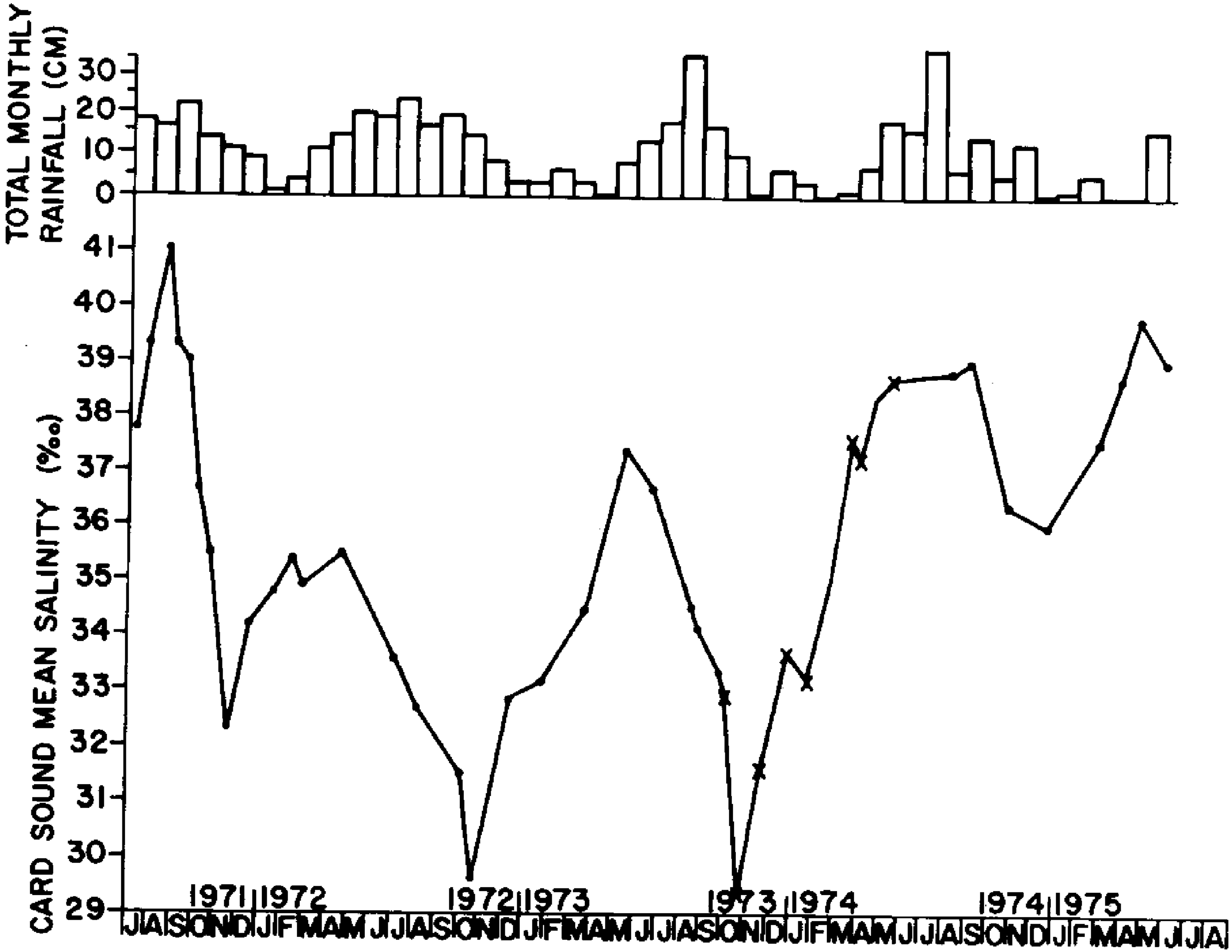


Figure 2. Mean salinity of Card Sound (• from thermosalinograph mapping, x from biological station data).

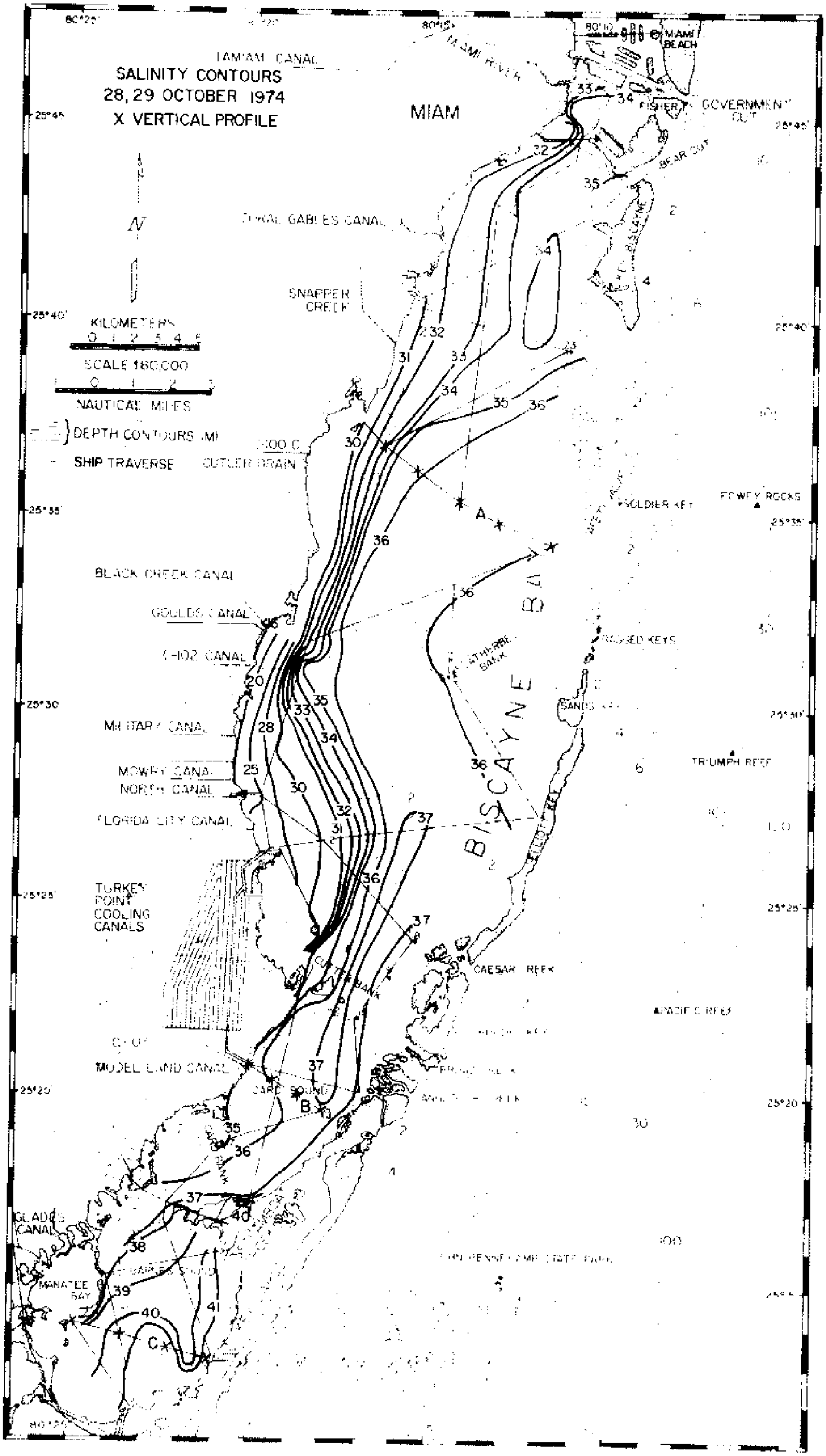
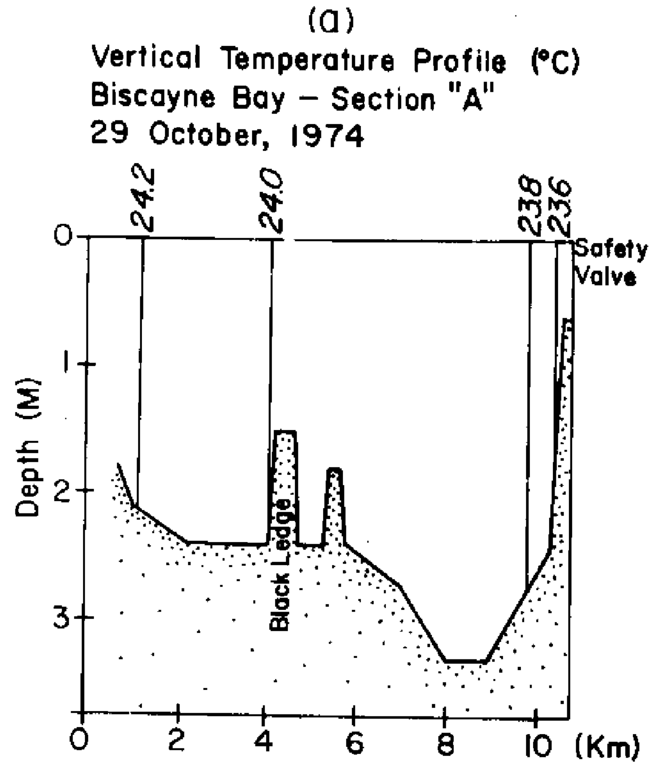
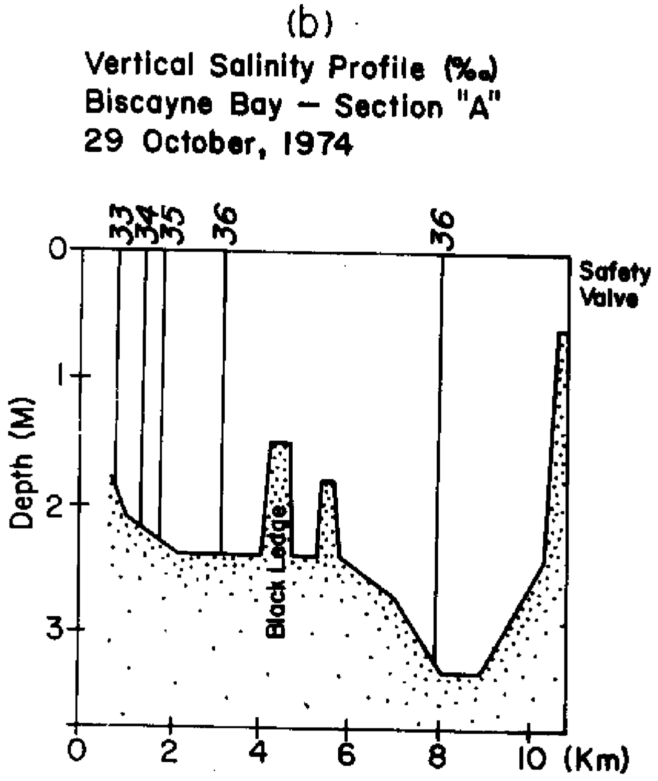


Figure 3. Salinity contours: 28, 29 October 1974.



(a)
Vertical Temperature Profile (°C)
Biscayne Bay – Section "A"
29 October, 1974



(b)
Vertical Salinity Profile (‰)
Biscayne Bay – Section "A"
29 October, 1974

Figure 4. Biscayne Bay vertical temperature and salinity profiles at section "A" on 29 October 1974.

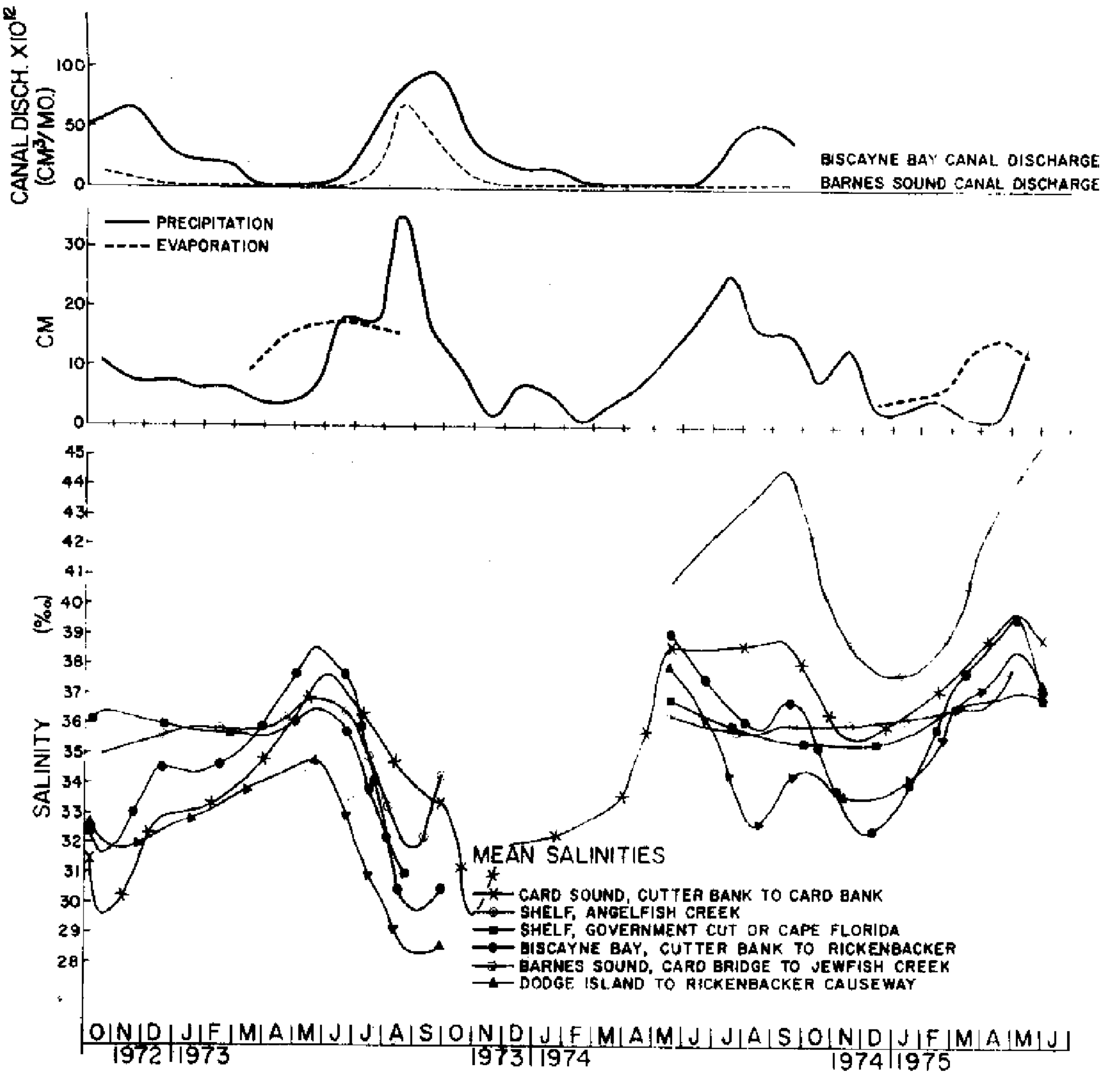


Figure 5. Time series of components used in salt balance computations.

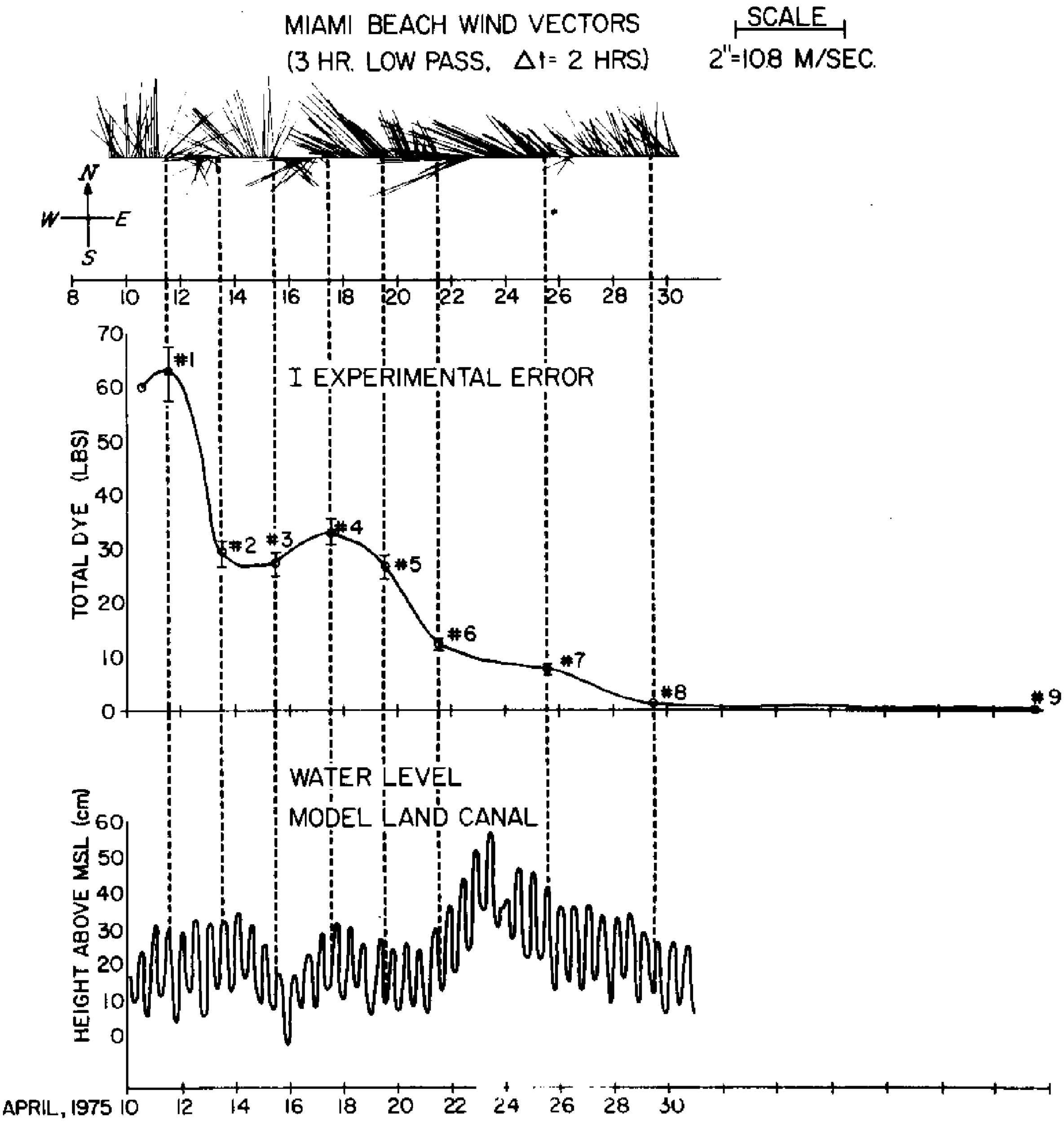


Figure 6. Time series of the total amount of dye (lbs.) in experiments #1 through #9, water level (cm) recorded at Model Land Co. canal by the U.S. Coast and Geodetic Survey, and wind vectors from the Miami Beach weather station.

Biology

THE ROLE OF EPIPHYTES IN SEAGRASS SYSTEMS

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ABSTRACT

Biscayne Bay contains several primary producers including many different species of seagrasses and algae. One of these primary producers, the epiphytes, is the complex of microalgae attached to the seagrass blades. Previous studies of epiphytes in Biscayne Bay suggest that they play an important role in this subtropical system. Productivity rates of epiphytes are high; they are a food source for several organisms; and nitrogen-fixing epiphytes are involved in nutrient cycling in the seagrass community. Epiphytes also are potentially useful as indicators of pollution. Despite the information that has been obtained on epiphytes in Biscayne Bay, much remains unknown. Studies in other locations suggest potential areas of study necessary to determine the role of epiphytes in Biscayne Bay.

INTRODUCTION

Seagrass systems have been studied for many years but only recently has their important contribution to the marine environment been evaluated. These systems, which include seagrasses and algae as primary producers, are widely distributed in coastal areas and are among the most productive in the ocean (McRoy and McMillan 1973, Thayer et al. 1975). The other primary producers in the seagrass systems are benthic microalgae and macroalgae, phytoplankton, and epiphytes (those microalgae attached to seagrass blades). Unfortunately, little is known of their biomass, productivity, and interrelationship with the seagrasses and with other components of the system. In this paper, we will discuss the role of one of these producers, the epiphytes, with an emphasis on Biscayne Bay, Florida. In addition, we will discuss what is not known about epiphytes and will make recommendations for further study.

DISCUSSION

Previous Epiphyte Studies in Biscayne Bay:

Seagrasses in Biscayne Bay support a large number of epiphyte species. Humm (1964) described 92 species of epiphytes on turtle grass, Thalassia testudinum, in south Florida waters, including Biscayne Bay. He noted that certain species occurred throughout the year and others were present only during certain seasons. A major component of the year-round epiphytes were several species of the Corallinaceae, calcareous red algae which at times almost completely cover the grass blades. Humm also reported that the epiphytes were least abundant in early summer, just after the rapid growth period of Thalassia. Reyes-Vasquez (1970) described 42 species of pennate diatoms which colonized Thalassia testudinum in Biscayne Bay. He noted no direct effect of salinity and temperature on the distribution and succession of the diatom species and suggested that sediment conditions may affect the seasonal occurrance of diatom species. Unfortunately, these studies were qualitative and provided no estimates of epiphyte biomass throughout the year. Also, no studies have been made of the epiphyte species attached to seagrass species other than Thalassia testudinum.

Measurements of epiphyte primary productivity indicated that epiphytes could make significant contributions to the total primary productivity of aquatic systems. Jones (1968) estimated that the total annual epiphytic productivity, 200 g C m^{-2} yr^{-1}, was 22% of the productivity of Thalassia testudinum in optimal stands in Biscayne Bay, Florida. Epiphytic productivity varied seasonally with peak rates observed in February and March (during early spring warming) and in July and October (following hurricanes). Estimates of net epiphyte productivity rates were 0.9 g C m^{-2} day^{-1} during the summer and 0.2 g C m^{-2} day^{-1} during the winter.

The productivity study of Jones (1968) provided useful estimates of the importance of epiphytes in the productivity of shallow aquatic systems; however, certain technical problems were involved in his study. The epiphytic production data was based on measurements of oxygen production by epiphytes colonizing dead or dying Thalassia leaves. Internal cycling of oxygen resulting from photosynthesis has been demonstrated for freshwater angiosperms (Hartman and Brown 1967). If any photosynthesis occurred within the dying Thalassia, the oxygen production and probable recycling could result in erroneous estimates of oxygen production by epiphytes. Also, if the dead or dying leaves supported increased microbial populations, the resultant oxygen consumption could result in an underestimate of oxygen produced by epiphytes.

Capone and Taylor (1975) recently have been studying the role of epiphytes in the nutrient cycles of Biscayne Bay. They used the acetylene reduction method to assay nitrogen fixation by epiphytes on leaves of Thalassia testudinum at several locations in the bay. They concluded that Calothrix crustacea, a blue-green alga, was the major nitrogen-fixing microorganism on the grass blades. Rates of epiphytic nitrogen fixation in the bay were generally low; for example, the calculated rate at Soldier Key was 0.5 kg N ha^{-1} yr^{-1}. They concluded that this amount of nitrogen was probably negligible in the nitrogen economy of the grass community. Capone and Taylor also determined that at the center of a Thalassia stand (located at Fowey Light, just outside of Biscayne Bay) the epiphytic nitrogen fixation supplied 3 to 13% of the calculated nitrogen requirement of Thalassia. Although nitrogen fixation by epiphytes does not appear to play a large role in the nitrogen economy of the seagrass itself, they suggested that the process might enhance the growth of other epiphytic species on the blades.

The epiphytes may play an important role in the food web in seagrass systems. In his study of the grass shrimp Tozeuma carolinense in Biscayne Bay, Ewald (1969) noted that shrimp maintained in laboratory aquaria fed directly on epiphytic algae attached to Thalassia blades. For example, a medium adult could denude 40 to 50 fourteen centimeter-long blades within 2 or 3 days. Randall (1964) reported the presence of epiphytes in the stomach contents of the queen conch (Strombus gigas) in the West Indies. Carr and Adams (1973) reported that juveniles of certain fish species such as Diplodus holbroki browsed on attached epiphytes in seagrass beds near Crystal River, Florida. In addition to being a direct food source for marine organisms, epiphytes may be an important constituent of the detrital food chain.

Epiphytic diatom communities have been used to evaluate the influence of thermal effluent waters in south Biscayne Bay, Florida. Sprogis (1975) compared the community structure of diatoms attached to glass slides located at five stations near the Florida Power and Light plant at Turkey Point. Eighty-seven diatom species were identified and species diversity was calculated over a one-year period. Diatom diversity was inversely related to temperature, especially during the summer months; such a decrease in diversity with abnormal increase in temperature is often indicative of environmental stress. Diversity was lowest at temperatures exceeding 32 C. Chlorophyll a concentrations were higher at stations with reduced diversity; this was most likely due to the observed increase in blue-green algae biomass.

The available information suggests that epiphytes attached to seagrasses are potentially an important part of the Biscayne Bay system. In summary, previous studies in the bay indicated that productivity rates of the epiphytes are high. The epiphytes are a food source for several species of vertebrates and invertebrates. Epiphytes also play a role in the nitrogen cycle in Biscayne Bay. In addition, epiphytes may be useful as indicators of pollution.

Recommendations for Future Study:

Despite the information that has been obtained on epiphytes in Biscayne Bay, much remains in question. Little is known of the factors which control the onset of epiphytic growth and subsequent species structure of the epiphytic community. Even a descriptive account of the initial colonization of the seagrasses by the epiphytes has not been made in the area. Sieburth and Thomas (1973) made scanning electron micrographs of the epiphytic colonization of eelgrass (*Zostera marina*) in Rhode Island. They found that the grass blades were initially colonized by a diatom species, and that the diatoms formed a crust which apparently was necessary for the further colonization by other epiphytic and microorganisms.

Quantitative estimates of epiphytic biomass are not available from Biscayne Bay; however, on the basis of other studies, it appears that the epiphytes are important in terms of biomass of seagrass systems (Thayer et al. 1975). For example, the diatom biomass attached to eelgrass in Alaska can amount to as much as 50% of the total leaf plus epiphyte dry weight (McRoy and McMillan 1973). The dry weight of epiphytes on eelgrass on the coast of North Carolina ranged from 17 to 52% of the dry weight of eelgrass and epiphytes over a one-year period (Penhale 1976). Certainly seasonal biomass data is necessary to understand food web dynamics of seagrass systems.

Seasonal primary productivity rates of epiphytes are also necessary for an understanding of the food web in seagrass systems. Since the previous study of epiphyte productivity in Biscayne Bay (Jones 1968) is unreliable due to technique problems, further productivity estimates should be made. Estimates should be based on ^{14}C uptake measurements, the most reliable method for short term estimates of epiphyte productivity. A year-long study would be necessary to obtain adequate information on the seasonal cycles of epiphyte biomass and productivity. Measurements should be made at different locations within the bay since measurements made in any one area may not be representative of the entire bay.

Little is known of the factors which affect epiphytic biomass and primary productivity rates. Environmental factors such as light, temperature, salinity, nutrient levels, and water current may influence epiphyte processes. Routine measurements of environmental factors should be made in conjunction with epiphyte biomass and productivity measurements. In addition, short term laboratory experiments would be useful in determining the interactions of factors which control epiphyte productivity rates.

The interaction between seagrasses and their epiphytes is poorly understood. Other than the work of Capone and Taylor, nothing is known of the interrelationship between seagrasses and epiphytes in nutrient cycling in Biscayne Bay. Studies in other seagrass systems indicate that there is a transfer of nutrients between seagrasses and their epiphytes. Harlin (1973) qualitatively described the transfer of phosphorus and products of photosynthesis from eelgrass to its red algal epiphytes. The reverse process from the epiphytes to the seagrass was also observed. McRoy and Goering (1974) reported rates of carbon and nitrogen uptake by eelgrass roots and the subsequent transfer of this material through the plant to its epiphytes. Similarly Penhale, (1976) observed the root uptake of phosphorus and carbon by eelgrass roots and the transfer of these nutrients to the epiphytes. The transfer process suggests that seagrasses are potentially an important source of nutrients for their epiphytic community. For the nutrients phosphorus or carbon, which are non-limiting in many aquatic ecosystems, this process may not be ecologically important. However, in waters deficient in certain nutrients, the seagrass source of nutrients may enable the epiphytes to attain high biomass and productivity rates.

The biomass and primary productivity cycles of seagrasses and their epiphytes are probably closely interrelated. Although no information is available from Biscayne Bay, such interactions have been suggested in other studies. Epiphyte biomass followed a seasonal trend similar to that of eelgrass (Penhale 1976); this is to be expected since epiphytes are dependent on seagrass for a surface for attachment. Penhale (1976) also observed that eelgrass photosynthetic rates were lower than epiphyte photosynthetic rates in a series of laboratory experiments. In these experiments (which were designed to test the effect of light and temperature on photosynthetic rates) plants were selected for a relatively heavy epiphyte cover. One reason for the lower eelgrass rates may be that the eelgrass received lower light levels due to shading by the epiphytes.

Another interaction between seagrasses, epiphytes and other members of the seagrass community is in the cycling of dissolved organic carbon (DOC). Dissolved organic carbon can be utilized as a food source by bacterial populations in the water and in the sediments. The release or excretion of DOC by seagrasses and epiphytes has been demonstrated in several marine systems. For example, Brylinsky (1971) reported an average release of 1.3% of the total carbon fixed by photosynthesis by *Thalassia testudinum* in the Florida Keys. No information on DOC excretion by epiphytes of *Thalassia* is available. Excretion rates by epiphytes of eelgrass are small, generally less than 2% of the total carbon fixed (P. Penhale and W. O. Smith, unpublished data).

The role of epiphytes in food web dynamics is also poorly understood. Although epiphytes are known to be a food source for certain organisms, they probably are consumed by many other species. Besides descriptive studies, experiments should be carried out to determine feeding rates and efficiencies of various organisms which consume epiphytes. Also, decomposition studies emphasizing epiphytes are needed to understand the role of epiphytes in detrital food chains.

Previous epiphyte studies in Biscayne Bay and in other areas suggest that the epiphytes are an important part of seagrass systems; however, more information is necessary to clearly understand the role of epiphytes in seagrass community structure and function. Seasonal biomass and productivity information is basic to any epiphyte study and is of the highest priority. Determination of the factors which control these processes is also of high priority. These studies are fundamental to an understanding of the role of epiphytes in food web in the seagrass ecosystem. Although important, studies of the interactions of seagrasses and their epiphytes in terms of nutrient and DOC cycling are of lower priority due to the technical complexity of these studies.

Additional knowledge of the contributions of the epiphytes to seagrass systems is essential to an understanding of the interactions and cyclic processes taking place in Biscayne Bay.

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THE BENTHIC ALGAE OF BISCAYNE BAY

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ABSTRACT

The many benthic algal habitats in Biscayne Bay support more than 331 species representing a tropical shallow water year around flora and a small group of winter-spring species. There are 46% red algae, 30% greens, 14% browns and 11% bluegreens. All bluegreen species known to exist in world oceans (*sensu* Drouet) are present in the Bay. An annotated list of the species is given.

INTRODUCTION

The benthic algae of Biscayne Bay have never been studied as a whole. The two most comprehensive studies were the master's thesis of L. B. Isham (1952), who recorded 65 species of green and brown algea in the Bay, and that of the writer (1964) on the epiphytes of the leaves of the seagrass, *Thalassia*, in which 92 species were recorded for the Bay.

Several intensive ecological studies have been done that deal with the more common species in Card Sound and the effects of the warm water effluent from the power plant at Turkey Point. Zieman (1970) dealt with thermal stress on algae at Turkey Point. Thorhaug et al. (1971) and Roessler (1971) studied the effect of water temperature on the green alga, *Penicillus capitatus*. Earlier, Thorhaug (1965) reported on the developmental morphology and biology of this species in laboratory and field studies. Thorhaug and Garcia-Gomez (1972) noted that the "dominant" alga in Card Sound is *Laurencia poitei* and that species of *Digenia*, *Dasya*, *Acanthophora*, *Gracilaria*, *Batophora*, *Acetabularia*, and *Laurencia papillosa* contribute significantly to the algal biomass. Thorhaug (1973) studied the effect of thermal effluent on five genera of Siphonales that colonize unconsolidated bottom sediments and on *Acetabularia*, *Batophora* and *Laurencia poitei*. The upper range of temperature tolerance was determined in a "polythermostat" of species of *Halimeda*, *Penicillus*, *Valonia*, *Acetabularia* and *Laurencia*. Details of the temperature range of growth were determined for five species of *Valonia* (Thorhaug, 1975).

Josselyn (1975), in his excellent study of *Laurencia poitei* and *L. obtusa*, found that the biomass of *L. poitei* is lowest in the fall and highest in the spring (March), as the best growth occurs when the water temperature is between 20 and 25°C. It produced 3×10^5 kg dry weight per year in Card Sound, an average of 8.1 g of dry weight per square m per year. *L. obtusa* appeared to have a wider temperature range of growth, as it seemed to do equally well during winter and summer, but its biomass was always lower than that of *L. poitei*.

Thorhaug et al. (1976) recorded the effect of power plant warm water effluent in Card Sound on the principal benthic algae present as a result of having studied the area prior to effluent discharge and for some time after the thermal effluent had begun. They found little damage to the plant and animal community except in an area of two to three hectares.

The writer began observations on the algae of Biscayne Bay in 1938 and has continued to make collections and gather field data at invervals since that time. The work has been fortuitous or opportunistic except for the year 1961-62 when the writer was in residence at the Rosenstiel School while on sabbatical.

Ordinarily, a summary of knowledge of the algae of Biscayne Bay would be based upon published records and herbarium specimens. Since it is impossible to compile a list of the latter, including those at Woods Hole, the New York Botanical Garden, Farlow Herbarium, Duke University, in time for this paper, the writer is obliged to rely upon his personal knowledge for some information and names included. To restrict the list to species in publications and local herbaria would leave out some of the common algae of the Bay.

The writer would like to devote one full year to a detailed study of the algae of Biscayne Bay. About one month would be required to compile all the principal herbarium records and the rest of the time could be spent in field work. A thorough and useful account could then be written that would serve as a guide to identification and describe distribution and seasonal behaviour of each species.

Studies of the Region

The closest comprehensive study of the benthic algal flora to Biscayne Bay was the work of Taylor (1928) at Dry Tortugas. In addition to the records of that area, Taylor included in his publication all previous records of benthic algae from other parts of Florida with the result that he listed 400 species (omitting varieties and forms). If the bluegreen names are converted to the taxonomy of Drouet (Drouet and Daily 1956, Drouet 1968,1973) and all species omitted that were not found at Tortugas or obtained only from depths considerably in excess of those of Biscayne Bay, then the total species is 292. In Taylor's 1960 publication, he lists 395 species for Florida, but the bluegreens are not included.

The algal flora of Jamaica was first detailed by Collins in 1901 who recorded 224 species. More recently Chapman (1961, 1963) has increased the total to 372.

Børgesen (1913-20) in his superb work on the algae of the Danish West Indies (American Virgin Islands) recorded 327 species. The writer and others (unpublished) have found quite a few additional species at St. Croix and St. John in the past 20 years.

Dawes (1967) listed 217 species for the Tampa Bay area (not including bluegreens), and later (1974) 289 species for the Florida Gulf coast (bluegreens included).

The richness of the flora of Biscayne Bay, especially when it is realized that the Bay is too shallow for any truly deep-water species, is clearly seen when comparison is made with these records and certain others, as summarized in Table 1.

RESULTS

The Bluegreen Algae

Probably all species of bluegreen algae (*sensu* Drouet and Daily 1956, Drouet 1968, 1973, and in preparation) that occur in the oceans and their estuaries occur in Biscayne Bay with one exception. *Entophysalis endophytica* Drouet and Daily is known only in the Pacific Ocean.

There are several other species of marine bluegreen algae not reported for Biscayne Bay, but all of these belong to the group (*Nostocaceae* with trichomes have constrictions) on which Drouet is currently at work as the final volume of his monumental monograph and revision of the classification of the bluegreens. The writer believes that these species will be relegated to synonymy with species already known to occur in Biscayne Bay.

The estuarine and generally tolerant species of bluegreens occur along the downtown waterfront, in and aound the Miami River mouth and other streams and canals that enter the Bay. The few strictly marine, intolerant species are found along the eastern margin of the southern part of the Bay between Cape Florida and Angelfish Creek. The open-sea, planktonic species, *Oscillatoria erythraea*, is carried into the Bay with tidal currents during summer and fall when it is often abundant in waters over the continental shelf and the Florida Current. This species fixes nitrogen.

There are 13 species of coccoid bluegreens in the list that follows and 23 filamentous species. Among the latter, the writer expects Dr. Drouet to place at least four in synonymy. If so, there are 19 distinct species of filamentous bluegreens in the Bay, a total of 32. Thus there are probably 33 species of bluegreen algae inhabiting permanently the oceans and estuaries of the world.

Class Myxophyceae
Order Coccogonales
Family Chroococcaceae

Coccochloris elabens Drouet and Daily. On seawalls in the intertidal zone of canals in brackish water; in tidal pools of low-energy beaches.

Coccochloris peniocystis Drouet and Daily. Intertidal on woodwork and walls in the Miami River near the mouth; temporarily in the plankton.

Coccochloris stagnina Drouet and Daily. On mangrove roots around the mouth of Snapper Creek; usually in brackish water, sometimes in the plankton.

Anacystis montana (Lightfoot) Drouet and Daily. In brackish water, intertidal and below, on woodwork, or forming globular masses on larger plants, usually as *forma montana* Drouet and Daily.

Anacystis aeruginosa Drouet and Daily. Forming small clumps or colonies of spherical cells on larger algae in quiet waters along mangrove beaches such as the wading beach at Matheson Hammock.

Anacystis dimidiata (Kützing) Drouet and Daily. Widely distributed in Biscayne Bay as single cells or 2-4-celled colonies on larger algae and sessile invertebrates.

Anacystis marina Drouet and Daily. On intertidal woodwork and seawalls in brackish water of the canals, the Miami River, and mangrove roots.

Johannesbaptista pellucida Taylor and Drouet. The uniseriate strands of this coccoid species are most often encountered in high intertidal and stagnant tide pools in limestone.

Gomphosphaeria aponina Kützing. On aerial roots of red and black mangroves and in tide pools in salt marsh and mangrove swamps.

Agmenellum thermale (Kutzing) Drouet and Daily. In the intertidal zone in the surface layer of beach sand of protected areas such as the wading beach at Matheson Hammock.

Agmenellum quadruplicatum Brebisson. In the muddy sediment layer on woodwork and seawalls in the intertidal zone of canals, the Miami River, and Snapper Creek in brackish water.

Family Chamaesiphonaceae

Entophysalis conferta (Kützing) Drouet and Daily. Throughout Biscayne Bay on larger algae and seagrasses.

Entophysalis deusta Drouet and Daily. One of the most abundant coccoid bluegreens in the Bay on stones, shells, and penetrating limestone, within which it forms a pseudofilament.

Order Hormogonales

Family Oscillatoriaceae

Spirulina subsalsa Oersted. Throughout the Bay on buoys, pilings, in the intertidal sand of beaches (as along the south side of Rickenbacker Causeway), and on larger algea.

Oscillatoria erythraea (Ehrenberg) Kutzing. This strictly plankton species is occasionally abundant in the plankton of the Bay during summer and fall. It is a nitrogen-fixer.

Oscillatoria lutea C. Agardh. On larger algae and mangrove roots, especially in the clearer water of south Biscayne Bay.

Oscillatoria submembranacea Ardissone and Strafforello. Forming a thin layer on old bottles in brackish water and a turf with wick-like bundles on rocks between Cape Florida and Angelfish Creek.

Schizothrix arenaria (Berkeley) Gomont. On tidal flats, salt marshes, mangrove swamps, often mixed with *Microcoleus lynbgyaccus* in areas of warm, shallow water.

Schizothrix calcicola (C. Agardh) Gomont. Probably the most widely-distributed filamentous bluegreen in Biscayne Bay. It is epiphytic on other algae and seagrasses, on solid surfaces, and it bores into limestone.

Schizothrix mexicana Gomont. Common throughout the Bay as an epiphyte on larger algae, invertebrates, oyster shells, and mangrove roots.

Schizothrix tenerrima (Gomont) Drouet. On muddy iterntidal areas and below, under mangroves and in salt marshes along the mainland side of south Biscayne Bay.

Arthrospira neapolitana (Kützing) Drouet. Occasional as an epiphyte of large algae between Cape Florida and Angelfish Creek.

Porphyrosiphon kurzii (Zeller) Drouet. In crevices of limestone in the intertidal zone and among *Porites* coral around Soldier Key and the Bay side of Ragged Keys.

Porphyrosiphon miniatus (Hauck) Drouet. Forming delicate brown streamers on seagrass leaves and other algae and on old soft corals at Featherbed Shoals in the cleaner water of south Biscayne Bay.

Porphyrosiphon notarisii (Meneghini) Kützing. A more tolerant species found on intertidal muddy sand, on oyster bars, mangrove swamps and salt marshes.

Microcoleus lyngbyaceus (Vaucher) Gomont. The most abundant species of filamentous bluegree in the Bay, especially during summer and fall. It was a major constituent of the bluegreen mat that formed in that part of the Turkey Point area where seagrasses and other algae were killed by the warm water from the power plant. Many other forms of this species are present throughout the Bay, and it is occasional in the plankton.

Microcoleus vaginatus (Vaucher) Gomont. A brackish water species that grows in intertidal sand near creek mouths and on oyster shells, seawalls and pilings.

Family Nostocaceae

Calothrix crustacea Thuret. One of the most widely distributed bluegreens in Biscayne Bay. It is most conspicuous as a black band on sea walls high in the intertidal zone, but occurs at all depths on solid surfaces and as an epiphyte.

Scytonema hofmannii C. Agardh. Most conspicuous as a high intertidal turf-like band on limestone around Soldier Key and the other keys to the south. It also forms a felt-like layer under mangroves and on muddy sand flats in the southern part of the Bay.

Anabaena inaequalis Kützing. In intertidal sand of protected beaches in south Biscayne Bay and around Cape Florida

Anabaena torulosa (Carmichael) Lagerhaim. On muddy sand among the aerial roots of black mangroves, and on the sediment surface in salt marshes, mainland side of south Biscayne Bay.

Anabaena variabilis Kutzing. In the muddy sediments adhering to pilings and sea walls in canals connected to the Bay and in red mangrove swamps.

Nodularia harveyana (Thwaites) Thuret. In intertidal sand of protected beaches such as wading beach at Matheson Hammock.

Hormothamnion enteromorphoides Grunow. Forming fascicles of tufts of filaments on various objects in shallow water including sponges especially around Soldier Key and southward.

Mastigocoleus testarum Lagerheim. Penetrating the shells of barnacles and molluscs, calcareous annelid tubes, and test of Bryozoa throughout the Bay.

Brachytrichia quoyi (C. Agardh) Bornet and Flahault. Forming gelatinous hemispheres on rocks, pilings, sea walls in full salinity sea water in exposed places from Cape Florida to Angelfish Creek, often part of the "black zone" along the Scytonema hofmanni and Calothrix crustacea.

Class Rhodophyceae
Order Bangiales
Family Bangiaceae

Asterocystis ramosa (Thwaites) Gobi. Epiphytic on larger algae and seagrasses throughout the shallow parts of the Bay.

Goniotrichum alsidii (Zanardini) Howe. On larger algae throughout the shallow parts of the Bay.

Bangiopsis humphreyi (Collins) Hamel. Intertidal on solid surfaces on the flats around Cape Florida and southward in the Bay.

Erythrocladia subintegra Rosenvinge. On larger algae and seagrass leaves in virtually all shallow parts of the Bay.

Erythrotrichia carnea (Dillwyn) J. Agardh. On larger algae and seagrass leaves to a depth of one to two meters over most of the Bay.

Bangia fuscopurpurea (Dillwyn) Lyngbye. On sea wall,s pilings, rocks, forming a high intertidal band in winter and early spring.

Order Nemaliales
Family Acrochaetiaceae

Acrochaetium crassipes Børgesen. Epiphytic on seagrasses and larger algae in the shallow areas of the entire Bay.

Acrochaetium infestans Howe and Hoyt. On sertularian hydroids attached to leaves of *Thalassia* in Bear Cut and elsewhere.

Acrochaetium liagoriae Børgesen. On the red alga, *Liagora*, from shallow water around Soldier Key; spring.

Acrochaetium sargassi Børgesen. On *Padina*, *Dictyota*, *Dictyopteris* in shallow ater around Soldier Key.

Acrochaetium flexuosum Vickers. Though not recorded from Biscayne Bay, the writer feels that it is present there because of its distribution from New England to the West Indies in shallow water.

Acrochaetium leptonema (Rosenvinge) Børgesen. On the seagrass *Syringodium* in shallow water.

Acrochaetium sagraenum (Montagne) Bornet. On leaves of the seagrass, *Syringodium*.

Acrochaetium seriatum Børgesen. On various larger algae from Bear Cut and around Soldier Key.

Acrochaetium thuretii (Bornet) Collins and Hervey. On *Caulerpa prolifera* from Bear Cut.

Acrochaetium hypneae (Børgesen) Børgesen. On *Hypnea musciformis* at Matheson Hammock, winter.

Family Helminthocladiaceae

Liagora farinosa Lamouroux. In shallow water off Cape Florida, around Soldier Key, on Featherbed Shoals, attached to dead *Porites*, seagrass leaves, and other objects, winter and spring.

Liagora ceranoides Lamouroux. On limestone in shallow water at Bear Cut, Matheson Hammock, spring.

Liagora valida Harvey. On limestone and shells, flats south of Cape Florida and southward.

Trichogloeopsis pedicellata (Howe) Abbott and Doty. On limestone, Featherbed Shoals, spring.

Family Chaetangiaceae

Galaxaura cylindrica (Ellis and Solander) Lamouroux. On dead corals on the flats south of Cape Florida and around Soldier Key.

Galaxaura marginata (Ellis and Solander) Lamouroux. Adrift, beach west of the Cape Florida lighthouse.

Galaxaura obtusata (Ellis and Solander) Lamouroux. In shallow water, west side of Elliot's Key.

Galaxaura rugosa (Ellis and Solander) Lamouroux. On stones and shells, seagrass flats at Matheson Hammock, winter.

Galaxaura squalida Kjellman. On stones, shells, dead corals around Soldier Key, winter and spring.

Galaxaura subverticillata Kjellman. On stones and shells, seagrass flats near Matheson Hammock.

Order Gelidiales

Family Gelidiaceae

Galidiella acerosa (Forsskal) Feldmann and Hamel. Common from Cape Florida southward on limestone.

Gelidium pusillum (Stackhouse) LeJolis. Forming a short, wiry turf on old shells and corals, Bear Cut, west side of Biscayne Key, Matheson Hammock.

Gelidium crinale (Turner) Lamouroux. On stones and shells in shallow water, Bear Cut, Dinner Key, Cocoplum Beach, Matheson Hammock.

Pterocladia bartlettii Taylor. Around margins of rock reef near mouth of Bear Cut; on seawall of small boat harbor, southwest side of Biscayne Key.

Order Cryptonemiales
Family Squamariaceae

Hildenbrandia prototypus Narto. On rocks in the surf, west side of Elliott Key.

Peyssonelia rubra (Greville) J. Agardh. On stones, shells, dead corals around Soldier Key.

Family Corallinaceae

Melobesia membranacea (Esper) Lamouroux, Epiphitic on seagrass leaves and larger algae at Bear Cut, Matheson Hammock, and on most seagrass flats in the Bay.

Lithothamnium et al. Species of the subfamily Melobesieae in the genera *Lithothamnion*, *Lithophyllum*, *Porolithon*, and *Goniolithon* in the older literature are taxonomically difficult and require a specialist for proper placement. The writer feels that consultation with Dr. Walter Adey of the U. S. National Museum is required before species in Biscayne Bay can be listed. Taylor (1960) records 17 species of these genera for Florida, most of which are to be expected in Biscayne Bay.

Fosliella atlantica (Foslie) Taylor. On dead corals around Soldier Key.

Fosliella lejolisii (Rosanoff) Howe. On seagrasses throughout the Bay.

Fosliella farinosa (Lamouroux) Howe. On seagrasses and larger algae throughout the Bay.

Lithophyllum pustulatum (Lamouroux) Foslie. On lower stems of *Sargassum* and other large algae around Soldier Key and on Featherbed Shoals; occasional on seagrasses, Bear Cut.

Amphiroa fragilissima (L.) Lamouroux. Abundant among seagrasses in Bear Cut and at Matheson Hammock.

Amphiroa rigida Lamouroux. Common on seagrass beds from Cape Florida to Angelfish Creek.

Amphiroa tribulus (Ellis and Solander) Lamouroux. Occasional on limestone at Featherbed Shoals and along the west side of Elliott Key.

Corallina cubensis (Montagne) Kützing. Occasional on larger algae, especially *Digenia simplex* in Bear Cut and around Soldier Key.

Jania adhaerens Lamouroux. Common on stones and dead corals in Bear Cut, Matheson Hammock, Cocoplum Beach.

Jania capillacea Harvey. Common on larger algae and seagrass leaves in shallow water throughout the Bay.

Jania pumila Lamouroux. Occasional on *Sargassum* and *Turbinaria* around Soldier Key and along Elliott Key.

Jania rubens (L.) Lamouroux. On larger algae and limestone among seagrasses at Matheson Hammock and Bear Cut.

Family Grateloupiaceae

Grateloupia filicina (Wulfen) C. Agardh. On stones at edge of channel in Bear Cut. Among seagrasses at Matheson Hammock. Beside boat channel at Cocoplum Beach.

Cryptonemia crenulata crenulata J. Agardh. On core of dead soft coral, Bear Cut, the flats south of Cape Florida.

Cryptonemia luxurians (Mertens) J. Agardh. On core of dead soft coral that was loose on the bottom, west side of Elliott Key.

Order Gigartinales
Family Gracilariaceae

Gracilaria verrucosa (Hudson) Papenfuss. Occasional throughout the Bay especially Bear Cut, Matheson Hammock, along the Venetian Causeway.

Gracilaria armata (C. Agardh) J. Agardh. Among seagrasses, Matheson Hammock.

Gracilaria blodgettii Harvey. Occasional in Bear Cut and at Matheson Hammock.

Gracilaria cervicornis (Turner) J. Agardh. On limestone around Soldier Key and southward.

Gracilaria compressa (C. Agardh) Greville. Common in Bear Cut and at Matheson Hammock among seagrasses.

Gracilaria cylindrica Børgesen. Occasional on Featherbed Shoals and along the west side of Elliott Key.

Gracilaria debilis (Forsskal) Børgesen. Occasional in Bear Cut, at Matheson Hammock and around Soldier Key.

Gracilaria foliifera (Forsskal) Børgesen. The most widely distributed *Gracilaria* in Biscayne Bay.

Gracilariopsis sjoestedtii (Kylin) Dawson. Occasional in Bear Cut, at Matheson Hammock and elsewhere.

Family Solieriaceae

Soliera tenera (J. Agardh) Wynne and Taylor. Common throughout the Bay, especially during winter and spring. (Synonym: *Agardhiella tenera* (J. Agardh) Schmitz.)

Eucheuma isiforme (C. Agardh) J. Agardh. Occasional on Featherbed Shoals . Cheney (1975) regards *E. nudum* J. Agardh as a synonym.

Meristiella gelidium (J. Agardh) Cheney. Occasional on Featherbed Shoals and along the west side of Elliott Key. Cheney (1975) erected the genus *Meristiella* and transferred *Eucheuma gelidium* (J. Agardh) J. Agardh to it. He regards *E. acanthocladum* (Harvey) J. Agardh as a synonym.

Family Rhabdoniaceae

Catenella repens (Lightfoot) Batters. Intertidal on the roots of red mangroves throughout the Bay.

Family Hypneaceae

Hypnea cervicornis J. Agardh. Occasional in Bear Cut, at Cocoplum Beach, Matheson Hammock and southward.

Hypnea cornuta (Lamouroux J. Agardh. Occasional around Soldier Key and along the west shore of Elliott Key.

Hypnea musciformis (Wulfen) Lamouroux. One of the most abundant and widely distributed red algae in Biscayne Bay.

Hypnea spinalla (C, Agardh) Kützing. On rocks in surf or strong current just south of Cape Florida and southward.

Family Gigartinaceae

Gigartina acicularis (Wulfen) Lamouroux. On rocks in Bear Cut and around Soldier Key.

Order Rhodymeniales
Family Champiaceae

Champia parvula (C. Agardh) Harvey. On seagrasses, larger algae and rocks in Bear Cut, at Matheson Hammock and elsewhere.

Champia salicornoides Harvey. Occasional around Soldier Key and southward.

Lomentaria baileyana (Harvey) Farlow. Comon on seagrasses and other algae in Bear Cut and throughout the Bay during winter and spring.

Coelothrix irregularis (Harvey) Børgesen. Occasional in Bear Cut and around Soldier Key. The branches are usually remarkably irridescent.

Order Ceramiales
Family Ceramiaceae

Crouania attenuata (Bonnemaison) J. Agardh. Common seagrass leaves throughout the Bay.

Crouania pleonospora Taylor. On seagrass leaves off Cape Florida and southward.

Antithamnion antillarum Børgesen. On rocks along the west side of Elliott Key.

Wrangelia argus Montagne. On rocks in Bear Cut, Cape Florida, Matheson Hammock.

Wrangelia penicillata C. Agardh. Occasional on rocks in Bear Cut, at Cocoplum Beach, and Matheson Hammock.

Callithamnion cordatum Børgesen. On seagrasses in Bear Cut.

Callithamnion hallinae Collins. On seagrass leaves, other algae and rocks throughout most of Biscayne Bay.

Griffithsia barbata (Smith) C. Agardh. Although not known by the writer to have been collected in Biscayne Bay, it is believed to occur in the southern part of the Bay.

Griffithsia globulifera Harvey. On seagrass leaves from flats off Southwest Point, Biscayne Key.

Griffithsia tenuis C. Agardh. On seagrass leaves from flats off Southwest Point, Biscayne Key.

Spermothamnion investiens (Crouan) Vickers. On club-spine urchins from Featherbed Shoals and the west shore of Elliott Key.

Tiffaniella gorgoneum (Montagne) Doty and Menez. On *Codium* that was loose and drifting, Matheson Hammock.

Ceramium byssoideum Harvey. Epiphytic on seagrass leaves and larger algae. Probably the most common *Ceramium* in the Bay.

Ceramium corniculatum Montagne. On stones and larger algae at Bear Cut and Matheson Hammock.

Ceramium fastigiatum (Roth) Harvey. On seagrass leaves and larger algae throughout the Bay.

Ceramium leptozonum Howe. A loose, spherical plant was found in Bear Cut.

Ceramium nitens (C. Agardh) J. Agardh. Common on shells, large algae, and seagrass leaves throughout the Bay.

Ceramium strictum (Kützing) Harvey. Occasional on stones and shells in Bear Cut and elsewhere during winter and spring.

Ceramium subtile J. Agardh. On large algae at Cocoplum Beach and Matheson Hammock.

Centroceras clavulatum (C. Agardh) Montagne. One of the most widely distributed and abundant algae in Biscayne Bay, occurring in the intertidal zone and below.

Spyridia aculeata (Schimper) Kützing. Occasional around Soldier Key and to the south.

Spyridia clavata Kutzing. Occasional at Matheson Hammock and on Featherbed Shoals.

Soyridia filamentosa (Wulfen) Harvey. One of the most common of the red algae throughout the Bay.

Family Delesseriaceae

Caloglossa leprieurii (Montagne) J. Agardh. On prop roots of red mangroves in the intertidal zone throughout the Bay, and also on sea walls and other structures.

Hypoglossum tenuifolium (Harvey) J. Agardh. On seagrass leaves and other substrata, Bear Cut, Matheson Hammock, and other areas, fall and winter.

Hypoglossum involvens (Harvey) J. Agardh. On *Thalassia* leaves, Cocoplum Beach to Matheson Hammock and southwards; ephemeral.

Cottoniella filamentosa (Howe) Børgesen. This species was once found in abundance around Cape Florida but has not been seen in the Bay since, apparently. It has never been seen attached and reproductive structures are unknown. Although reported as an epiphyte, it merely entangles other algae.

Family Dasyaceae

Dasya collinsiana Howe. On seagrass leaves and other substrata, Bear Cut.

Dasya corymbifera J. Agardh. On seagrass leaves and other substrata, Bear Cut, winter.

Dasya harveyi Ashmead. Matheson Hammock, winter.

Dasya pedicellata (C. Agardh) C. Agardh. Common throughout the Bay on stones, seagrass leaves during winter and spring.

Dasya ramosissima Harvey. Occasional on limestone around Soldier Key and southward.

Dasya rigidula (Kützing) Ardissone. Occasional on stones around Soldier Key and southward.

Heterosiphonia gibbesii (Harvey) Falkenberg. Common on rocks in Bear Cut, at Cocoplum Beach, Matheson Hammock and elsewhere.

Heterosiphonia wurdemanni (Bailey *ex* Harvey) Falkenberg. On stones, shells, seagrass leaves, Bear Cut, Matheson Hammock, and at many other areas.

Family Rhodomelaceae

Falkenbergia hillebrandii (Bornet) Falkenberg. Common in Bear Cut on other algae and seagrass leaves, and at many other areas.

Polysiphonia binneyi Harvey. Common on seagrass leaves in the southern part of the Bay; west side of Elliott Key.

Polysiphonia echinata Harvey. Occasional on seagrass leaves and other substrata in the southern part of the Bay.

Polysiphonia exilis Harvey. Abundant in the intertidal zone on a rock ledge near the mouth of Bear Cut, Biscayne Key side.

Polysiphonia gogoniae Harvey. Probably the most common *Polysiphonia* in the Bay on seagrass leaves.

Polysiphonia hapalacantha Harvey. Occasional on stones around Soldier Key.

Polysiphonia opaca (C. Agardh) Moris and De Notaris. On rocks along the west side of Elliott Key and on Featherbed Shoals.

Polysiphonia howei Hollenberg. Intertidal on rocks, sea walls, mangrove roots throughout the Bay.

Polysiphonia hemisphaerica Areschoug. On stones and shells, Cocoplum Beach and Matheson Hammock. This species has in the past been erroneously referred to P. *denudata* Dillwyn) Kutzing in Florida.

Polysiphonia ramentacea Harvey. On seagrass leaves throughout the Bay.

Polysiphonia havenensia Montagne. On seagrass leaves and other substrata throughout the Bay.

Bryocladia cuspidata (J. Agardh) De Toni. On rocks and mangrove roots, low intertidal and below, Bear Cut, Matheson Hammock and many other areas.

Bryocladia thyrsigera (J. Agardh) Schmitz. On rocks near the mouth of Bear Cut, Biscayne Key side, low intertidal and below.

Bryothamnion triquetrum (Gmelin) Howe. On Featherbed Shoals and southward, though often found adrift in Bear Cut and elsewhere in the Bay.

Digenia simplex (Wulfen C. Agardh. On stones and shells among seagrasses and along channel margins throughout the Bay.

Micropeuce mucronata (Harvey) Kylin. Occasional on prop roots of red mangroves where well-shaded and an area of clean, high-salinity water, as at Ragged Keys.

Lophocladia trichoclados (Mertens) Schmitz. On leaves of *Thalassia* at Cocoplum Beach, January 14, 1946, apparently the only record from Biscayne Bay.

Wrightiella blodgettii (Harvey) Schmitz. Around Soldier Key and Ragged Keys, and probably southward.

Murrayella periclados (C. Agardh) Schmitz. A member of the community growing upon prop roots of red mangroves, especially in the shade. Common in Bear Cut.

Bostrichia binderi Harvey. Forming a high, intertidal mat on rocks in exposed situations as at Soldier Key, Ragged Keys, and near the mouth of Bear Cut, Biscayne Key side.

Bostrichia moritziana (Sonder) J. Agardh. On mangrove roots along the wading beach at Matheson Hammock.

Bostrichia montagnei Harvey. On red mangrove prop roots south of Matheson Hammock and around the mouth of Snapper Creek.

Bostrichia radicans Montagne. On the rock wall of canals connected to Biscayne Bay in the intertidal zone.

Bostrichia scorpioides (Gmelin) Montagne. On red mangrove prop roots and black mangrove aerial roots Cocoplum Beach and southward.

Bostrichia tenella (Vahl) J. Agardh. On seawalls, woodwork, red mangrove prop roots in the intertidal zone, Bear Cut and elsewhere.

Herposiphonia pecten-veneris (Harvey) Falkenberg. On seagrass leaves and stones in shallow water in most areas of the Bay.

Herposiphonia secunda (C. Agardh) Ambronn. Common on seagrass leaves throughout the Bay.

Herposiphonia tenella (C. Agardh) Ambronn. On rocks low intertidal and below in all parts of the Bay.

Lophosiphonia saccorhiza Collins and Hervey. On *Codium* adrift in Bear Cut.

Chondria atropurpurea Harvey. At one time, common at the foot of S.W. 25th Road, but this area has since been dredged.

Chondria baileyana (Montagne) Harvey. On solid substrata and seagrass leaves throughout most of the Bay, winter and spring.

Chondria collinsiana Howe. On seagrass leaves, Bear Cut, Matheson Hammock.

Chondria curvilineata Collins and Hervey. On seagrass leaves, Bear Cut, fall and winter, perhaps the year around.

Chondria dasyphylla (Woodward) C. Agardh. On stones and shells off Southwest Point, Biscayne Key, December.

Chondria floridana (Collins) Howe. Featherbed Shoals.

Chondria leptacremon (Melvill) De Toni. On larger algae and stones, Matheson Hammock.

Chondria polyrhiza Collins and Hervey. On seagrass leaves, Bear Cut, Matheson Hammock.

Chondria tenuissima (Goodenough and Woodward) C. Agardh. Occasional on rocks in Bear Cut and at Matheson Hammock.

Acanthophora spicifera (Vahl) Børgesen. One of the most abundant of the larger red algae in the Bay and widely distributed.

Laurencia corallopsis (Montagne) Howe. Occasional on Featherbed Shoals.

Laurencia gemmifera Harvey. Occasional around Soldier Key and Ragged Keys.

Laurencia intricata Lamouroux. Common in Bear Cut, at Matheson Hammock and many other Bay areas.

Laurencia obtusa (Hudson) Lamouroux. Common in Bear Cut, at Matheson Hammock, and in most shallow water areas of the Bay.

Laurencia papillosa (Forsskal) Greville. Common on rocks in Bear Cut, at Matheson Hammock and elsewhere.

Laurencia poitei (Lamouroux) Howe. The most common and widely distributed Laurencia in Biscayne Bay.

Laurencia microcladia Kutzing. Occasional around Ragged Keys and on Featherbed Shoals.

Phylum Phaeophat
Class Phaeophyceae
Order Ectocarpales
Family Ectocarpaceae

Acinetospora crinita (Carmichael) Kormann. On rocks, dead corals, seagrass leaves and large algae around Soldier Key and southward. Probably also in Bear Cut.

Bachelotia antillarum (Grunow) Gerloff. On stones, shells, and probably seagrass leaves in shallow water, Bear Cut, Matheson Hammock, and many other areas of the Bay.

Ectocarpus elachisteaeformis Heydrich. On seagrass leaves and other algae in Bear Cut, and also the western shore of the Bay at Coconut Grove and southward.

Ectocarpus variabilis Vickers. On seagrass leaves and larger algae in Bear Cut, and probably widely distributed in the Bay.

Giffordia conifera (Børgesen) Taylor. On stones and shells, Bear Cut, Matheson Hammock, and probably generally distributed in the Bay.

Giffordia rallsiae (Vickers) Taylor. Common on leaves of seagrasses throughout the Bay.

Giffordia mitchelliae (Harvey) Hamel. On seagrass leaves, stones, shells, seawalls, and woodwork throughout the Bay the year around.

Giffordia indica (Sonder) Papenfuss and Chihara. On seagrass leaves throughout the Bay during winter and spring.

Phaeostroma pusillum Howe and Hoyt. On a sheet of plastic from a sea water pond behind Agassiz Building, Rosenstiel School, University of Miami, Rickenbacker Causeway, December, 1961. Probably present in southern Biscayne Bay as a microscopic epiphyte on various algae.

Order Sphacelariales
Family Sphacelariaceae

Sphacelaria furcigera Kutzing. On stones, shells, and on the basal parts of larger algae such as *Sargassum* in Bear Cut, at Matheson Hammock and other areas of the Bay.

Sphacelaria tribuloides Meneghini. Distribution in the Bay apparently the same as *S. furcigera*.

Order Dictyotales
Family Dictyotaceae

Dictyota bartayresii Lamouroux. Forming dense cushion-like plants on seagrass flats and among *Porites* corals on the shallow flats from Cape Florida southward.

Dicyota cervicornis Kutzing. On stones and shells in somewhat protected areas in Bear Cut and on the west side of Soldier Key, Ragged Keys, Elliott Key.

Dictyota ciliolata Kutzing. Occasional on rocks in Bear Cut, around Southwest Point of Biscayne Key, and in protected areas southward.

Dictyota dentata Lamouroux. Probably on Featherbed Shoals and along the west side of Elliott Key.

Dictyota dichotoma (Hudson) Lamouroux. Widely distributed in shallow water throughout the Bay.

Dictyota divaricata Lamouroux. Common on rocks and shells in Bear Cut and from Rickenbacker Causeway along the west shore southward.

Dictyota indica Sonder. In Bear Cut, at Matheson Hammock and many other stations in the Bay.

Dilophus guineensis (Kutzing) J. Agardh. Around Ragged Keys, on Featherbed Shoals, and along the west side of Elliott Key.

Dilophus alternans J. Agardh. Occasional in Bear Cut, but more common round Soldier Key and southwards.

Dictyopteris delicatula Lamouroux. In Bear Cut and at Matheson Hammock and southward.

Dictyopteris plagiogramma (Montagne) Vickers. Though not recorded, this plant probably occurs on Featherbed Shoals and southward.

Padina gymnospora (Kutzing) Vickers. In Bear Cut and around Soldier Key and southward.

Padina sanctae-crucis Børgesen. Common in shallow water in most areas of the Bay.

Padina vickersiae Hoyt. In Bear Cut and along the west shore of the Bay from Rickenbacker Causeway south.

Lobophora viriegata (Lamouroux) Womersley. Common in Bear Cut on stones and shells in shallow water and at many areas of the Bay.

Stypopodium zonale (Lamouroux) Papenfuss. Though not recorded from the Bay, the writer feels that this species occurs at Featherbed Shoals.

Order Chordariales
Family Myrionemataceae

Myrionema strangulans Greville. Although not known in Biscayne Bay, its known distribution is such that it is highly likely that it occurs in the Bay. It is a microscopic epiphyte.

Family Chordariaceae

Cladosiphon occidentalis Kylin. Abundant throughout the Bay on leaves of *Thalassia* during winter and spring.

Family Myriotrichiaceae
Order Dictyosiphonales
Family Striariaceae

Stictyosiphon subsimplex Holden. Common in Biscayne Bay as an epiphyte of the leaves of *Diplanthera wrightii* and occasionally on other seagrasses, winter and spring only.

Myriotrichia subcorymbosa (Holden) Blomquist. Common throughout Biscayne Bay on the leaves of *Diplanthera* and occasionally on other seagrasses. This species and the one above have been shown by culture experiments to be stages in the life cycle of the same plant (Fiore 1968).

Family Punctariaceae

Colpomenia sinuosa (Roth) Derbes and Solier. On rocks around Soldier Key, Ragged Keys, and southward, spring.

Hydroclathrus clathratus (Bory) Howe. Though apparently not recorded for Biscayne Bay, the writer believes that it may occur on Featherbed Shoals or around Ragged Keys.

Rosenvingia floridana (Taylor) Taylor. Occasional in Biscayne Bay during spring at Coconunt Grove southward.

Rosenvingia intricata (J. Agardh) Børgesen. Loose plants have been found at Matheson Hammock in spring, and attached to seagrass leaves off Southwest Point, Biscayne Bay, winter.

Rosenvingia orientalis (J. Agardh) Børgesen. Although the writer does not know of a collection from the Bay, it probably occurs there during winter and spring.

Order Fucales
Family Sargassaceae

Sargassum filipendula C. Agardh. Occasional in Bear Cut.

Sargassum hystrix J. Agardh. Adrift in the Bay but not observed attached (the variety *buxifolium* [Chauvin] J. Agardh).

Sargassum polyceratium Montagne. Occasional in Bear Cut and around Soldier Key.

Sargassum pteropleuron Grunow. Common on Featherbed Shoals and along the west side of Elliott Key.

Sargassum vulgare C. Agardh. Occasional on rocks around Solder Key.

Sargassum fluitans Børgesen.

Sargassum natans (L.) Meyen. These two strictly pelagic species are often abundant floating in Biscayne Bay.

Chlorophyceae
Order Ulotrichales
Family Ulotrichaceae

Phaeophila dendroides (Crouan) Batters. A common epiphyte on larger algae and seagrasses throughout the Bay.

Entocladia viridis Reinke. A common microscopic epiphyte growing within the surface polysaccharide of larger algae throughout the Bay.

Entocladia vagans (Børgesen Taylor. Though not recorded for the Bay, apparently, its known distribution is such that the writer believes it to occur in Biscayne Bay.

Protoderma marinum Reinke. Forming a high intertidal light green band on seawalls and pilings along the Miami waterfront and in canals.

Ulvella lens Crouan. A common microscopic epiphyte on larger algae throughout the Bay.

Family Chaetopeltidaceae

Diplochaeta solitaria Collins. A common microscopic epiphyte on larger algae and seagrasses in the high salinity areas of the Bay.

Family Gomontiaceae

Gomontia polyrhiza (Lagerheim) Bornet and Flahault. Penetrating old shells and other forms of limestone throughout the Bay and sometimes growing within the tissue of seagrass leaves.

Family Ulvaceae

Monostroma oxyspermum (Kutzing) Doty. On stones, shells, mangrove roots in the intertidal zone in protected areas in Bear Cut, Matheson Hammock and elsewhere during winter and spring.

Enteromorpha chaetomorphoides Børgesen. Common in the Bay loose and drifting or entangled in larger algae, fall and winter.

Enteromorpha clathrata (Roth) J. Agardh. Common during the cooler months throughout the Bay as an epiphyte and on solid surfaces; present in summer in stunted form.

Enteromorpha compressa (L.) Greville. In Bear Cut and around Soldier Key, winter and early spring, on mangrove roots, woodwork, rocks.

Enteromorpha erecta (Lyngbye) J. Agardh. On rocks around Soldier Key and Ragged Keys, winter and early spring.

Enteromorpha flexuosa (Wulfen) J. Agardh. Common in the intertidal zone and below throughout the Bay; the most conspicuous *Enteromorpha* during the warmer months.

Enteromorpha intestinalis (L.) Link. Appearing throughout the Bay in November or December with a peak abundance in February or March and disappearing in spring.

Entermorpha lingulata J. Agardh. Abundant on seagrass leaves and other surfaces throughout the Bay the year around but best developed during the cooler months.

Entermorpha linza (L.) J. Agardh. Appearing annually in many parts of the Bay in winter and disappearing in spring.

Enteromorpha minima Nageli. Around the mouth of Snapper Creek and other brackish water areas forming an intertidal band, winter and spring.

Enteromorpha plumosa Kutzing. On seagrasses and algae, stones and shells, throughout the Bay, principally during winter and spring.

Enteromorpha prolifera (Muller) J. Agardh. Common throughout the Bay, especially during cooler months.

Enteromorpha salina Kutzing. On red mangrove prop roots, Matheson Hammock, and probably other mangrove areas.

Ulva lactuca L. Common throughout the lower salinity areas of the Bay and the areas affected by sewage effluent.

Ulva fasciata Delile. On rocks exposed to the surf, Bear Cut, Soldier Key, jetties in the Government Cut, and elsewhere.

Order Cladophorales
Family Cladophoraceae

Chaetomorpha brachygona Harvey. Common in shallow water along mangrove shorelines such as Matheson Hammock.

Chaetomorpha clavata (C. Agardh) Kutzing. On rocks in the surf or in exposed situations, Bear Cut, Soldier Key, Ragged Keys.

Chaetomorpha gracilis Kutzing. Among the aerial roots of black and red mangroves and in other protected places.

Chaetomorpha linum (Muller) Kützing. Forming loose, entangled masses in seagrass beds and other areas in shallow water, Matheson Hammock, around Chicken Key and elsewhere.

Chaetomorpha minima Collins and Harvey. A minute epiphyte on larger algae and seagrasses, Bear Cut, Matheson Hammock, and elsewhere.

Rhizoclonium hookeri Kützing. Among aerial roots of black and red mangroves, Matheson Hammock and around the mouth of Snapper Creek.

Rhizoclonium kerneri Stockmayer. On aerial roots of red and black mangroves, oyster bars, intertidal muddy sand, Bear Cut, Matheson Hammock and southward. Material that would fit *R. kochianum* Kützing with shorter cells is included here as it seems to be a variety.

Rhizoclonium riparium (Roth) Harvey. On seagrass leaves, larger algae, mangrove roots, and loose on the substrate under mangroves and in brackish water areas of canals and stream mouths.

Cladophora albida (Hudson) Kützing. Occasional in shallow water along the beach south of Matheson Hammock. This material agrees with *C. glaucescens* (Griffiths) Harvey, a synonym, in part.

Cladophora crystallina (Roth) Kützing. On intertidal rocks around Soldier Key and southward.

Cladophora delicatula Montagne. On seagrass leaves, shells and stones in protected areas throughout the Bay.

Cladophora fascicularis (Mertens) Kützing. On seagrass leaves in more or less exposed areas and intidal currents as along the edge of the channel in Bear Cut.

Cladophora flexuosa (Griffiths) Harvey. Oe moderately exposed rocks in Bear Cut and around Soldier Key.

Cladophora fuliginosa Kützing. On rocks in exposed places, Bear Cut and Soldier Key. This plant always has a fungus growing within the outer polysaccharide layer of the cell walls.

Cladophora gracilis (Griffiths) Kützing. On stones and shells in shallow water, Bear Cut.

Cladophora howei Collins. Forming dense cushions or mats on rocks in the mouth of Snapper Creek.

Cladophora sericea (Hudson) Kützing. Material which he referred to this species was collected in Biscayne Bay by Dr. C. van den Hoek, but the writer is not clear to its synonymy.

Order Siphonocladiales
Family Dasycladaceae

Batophora oerstedi J. Agardh. On shells, stones, and sticks in shallow water throughout Biscayne Bay.

Dasycladus vermicularis (Scopoli) Krasser. Common in more or less exposed shallow areas on stones, rocks, shells in Bear Cut, around Soldier Key and southward.

Neomeris annulata Dickie. Occasional on dead corals and rocks in shallow water in exposed places such as Soldier Key, Ragged Keys, near the mouth of Bear Cut.

Acetabularia antillana (Solms-Laubach) Eiseman. On old shells and dead corals in more or less open areas of shallow water in Bear Cut and southward. Eiseman (1970) transferred Chalmasia antillana Solms-Laubach to this genus and indicated that A. farlowii Solms-Laubach) is a form of this species.

Acetabularia crenulata Lamouroux. Common in the Bay along sheltered beaches on shells and stones in shallow water.

Acetabularia pusilla (Howe) Collins. On stones and shells usually under other algae, Featherbed Shoals.

Acetabularia shenckii Mobius. On shells and stones in shallow water in the same areas as A. crenulata.

Family Valoniaceae

Valonia aegagropila C. Agardh. Around Soldier Key and Ragged Keys.

Valonia macrophysa Kutzing. On dead Porites corals, Bear Cut and southward.

Valonia ocellata Howe. On rocky bottom areas of Bear Cut and around Soldier Key.

Valonia utricularis C. Agardh. On rocky-bottom areas of Bear Cut and southward.

Valonia ventricosa J. Agardh. On or among dead Porites corals around Soldier Key and southward.

Ernodesmis verticillata (Kutzing) Børgesen. Along the west side of Elliott Key, winter.

Siphonocladus rigidus Howe. West side of Elliott Key and Featherbed Shoals.

Dictyosphaeria cavernosa (Forsskal) Børgesen. Widely distributed in the Bay on seagrass flats and over rock bottoms in shallow water.

Cladophoropsis macromeres Taylor. On rock bottoms in the more exposed areas of the Bay including Bear Cut, around Soldier Key and southward.

Cladophoropsis membranacea (C. Agardh) Børgesen. Widely distributed in the Bay on seagrass flats and under mangroves.

Anadyomene stellata (Wulfen) C. Agardh. Widely distributed in the Bay on seagrass flats, especially at Matheson Hammock and southward.

Order Siphonales
Family Derbesiaceae

Derbesia vaucheriaeformis (Harvey) J. Agardh. On stones and shells in shallow water around Soldier Key, and probably Bear Cut.

Family Bryopsidaceae

Bryopsis duchassaingii J. Agardh. Featherbed Shoals, Bear Cut (winter).

Bryopsis hypnoides Lamouroux. On stones, red mangrove prop roots, in Bear Cut, at Matheson Hammock and many other areas of the Bay.

Bryopsis pennata Lamouroux. On pilings, sea walls, and other surfaces in Bear Cut, on the seagrass flats off Cape Florida and southward.

Bryopsis plumosa (Hudson) C. Agardh. This species has been reported for Biscayne Bay by Isham (1952) and others, but the writer doubts that it occurs as far south as Florida. Plants referred to this species from Florida appear to be B. pennata.

Family Caulerpaceae

Caulerpa ashmeadii Harvey. On seagrass beds at depth of 0.5 m at low tide or deeper; not common.

Caulerpa cupressoides (West) C. Agardh. On seagrass flats and on sandy bottoms in the outer part of Bear Cut, at Matheson Hammock, Soldier Key, and elsewhere.

Caulerpa fastigiata Montagne. Forming a dense turf-like growth in muddy sand or mud in very protected intertidal areas, as at Matheson Hammock.

Caulerpa lanuginosa J. Agardh. On sandy or rocky-sandy bottoms in relatively exposed situations as around Ragged Keys.

Caulerpa mexicana (Sonder) J. Agardh. On sandy bottoms, sometimes on rocks, and also on seagrass beds. The numerous forms or varieties occur throughout the Bay.

Caulerpa paspaloides (Bory) Greville. Sommon on the seagrass flats off Matheson Hammock but also present in Bear Cut and off Southwest Point, Biscayne Key.

Caulerpa prolifera (Forsskal) Lamouroux. Common in shallow water throughout Biscayne Bay.

Caulerpa racemosa (Forsskal) J. Agardh. Common and widely distributed in the Bay; well represented in Bear Cut. Taylor (1960) lists 11 forms and varieties.

Caulerpa sertularioides (Gmelin) Howe. Common throughout the Bay, especially on seagrass flats.

Caulerpa verticillata J. Agardh. This species colonizes the tops of rounded rocks, forming a dense, soft mat that tends to accumulate fine sediments. Throughout the Bay except in brackish or dirty water.

Caulerpa vickersiae Børgesen. Usually on rocks, this tiny species is difficult to find. Featherbed Shoals.

Boodleopsis pusilla (Collins) Taylor, Joly, and Bernatowicz. Forming a short, fine green turf under mangroves, Matheson Hammock and southward.

Avrainvillea nigricans Decaisne. Occasional on seagrass beds and sandy bottoms in Bear Cut, around Soldier Key and southward.

Avrainvillea levis Howe. Though there may not be records for the Bay, this species has been found around Key Largo and probably occurs in south Biscayne Bay.

Udotea flabellum (Ellis and Solander) Lamouroux. Common in the Bay on seagrass flats and sandy bottom.

Udotea conglutinata (Ellis and Solander) Lamouroux. From one end of the Bay to the other, ad the above species.

Udotea spinulosa Howe. Occasional on sandy bottom in Bear Cut, around Soldier Key and southward on Featherbed Shoals.

Penicillus capitatus Lamarck. Abundant on sandy bottom in shallow water the entire length of the Bay.

Penicillus dumetosus (Lamouroux) Blainville. Common on sandy bottom in Bear Cut, along Matheson Hammock, and southward.

Penicillus pyriformis A. and E.S. Gepp. Occasional on sandy bottom in Bear Cut, around Soldier Key and southward.

Penicillus lamourouxii Decaisne. Distribution similar to the above species.

Rhipocephalus phoenix (Ellis and Solander) Kützing. Occasional in Bear Cut and more common around Soldier Key and southward.

Rhipocephalus oblongus (Decaisne) Kutzing. Less common than the above. Occasional on Featherbed Shoals and southward.

Halimeda discoidea Decaisne. A dense stand occurs around the rock ledge at the mouth of Bear Cut, Biscayne Key side. Widely distributed in the Bay.

Halimeda incrassata (Ellis) Lamouroux. Common to abundant on seagrass beds throughout the Bay.

Halimeda monile (Ellis and Solander) Lamouroux. Occasional in Bear Cut; more common on Featherbed Shoals.

Halimeda scabra Howe. Common in seagrass beds in Bear Cut and many other areas of the Bay as at Matheson Hammock.

Halimeda simulans Howe. On sandy bottom and in seagrass beds, southern part of the Bay.

Halimeda tuna (Ellis and Solander) Lamouroux. Occasional in Bear Cut, on Featherbed Shoals, and on seagrass flats throughout the Bay but not abundant.

Codium isthmocladum Vickers. Found adrift in the Bay but the writer does not know of an attached record.

Codium decorticatum (Woodward) Howe. Occasional in Bear Cut attached and found adrift along the waterfront at Coconut Grove.

Codium taylori Silva. Occasional on rocks near the mouth of Bear Cut, perhaps seasonally.

Family Phyllosiphonaceae

Ostreobium quekettii Bornet and Flahault. Boring into shells, corals, and other forms of limestone in shallow water.

Ostreobium constrictum Lukas. Although not reported for Biscayne Bay, this species is reported (Lukas 1974) as so common in corals from the Florida Keys that it is surely in Biscayne Bay in similar abundance.

Phylum Xanthophyta
Class Xanthophyceae
Order Heterosiphonales
Family Vaucheriaceae

The genus Vaucheria, though common in Biscayne Bay, is poorly known primarily because reproductive material is essential for determination and these plants usually reproduce for a short period of time each year, usually winter or spring, so that collections must be made at the proper time. Their period of reproduction seems to be much shorter in tropical areas than in temperate seas. At least three species are known to occur in Biscayne Bay but only two have been determined with reasonable confidence.

Vaucherie dichotoma (L.) C. Agardh. Along the mangrove fringe of muddy-sand bottoms, west side of Biscayne Key and occasionally in Bear Cut.

Vaucheria bermudensis Taylor and Bernatowicz. On a fine sandy bottom along a mangrove fringe at the foot of S.W. 25th Road, an area that has since been dredged and a sea wall added. The species is probably still to be found during winter and spring in the general area.

Phylum Cryptophyta
Class Cryptophyceae
Order and Family Uncertain

Chrysophaeum tayloria Lewis and Bryan. Forming delicate tufts of yellow-brown streamers on rocks and other algae in shallow water off Southwest Point, Biscayne Key, spring.

Phylum Chrysophyta
Class Crysophyceae
Family Phaeothamniaceae

Chrysonephos lewisii (Taylor) Taylor. Though apparently not recorded for the Bay, the writer believes he has seen this species on stones and seagrasses off Southwest Point, Biscayne Bay.

FUTURE RESEARCH

As clean-up of Biscayne Bay progresses, there are a number of areas of research in benthic algae that should receive consideration, especially in ecology and related problems. A creditable beginning in this kind of research has been made in the southern part of the Bay by Thorhaug (1965, 1974, 1976), Josselyn (1975), Bach (1975), and others.

Ecological work on the algae is especially needed between the causeways, around the Miami River mouth, along the downtown area, and in the northern part of the Bay.

Research is needed on the extent of grazing on benthic algae by invertebrates and fishes throughout the Bay in order to understand its effect on distribution and abundance of various species and the importance of benthic algae in various food chains. Algal grazing is not limited to the larger invertebrates. The writer has seen large plants of Gracilaria, Hypnea, and Agardhiella completely consumed in a few days by amphipods less than one cm long. These amphipods in turn are eaten by small fishes so that even for carnivorous fishes, benthic algae can be put one step away in the food chain. However, we know very little about food chains or "food webs" in the Bay.

The seasonal behavior of benthic algae in the Bay is also poorly known. We do know that there is a winter-spring flora that appears in November and disappears in April or May, but we don't know all the species involved or how most of them survive during the unfavorable season. We know little or nothing about seasonal reproductive periods, the effect of season on growth rate, or the time of settlement and germination. It is apparent that few species behave in the same way the year around.

The life histories of even the most common species are not understood. Some of these life histories are profoundly affected by environmental conditions, including water temperature, and hence season, but we do not understand any of the details. We should culture these algae in apparatus that provides combinations of light and temperature over their full range of tolerance as well as under various daylength regimes and nutrient concentrations.

Intertidal zonation apparently has never been studied in Biscayne Bay. The flora of the breakwaters bordering the harbor entrance has not been studied.

We know nothing about the extension of the Bay algal flora into the many canals or waterways that enter the bay in which there may be a salinity gradient or gradients of other environmental factors.

There are scores of species in the Bay that produce an abundance of cell wall polysaccharides about which we know nothing. There are many species that produce various physiologically active compounds of potential value and of environmental significance. Some of these compounds inhibit grazers, including crustacea and fishes. There is evidence that some of these compounds can be absorbed by land plants and that they then inhibit insect, fungus, and nematode diseases. There are many benthic algae in the Bay of potential economic importance, and while they may not be naturally abundant, any of them can be grown in culture on a large scale.

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	Reference	Blue-greens	Reds	Browns	Greens	Total
Biscayne Bay	This paper	36	152	45	98	331
State of Florida	Taylor 1928	18	213	51	98	380
State of Florida	Taylor 1960		223	57	115	395
Jamaica	Chapman 1963, 63	18	183	47	124	372
Virgin Islands	Børgesen 1913-20		192	45	90	327
Tampa Bay area	Dawes 1967		111	40	66	217
Fla. Gulf coast	Dawes 1974	27	135	42	85	289
Gulf of Mexico	Earle 1972	26	325	84	175	610
Alacran Reef	Kim 1964	20	76	29	69	194

Table 1. A comparison of the benthic algal flora of Biscayne Bay with certain other areas or regions of the southwestern North Atlantic. In all cases, the number of bluegreens has been changed to conform to the taxonomy of Drouet's monographic revisions resulting in a reduction in number. Species of Vaucheria have been include with the green algae, and yellow-brown species have been included with the browns. All figures are species, varieties and forms have not been included.

THE VASCULAR PLANTS OF BISCAYNE BAY

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ABSTRACT

The major vascular marine plants found in Biscayne Bay are *Thalassia testudinum* (turtle grass) a dominant species in many areas, *Halodule wrightii* (Cuban shoal grass), and *Syringodium filiforme* (manatee grass). The function of these plants is 1) food source 2) shelter and protection, especially for nursery forms and laying of eggs 3) sediment stabilizer, which helps preserve water clarity and prevent sediment erosion and 4) an important chemical sink in terms of cycling of elements. The distributional patterns in areas not heavily impacted by man are as follows: intertidally, a band of *Halodule*; from sublittoral, a dense band of *Thalassia* interspersed with the other two grasses: this thins into a green algal and sand environment toward mid-Bay. The northern part of the Bay has been highly disrupted and the normal *Thalassia* community does not appear above Dodge Island. Seasonal fluctuation of abundance and productivity of *Thalassia* and *Halodule* is marked. Yearly production of blade material of *Thalassia* is from 36.5 to 1340.5 g dry wt/m^2/yr as an average for various types of *Thalassia* beds. Abundance of blades per square meter appears the major factor in production rates. In terms of chemical cycling iron, cobalt, zinc, copper, cadium and lead are in high concentration. The sediment grass interaction is complex and currently being investigated by Wanless (this volume). Sediment is generated by the *Thalassia* community and removal of *Thalassia* appears to be associated with major modification of sediments. Successional patterns of the *Thalassia* community differ as to bottom type and are discussed. Rate of natural revegetation of *Thalassia* in areas impacted by man is slow. North Biscayne Bay has not revegetated from the extensive modifications begun about 1910. Restoration of *Thalassia* on a large scale is now possible. A revegetation effort in the southwest shoreline shows high success rate four years after reseeding. Areas in north Biscayne Bay were more difficult to revegetate, because of tidal current, wave action and turbidity. Certain areas of the north Bay showed excellent restoration potential. A cost analysis is now underway.

The sea grass community is relatively sensitive to pollution. Some types of pollutants have been studies intensively while there is almost nothing known about the effect of others on seagrasses. The effect of pollutants on seagrasses often causes mortality with the effect that the whole community dependent on the seagrasses disappears from that location. Dredge and fill activities have had the greatest impact on seagrasses in Biscayne Bay; the most extreme example being north Biscayne Bay, where the dominant grass, *Thalassia* is absent. Heated effluents have denuded certain areas of *Thalassia* at the Cutler Ridge and Turkey Point effluent canals. However, revegetation efforts (after heated effluents were cooled offstream) have alleviated much of the problem at Turkey Point. Other pollutants include oil, heavy metals, sewage, pesticides, and radioactivity about which little is known on seagrasses.

In summary, the major submerged plant of Biscayne Bay is the seagrass, *Thalassia testudinum*. Associated with it is a rich animal community. This system is vulnerable to man's activity and management of this resource is necessary.

INTRODUCTION

The submerged waters of Biscayne Bay generally are dominated by the seagrass Thalassia testudinum (Konig) commonly called turtle grass. Three other species of vascular plants occur with regularity, Syringodium filiformis (previously named Cymodocea), or manatee grass, Halodule wrightii (previously named Diplantherea wrightii), or Cuban shoal weed, and Halophila baillonis. The taxonomy, general aspects of biology, has been discussed by den hartog (1972) and Phillips (1960).

A series of workers have investigated the seagrasses of Biscayne Bay, emphasizing their importance and making them the best documented plant group in the Bay. Voss and Voss (1955) were the first to define the Thalassia community, recognizing the dominance of this seagrass, and Voss (1975) has recently published a field guide to the seagrasses.

Phillips (1960) and Tomlinson and Vargo (1966) studies aspects of flowering and fruiting of Thalassia and Tomlinson (1969 and 1972) clarified morphological characteristics of Thalassia. Moore, Thomas and Work (1961) studies the effect of hurricanes on Thalassia, finding a great deal of shoreline wrack accumulated from leaf debris. Although old maps generally indicate lush bottom communities (see Chardon, this volume) the first detailed mapping of bottom vegetation was carried out by McNulty (1961) from a grid of 65 stations in North Biscayne Bay. He found vascular plants to be the dominant vegetation at that time, but there were large areas where there was no vegetation. In addition, the dominant species Thalassia testudinum in untouched regions of South Biscayne Bay was found only in a few locations in North Biscayne Bay in 1961, while the secondary seagrasses Halophilia baillonis and Halodule wrightii had become dominant: Halophila penetrated more heavily polluted areas in unusual abundance. The animal communities associated with these seagrasses appeared to be depauperate. McNulty's attempt to quantify the plant communities was made in units of ml displacement volume and is difficult to relate to the usual quantitative measurements of standing crop to g dry wt/m^2 or C/m^2. However, it is clear that substantial standing crops of Halodule occurred in North Biscayne Bay. Roessler et al (1974) have published maps of the bottom communities (Fig. 1) summarized by Wilson (1975), which was accomplished by diver observations from a small craft. In comparison to the map of McNulty, a large area between Rickenbacker Causeway and Julia Tuttle (36th Street) Causeway was denuded of plants. McNulty (1970) describes heavy siltation during channel dredging at Dodge Island, which may account for this. Since McNulty only mapped north of Rickenbacker Causeway, we have no published details of what the seagrass population of South Biscayne Bay may have been. However, from studying old versus my own aerial photographs and diving observations it is clear that many areas of the western shoreline from the northern boundary of Biscayne Bay to the Chicken Key area have been disturbed by a series of impacts ranging from dredging and filling to aerial and channel construction.

Other studies concerning vascular plant communities have included Humm's (1965) study of the epiphytes of Thalassia, Jones (1968) study of productivity of Thalassia and its epiphytes by the oxygen method (shown by Westlake to be nota valid method for measuring production of vascular plants), Zieman (1970) and Smith and Teas (1976) who documented seagrass denudation respectively at the Turkey Point and Cutler Ridge Power plants. Work in our own laboratories and in the field have established a realistic concept of the long-term porductivity, spatially and temporarily, of Thalassia and its associated plant community, (Thorhaug, 1974; Thorhaug, in press, Thorhaug, Roessler and Segar, 1975). Thorhaug et al (1976) determined the effect of various levels of heated efflents on the tolerance limits of Thalassia and major macroalgae in the Thalassia community both in the field and laboratory (Thorhaug, 1974; Thorhaug and Hixon, 1975: Thorhaug and Hixon in press; Thorhaug, 1976) and determined the combined salinity and temperature upper limits for Thalassia. Recently we have outlined the dynamics of Thalassia in unpolluted areas and described major animal communities found in untouched Biscayne Bay Thalassia beds (Thorhaug, Roessler, Segar, 1974; Thorhaug and Roessler, 1976; and Thorhaug et al, 1975).

RESULTS AND DISCUSSION

Major Functions of Seagrasses

The seagrass community, that is, the seagrasses, the plants that grow on seagrasses, and macroalgae growing among the seagrasses, appear to be the chief source of food material for the animals living in the Bay through a detritus food chain. A few investigators disagree with this since the critical experiments to trace nutritional compounds through the food web have not yet been accomplished. Therefore, the fact that the seagrass community is the base of the food chain is an indirect conclusion based on several assumptions, not a directly proven fact. In general, however, most investigators do agree that seagrasses are of importance to the food chain.

The seagrass community is a place of protection and shelter for many important animal species, especially during nursery stages. In a series of studies done in polluted and non-polluted areas of Biscayne Bay we have shown a direct correlation between removal of seagrasses and absence of animal species and numbers (Thorhaug, Roessler and Segar, 1974; Thorhaug and Roessler, 1967). When seagrass beds are removed, many important commercial and sport fisheries organisms leave the area.

The seagrasses are important in binding and trapping the sediment and in the creation of new sediments. By their baffling effect, they increase and maintain water clarity. Therefore, the seagrass community is important to water quality in terms of lack of reducing turbidity. In areas where seagrasses have been removed the water remains turbid or murky much longer after storms; sediments erode more rapidly in these areas as shown by Wanless.

Seagrasses are a reservoir for chemicals and function as an important link in cycling of elements.

Spatial Distribution

Figure 1 represents in general terms the distribution of vascular plants in Biscayne Bay, although it presents a broad outline and is not necessarily accurate enough for decision-making, especially along the western shoreline. It was done from widely spaced transects and then extrapolations made between the transects.

Spatial patterns in areas relatively untouched by man in southern Biscayne Bay show the grasses are more dense close to the shoreline, and sparser in the central portion, especially if there is a bedrock outcrop which often combines sand with green algae and sparse *Thalassia*. The wide peaty wedge along the western shoreline tends to support higher standing crops of vascular plants.

In areas with little influence from man there is a thin *Halodule* band adjacent to shore, a wide, dense *Thalassia* band and then an area of less dense *Thalassia* as one proceeds outward from shore. In areas of wide salinity fluctuation, such as the mouth of streams or creeks, the *Halodule* often replaces *Thalassia* in the zone of fluctuating salinity. With the number of new canals and drainage structures along western Biscayne Bay, the vegetation varies considerably.

In areas where man's impact has been greatest, along the north Biscayne Bay shoreline, causeway and filled areas, the dominant species of plant, *Thalassia*, has disappeared. The secondary seagrasses are found in places here, sometimes in abundance, but usually very sparsely.

In general, the southeastern shoreline is more or less a mirror image of the western shoreline. This fact, verbal reports from early scientists and fishermen, as well as early charts reported on by Chardon (this volume) cause us to conclude that the area north of Dodge Island on the northeastern shoreline of Biscayne Bay was once a lush meadow of *Thalassia* up to the shoreline mangroves. After the Collins Bridge in 1913 and artificial islands and causeways as well as shoreline filling began appearing, the *Thalassia* meadows were evidently badly damaged. The first detailed report by McNulty (1961) showed the *Thalassia* almost entirely absent.

If one looks at depth distribution of the seagrasses in Biscayne Bay, one finds the following: mangroves with their associated epiphytes are from the higher intertidal seaward; *Halodule wrightii* is often the dominant plant from mean low tide to low low tide and sometimes to about 1-1/2 feet below this level; in some areas *Acetabularia crenulata* or *Batophora oerstedii* dominate the intertidal. The *Thalassia testudinum* bed becomes dominant from this point to about six to eight feet, depending upon the clarity of the water. Often there is a band of *Syringodium filiformis* or *Halophila baillonis* at the deeper fringe of the *Thalassia* bed. Often a coarse sand with green algae lies along the deeper edge of the *Thalassia* bed.

Despite the above generalizations, the seagrasses are very patchy in growth and are often not found homogeneously throughout an area, but rather are clumped. For instance, aerial photographs clearly show round beds of *Thalassia* throughout the southern central Bay, surrounded by less dense grass on sand.

The spatial distribution of standing crop of *Thalassia* in its natural beds, varies from 250 blades/m^2 to 6000/m^2 being more dense along the peaty wedge of shoreline. Our measurements of *Halodule* range from 200 blades/m^2 to more than 13,500 blades/m^2 in intensely growing areas *Syringodium* ranges from 300 blades /m^2 to 8,600 blades/m^2. This large natural variation makes quantification of the whole Bay difficult.

Temporal Distribution

The dynamics of *Thalassia* abundances has a definite seasonal cycle with May-June being months of peak abundance and about 50% reduction in blades in the winter (Thorhaug, 1971). The abundance of blades is highly temperature dependent, so that during warm winters or in low increments of heated effluents in the winter, abundance is increased above normal. *Halodule* also is highly seasonal with peaks in May and lows in December to January (Thorhaug, 1973). No data is available on the other seagrasses.

Productivity

The productivity of *Thalassia* was measured at 30 stations in South Biscayne Bay and Card Sound over a 5 year period. It was measured by marking blades, collecting them for dry weight after 2 weeks and multiplying this value times standing crop. Various areas ranged from 0.1 to 3.7 g dry wt/m^2/day or 36.5 to 1340.5 g dry wt/m^2/yr, a considerable amount of productivity compared to any plant system (Thorhaug, Roessler and Segar, 1974; Thorhaug, in press). Unfortunately, no similar results are available for the other seagrasses. Growth of these plants are not known; however, standing crop of *Halodule* ranges from 4.99 to 117.45 g dry wt/m^2 and *Syringodium* from 4.20 to 120.4 g dry wt/m^2.

Chemical Cycling

A good deal of the nutrient and trace metal material in Biscayne Bay in incorporated into *Thalassia* (Thorhaug, Segar and Roessler, 1973; Gilio, this volume). In particular iron, cobalt, zinc, copper, cadmium and lead were high in concentration. It has been hypothesized that grass may pump trace metals from the sediments out into the water and detritus food chain (Segar et al., 1972; also see Uptake studies).

Sediment-Grass Relations

Wanless (1974; and this volume) has found generation of sediments by grass beds. Conversely, where grass beds are being lost by natural or man-introduced processes, there is a major modification of sediments including erosion and turbidity, a major effect in the estuary.

Physiological Aspects

Salinity tolerances

This subject has been reviewed by Thorhaug (1974) and Thorhaug and Hixon (1975). Little work has been done on the salinity tolerance of *Thalassia*. Much of the available data on the effect of salinity on submerged aquatic grasses has recently been summarized by McMillan (1974). *Thalassia* was found to have a lower tolerance to salinity extremes than some other seagrasses such as *Halodule*. In laboratory experiments by McMillan and Mosely (1967) on *Thalassia* from Redfish Bay, Texas, both in growth chamber and outdoor conditions, *Thalassia* showed no further growth above 60 o/oo. *Thalassia* from Lower Laguna Madre in Mexico was exposed to salinities between 5 to 60 o/oo by McMillan (1974). He concluded that *Thalassia* leaves react slowly to a rapid change in salinity. The influence of salinity on flowering of *Thalassia* was studied by McMillan (unpublished) and Marmelstein, et al. (1968). Propagation is mainly due to rhizome growth, however, levels become an important factor with lowered survival at 50 o/oo. However, salinity between 20 o/oo and 45 o/oo does not appear to be as critical a factor in survival as temperature.

Temperature tolerances

The effects of temperature on seagrasses has gained recent attention due to the effects of thermal effluents from power plants on seagrass communities throughout the United States and trust territories (Puerto Rico and Guam). Kolehmainen (1974) examined seagrass communities on the south coast of Puerto Rico at a fossil fuel power plant site. In a two year study he found that the limits of *Thalassia* survival were 34°C. In Biscayne Bay we have found that the disappearance of *Thalassia* followed the development of persistent isotherms produced by a power plant effluent in South Biscayne Bay. The *Thalassia* community disappeared in an area of about 9.3 ha adjacent to the mouth of the effluent canal. This area averaged 5°C above ambient (30° ± 1.5°C). In an area of approximately 30 ha, 3° to 4°C above ambient, the *Thalassia* community declined by about 50% and the important macroalgae, *Halimeda* and *Penicillus*, fell to about 30% of their former population. As a result of this modification, selected entities of the animal population feeding on the dying plant material increased temporarily. After exploiting this food, these animals left the area. The denuded area then became covered with blue-green algae.

Increased temperature is not necessarily detrimental to a subtropical ecosystem; control and limitation is the essential factor. For example, in the areas of Biscayne Bay where a +3°C isotherm was maintained, the macroalgae and grass populations fell markedly in the summer as temperatures exceeded 30°C. However, during the winter months *Thalassia* blades grew back. Comparatively speaking the +2°C isotherm was extremely productive, exceeding that of the control stations, which were outside the obvious influence of the thermal plume. This may be due to a number of factors: the increased availability of nitrogen via decaying detritus, or a modification of circulation and elevated winter temperatures. These short-term tolerances are several degrees Celcius above the previously discussed long-term tolerances seen in field conditions.

Temperature tolerances of young plants were the same as older plants. Salinities of 50 o/oo decreased high temperature tolerances.

Uptake studies (including nutrients)

Uptake studies have been done in the seagrass *Zostera*, which is not closely related to *Thalassia* and thus may take up ions and other compounds in a different manner. Considerable argument exists as to the site of the uptake in submerged marine and freshwater vascular plants (Sculthorpe, 1967). Evidence from studies using labeled isotopes of phosphorus and nitrogen indicates that *Zostera* is capable of absorbing nutrients across the surface of leaves or roots (McRoy and Barsdate, 1976). The actual site in nature appeared to depend on kinetics and the gradient of driving forces of the specific nutrient compound. The sediments appeared to be the prime site of the nutrient uptake for *Zostera*.

In studies on *Thalassia*, which usually grows in sediments rich in calcium carbonate, the sediments and interstitial water contain a considerable reserve of phosphate, which appears to be available to the plant (McRoy et al., 1972; Patriquin, 1972). The source of nitrogen is more obscure. Patriquin and Knowles (1972) have measured high rates of nitrogen fixation associated with bacteria surrounding the Thalassia root system and suggest that this could account for the nitrogen requirements of the plant. Nitrogen fixation has also been reported by epiphytic (probably blue-green) algae on Thalassia blades (Goering and Parker, 1973; and Taylor and Capone, 1975). Research in this area is proceeding by several of the above workers.

Ion uptake has been preliminarily investigated by Kolehmainen (1971) in Thalassia blades. He found that green blades had a high Fe^{59} concentration factor and dead blades had a higher I^{131} concentration factor. Composition of metals in Thalassia blades has already been reported (Thorhaug, Roessler and Segar, 1973). The data are given for metals found in 165 g dry wt of Thalassia from Card Sound of which 62 g is carbon, 17 g protein and 1 g lipid.

Iron $\mu g/m^2$	7,443.0
Cobalt $\mu g/m^2$	66.2
Nickel $\mu g/m^2$	661.6
Copper $\mu g/m^2$	330.8
Zinc $\mu g/m^2$	2,481.0
Cadmium $\mu g/m^2$	132.3
Lead $\mu g/m^2$	148.9

Further analysis of trace metals in other major components of the Thalassia ecosystems is being done by Gilio (this volume). Obviously, much of the mineral content of these depauperate conditions is bound with Thalassia. The mechanism and kinetics of uptake are not known at present. (Gilio, this volume).

Successional Patterns

Thalassia testudinum community appears to be the climax community of submerged Biscayne Bay. When it is removed by natural or man-made activities various successional patterns appear, depending on substrata and recruitment potential of other plants. One successional pattern in peaty low energy bottom is Acetabularia crenulata + Batophora oestidii → Penicillus capitatus + Avrainvillea sp. + Halimeda incrassata → Halodule wrightii and/or Syringodium filiformis → Thalassia testudinum. A second successional pattern on high energy sand is Penicillus + Udotea → Syringodium → Thalassia. Other areas even after 50 years appear to not have recolonized or returned to a Thalassia-dominated community (Thorhaug and Bach, 1975).

The rate at which Thalassia recolonizes is very slow compared to the other seagrasses because it has slow lateral expansion (optimum about 1-1/2 feet per year) and few seeds produced in Biscayne Bay. Halodule, on the other hand, has very rapid lateral expansion so that it can recolonize moderate size adjacent areas within a year or two, if conditions are correct. It is not clear if seeds from Halodule or Syringodium are ever abundant enough in Biscayne Bay to affect successional patterns. Floating segments of rhizomes from these latter two plants are frequent and can re-establish themselves.

Restoration of Seagrasses

A major large-scale effort to restore Thalassia testudinum to Biscayne Bay resulted in thousands of seeds taking root and rapidly expanding in an area in South Biscayne Bay denuded of vegetation by man (Thorhaug, 1974). Four years later, plants are found on an average with blades 18 inches and 5 to 6 feet lateral rhizome expansion. Many animals have returned to this rapidly recovering Thalassia successional zone. Attempts to determine the feasibility of this method in other, more difficult, areas of Biscayne Bay was attempted (Thorhaug and Hixon, 1975). The results showed that many parts of North Biscayne Bay can now sustain Thalassia growth, although no Thalassia is presently there. Difficult areas to revegetate included those with high tidal currents, with frequent wake from boats, large grain sized sediment, and high turbidity. An especially promising area of restoration of Thalassia community is the central portion of the basin, between 36th Street and 79th Street Causeways.

A comparison of the various methods of transplantation has been made (Thorhaug, 1976). Sodding appears feasible in Biscayne Bay only in very shallow areas and where a small (one-fourth acre or less) area is to be restored. Seeding is the only feasible method for large scale restoration in Biscayne Bay.

A cost analysis is now underway to allow rational decision making as to feasibility of various planting techniques. This analysis is based on seeding in Biscayne Bay (Thorhaug and Austin, 1965).

No work has been done on restoring the other species of seagrasses. There are areas where these grasses might be the correct ones to restore since they were dominated originally at that location. In addition, restoration of mixed grass communities might be of economic and biological advantage. This is an important area of future research.

Pollution Effects

In general, the seagrass community is quite sensitive to pollutants. Once the dominant species, Thalassia are removed, a very long period is required for the regrowth. An example is North Biscayne Bay (above Dodge Island) where almost no Thalassia has returned after decades. Removal of seagrasses increases turbidity, decreases markedly the animal species present, and therefore decreases the quality of the water. Removal of Thalassia beds is one of the chief environmental problems of Biscayne Bay. This problem is no longer irreversible due to restoration techniques. Pollution of seagrasses is discussed further in this volume in Roessler and Thorhaug.

Dredging and other bottom disturbances.

Dredging of Bay bottom, dredging for channels and canal construction, removal of sediment for borrow pits and other dredging activities have severe effects on the Thalassia community. In addition to bottom scouring activities (such as bottom dredging or trawling for animals), large or small vessels which touch bottom and thus leave scars have been documented to have a long-term effect on the seagrasses (Zieman, in press). Odum (1963) has studied the ecological effects of dredging on Thalassia and Halodule where he found reduced trowth of these grasses. Commercial fishing using bottom trawls has shown to be damaging to North Carolina grass beds (Thayer and Stuart, 1974). No similar work has been done on commercial fishing operations in Biscayne Bay.

The side effects of dredged areas are that suspended matter remains in the water column for long periods of time, blocking necessary light for growth of seagrasses, and siltation from dredging often smothers adjacent grass beds completely, causing them to die.

Bulkheading has damaged extensive areas of very productive areas of seagrass beds since the seagrasses are particularly dense directly adjacent to shore.

Sand removal from the Bay bottom destroys the seagrass growing on the sand. In one area well studied by Wanless, the Thalassia removed in a borrow pit did not return after seven years. Some areas are far better for sand removal than others due to great differences in density of grasses. Areas in the central Bay with sparse seagrass would be better for borrow pits.

Chemical pollutants.

Little is known about the effects of oil, pesticides, heavy metals or sewage on seagrasses. Oil spills have been documented to kill Thalassia in Puerto Rico and Jamaica (Diaz-Piferrer, 1962). Effects of low concentrations of chemicals such as in non-point sources of pollution are not yet studied with respect to our local seagrass. However, caution should be used in runoff standards until data is available. Presently we are working on oil, copper and chlorine effects on Thalassia in our laboratories.

Thermal pollution

The effect of heated effluents +3°C above ambient in the summer severely damages or destroys the seagrass community. This has been well documented at the Turkey Point Power Plant in a series of studies. (Bader, Roessler and Thorhaug, 1971; Thorhaug, 1974; Thorhaug, Roessler and Segar, 1974). The animal species decline in diversity and abundance. Lower levels of thermal effluent such as +1°C above ambient appear to stimulate growth. The Cutler Ridge Power Plant has released effluents into Biscayne Bay over many years and a large area of 35 hectares is now decimated with respect to Thalassia and other members of the seagrass community (Teas and Smith, 1976).

A Long-Term Investigation for Understanding the Dynamics of Seagrass Processes

The seagrasses live in a delicate balance with the chemical, physical, geological and biotic factors in their environment. Efforts have been made to understand the effects of many of these factors and interaction of environmental factors with Thalassia must be carried out. Extremely little is known about the other three seagrasses, and a program to investigate their role, productivity and dynamics should be initiated.

One important long-term goal necessary to an understanding of seagrasses is to trace the food chain from seagrasses through the detritus phase and up through various consumer levels. An important tool in this study would be radiotracer experiments, loading the seagrasses, with, for instance, Zinc^{65} and tracing its fate.

A second major goal would be to understand the delicate balance between the presence of the plant constituents in the seagrass community and the animals. Absence of the plant community in areas of thermal effluent (Thorhaug, Roessler and Segar, 1974) and North Biscayne Bay (McNulty, 1961) has shown a decline in diversity and abundance of animals. However, as natural and restored plant communities revegetate, how dies the animal community restructure itself? Detailed studies of declining and successional stages of Thalassia communities would provide much useful information for management purposes.

We also need basic physiological data on the effects of certain important factors on seagrass productivity factors such as light levels, turbidity, siltation rates, currents, and low salinities, as well as various levels of chemical species. In addition, the synergistic effects of multiple stresses on seagrasses of several sublethal factors must be determined. The only study of this type to date is that of Thorhaug and Hixon (1975) on high temperature and high salinity.

Further interdisciplinary work on relationships between growth and abundance of seagrass and (1) sediment types (2) chemical constituents in the water and sediments (3) physical regime (4) man's activities in the seagrass bed is sorely needed. In addition, the process of restoration of seagrasses into those parts of Biscayne Bay previously denuded by man's activities and the animal communities which result is critical to managing and protecting Biscayne Bay.

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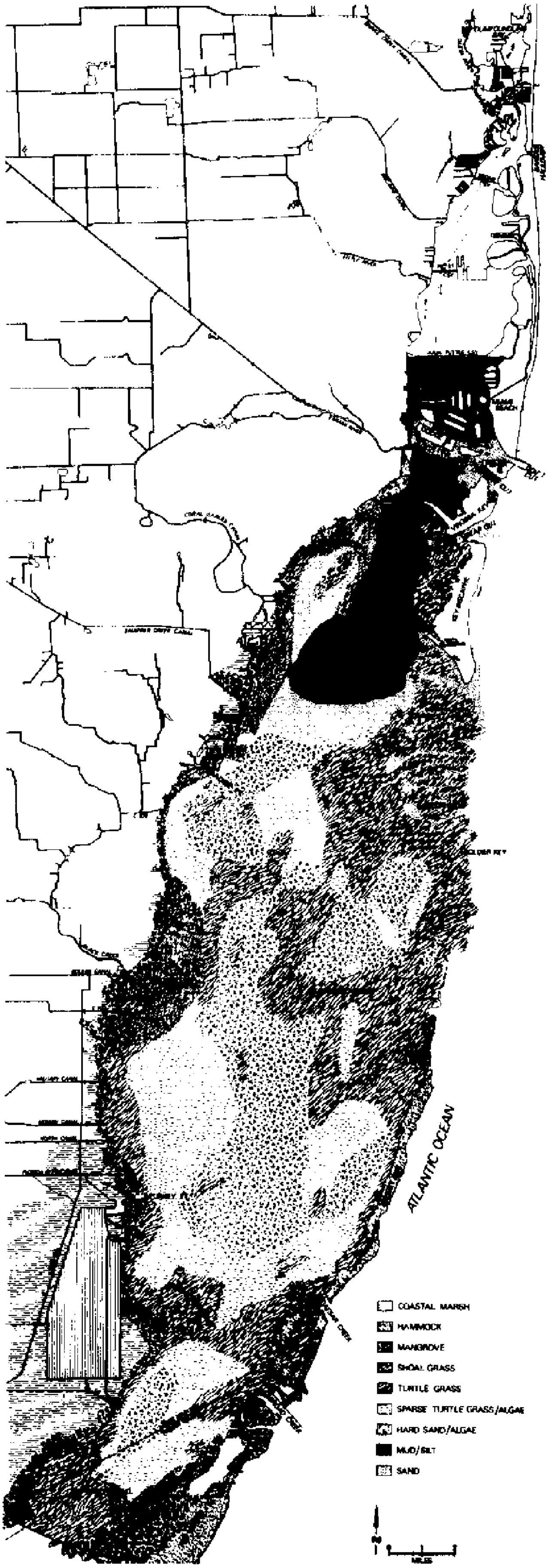

Figure 1. Vegetation map of Biscayne Bay (from Roessler and Beardsely, 1975)

PRODUCTIVITY OF BISCAYNE BAY MANGROVES

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ABSTRACT

Mangroves of Biscayne Bay have been classified into 5 community types: Coastal Band, which is predominantly red mangroves (Rhizophora mangle) growing as a band along the shore and along tidal creeks; Dense Scrub, which is predominantly red mangrove growing very densely on marl soil; Sparse Scrub, which is predominantly red mangrove forest made up of widely spaced stunted plants; Black Swamp, which is a basin forest made up principally of black mangroves (Avicennia germinans); and the White and Mixed community which is made up principally of white mangroves (Laguncularia racemosa). Four of these 5 community types have developed in their present form or location because of saltwater encroachment that followed draining of the Everglades, the cutting of agricultural and mosquito ditches, and the blocking of overland freshwater flow by roads and levees.

Estimates of mangrove Gross Primary Productivity (total photosynthesis), Net Primary Productivity, and Respiration indicate that the Coastal Band mangrove community along Biscayne Bay (or the mangrove forests of southwest Florida) have a Net Primary Productivity of about 10.7 metric tons of dry matter per hectare per year. This is low compared to other tropical forests which range from 13-123 mt/ha/yr for an average of 25.3 mt/ha/yr, more than twice that of the most productive of Biscayne Bay mangroves.

Estimates of seagrass productivity indicate that the whole of Biscayne Bay probably produces 9-12 times as much weight of leaves as do the mangroves along the shore.

Research needs center on the problems of mangroves that are growing under stressed conditions on former freshwater marshlands to which they are poorly adapted. Because of the documented spread of mangroves into these marl lands it may be that in spite of losses to shoreline landfill activities there is currently a greater area of mangroves along Biscayne Bay today than there was in 1900.

INTRODUCTION

Mangroves

Mangroves are trees or shrubs that grow in and along the edges of the warm seas of the world; it has been estimated that mangroves dominate about 75% of all the coastlines between 25° North and South latitude (McGill, 1959). Mangroves reach their maximum development and greatest luxuriance in Southeast Asia, Indonesia and Borneo (Macnae, 1968).

Mangroves are a botanically diverse group all of which have close relatives among ordinary land plants. Mangroves are therefore considered by botanists to be land plants that have developed adaptions to the salt or brackish water habitat, rather than plants that have evolved in the sea. In spite of the ability of many mangrove species to grow under non-saline conditions, they are not usually found to be successful competitors in upland or freshwater environments (Macnae, 1968).

The mangrove species of the Indian Ocean - Western Pacific area are much more numerous than those of Florida; they include 44 species and 14 genera that fall into 11 families. Chapman (1970) lists a total of 4 genera and 8 species for the mangroves of the western hemisphere.

Mangroves are usually found between the levels of equinoctial high tides and slightly below mean low tide. Mangroves of the Western Pacific-Indo Pacific frequently occur in bands or zones made up almost solely of a single species or a characteristic species mix or community association. Actually, the occurrence of a species is not absolutely limited to a given zone or zones, but its distribution in typically in specific communities. Zonation is most often attributed to such factors as frequency and depth of tidal inundation, salinity of the waters or soil, or soil maturity along an accreting shoreline (Macnae, 1968). Zonation of mangroves is most marked in areas such as Malaysia where the average tidal range is great and where there is high, relatively non-seasonal rainfall (Watson, 1928). Mangrove zonation does not occur where rainfall is less than 1778 mm per year (Macnae, 1968). In zoned Asian mangrove forests, the tidal ranges are typically 2.4-3.6 m.

Florida and Biscayne Bay Mangroves

Florida mangroves are made up on only 3 species in 3 genera, each of which belongs to a different family. The Florida species are the red mangrove, *Rhizophora mangle* (family Rhizophoraceae); black mangrove, *Avicennia germinans* (family Avicenniaceae); and the white mangrove, *Laguncularia racemosa* (family Combretaceae). The so-called buttonwood mangrove (*Conocarpus erecta*) thrives without sea water and is rarely found growing where its roots are exposed to full strength seawater; it is often not classified as a mangrove. In any case, buttonwood and several other minor species made only a small contribution to the energy budgets of Dade County mangrove areas and are not considered in this study.

All three species of Florida mangroves occur in the southern part of the state. Their distributions were reported by Savage (1972). The white mangroves appear to be the most cold sensitive of the Florida mangroves; their range extends northward only to Brevard County on the east coast and Hernando County on the west. Red mangroves are more cold hardy; they extend to Volusia County on the east coast and Levy County on the west. Black mangroves are the most widely distributed; they extend to St. Johns County on the east coast and are found as scattered plants along the Gulf coast of Florida and from there to Mexico. Although the annual low and average temperatures in the Miami area are less favorable than in the main Indo-Pacific area, low temperature does not appear to limit mangrove distribution along Biscayne Bay. True zonation would not be expected to occur along Biscayne Bay where the mean tidal ranges vary from 13-62 cm (Schneider, 1969), which is very much less than that of Asian mangroves. The Biscayne Bay rainfall is also deficient for zonation (Macnae, 1968). Nevertheless, mangrove community differentiation along Biscayne Bay does occur and is probably based on some of the same factors as are involved in Asian zonation, i.e. soil type, elevation, drainage, soil salinity and species tolerance, seed supply and species competition. That many factors are involved in the species mix of a given sample of mangrove forest is indicated by planting experiments of Rabinowitz (1975) in Panama. She discovered that mangrove species were often found growing at sites where controlled experiments had shown they were not well adapted.

Mangrove communities of Davis

Davis (1940) studied the mangroves of Florida and described seven community types, as follows: "Pioneer Rhizophora", which is the community of developing small red mangrove trees growing along the edge of open water at elevations near mean low water; "Mature Rhizophora Consocies", which is dominated by red mangroves, often growing on deep mangrove peat; "Avicennia Salt Marsh", which is dominated by the black mangrove, is typically found at about mean sea level in basins that are infrequently flushed by the tides; "Laguncularia Consocies", which is white mangroves at about the mean high tide level, but often is found at other elevations and in mixtures with both the other species; "Conocarpus Transition", which is above the mean high tide level, inland from the mangrove communities but seaward of the tropical hammock species; "Mature Mangrove Forest", which is found at the mean high tide level, is an open forest, typically made up of tall red, black and white mangroves with other species included such as buttonwood, cabbage palm, sea grape (*Coccoloba uvifera*) and others; and the "Dwarf Form" or "Scrub" comminity, which in the coastal form is typically dominated by widely spaced red mangroves, and occurs in two types, one that grows below mean low water and the other which is found near the mean high tide level.

Lugo and Snedaker (1974) proposed a system of classification for mangroves in the Ten Thousand Islands and Rookery Bay area of southwest Florida that has merit but does not appear to be useful under the conditions of Biscayne Bay. Heald et al. (1974) divided black mangrove communities into three groups, but do not indicate the locations of any examples.

Communities evaluated in this report

Davis' classification was adapted to Biscayne Bay mangroves by Teas (1974), with some renaming of the community types and the addition of one community type not listed by Davis.

The Pioneer Rhizophora community occurs but is not important in Biscayne Bay. Macnae (1968) points up the importance of pioneer communities in silting shorelines, but the shore of Biscayne Bay is not accreting. A study of elevations in a Pioneer Rhizophora community along the western shore in Section 2 of T56, R40, showed that although many red mangrove seedlings had rooted, no red mangroves were established as trees at elevations below -4 cm (where the mean low tide elevation was ca. -11 cm, U.S.C. and G.S. Mean Sea Level Datum). Moreover, aerial photographs indicated that this Pioneer Rhizophora Community had not advanced into the bay in more than a decade. In any case, the area of Pioneer Rhizophora Community in Biscayne Bay is a very small component of the mangrove communities and is not evaluated in this report.

The Coastal Band community of Teas (1974) is the Mature Rhizophora Consocies forest of Davis, dominated by red mangroves. The Coastal Band community is the band of mature mangrove bordering the bay and edging creeks that lead to Biscayne Bay. Typically this community is from 10-250 m wide. Coastal Band is usually a mature forest growing on mangrove peat with trees sometimes widely spaced. The Coastal Band grows taller than the other community types, with an average height of about 10.6 m north of Turkey Point and 4 m along Card and Barnes Sounds. Typical trunk diameters of the large specimens of red mangrove are 33-46 cm, black are 76-91 cm and white are 25-46 cm. The black mangroves probably average at least 1.5 m taller than the nearby red and white mangroves in the Coastal Band. Coastal Band mangroves are made up of a mixture of species, the average composition of which is 79% red, 14% white, and 7% black. Examples of typical Coastal Band mangroves are found at Cocoplum and Black Point.

The soil elevation of the main part of the Coastal Band is about +24 cm. Along the shore there is typically a berm of sand, shells and plant wrack that have been thrown up by the waves. The berm averages about 15 cm higher in elevation than the more landward portions. The soil in the Coastal Band contains more organic matter, has a lower pH and contains more soluble phosphate than is the case for the other communities along Biscayne Bay (Teas, 1974).

In pre-drainage times stretches of Coastal Band community that were narrow probably contained only mangroves. However, as reported by Teas et al. (in this volume), where the Coastal Band mangroves of today form a broad band they have characteristics suggestive of origin from Davis' Mature Mangrove Forest. That is, within such Coastal Band communities are found trunks of buttonwood and cabbage palm that were a part of the forest in pre-drainage times when there was a narrow ribbon of graminoids (juncus-distichlis, i.e. *Juncus roemerianus* and *Distichlis spicata*) immediately behind the Coastal Band and upland of that was typically sawgrass (*Cladium jamaicensis*).

Black Swamp (or Black Marsh) is the Avicennia Salt Marsh Associes of Davis (1940), a community that is most often found in shallow basins that are only occasionally flushed by the tides. See photograph as Fig. 8 in Teas (1974). Salinities of 80 o/oo and greater have been found in Black Swamp communities during the dry season. Glasswort (*Salicornia* spp.), salt wort (*Batis maritima*) and sea purslane (*Sesuvium portulacastrum*) are common understory plants in the open parts of Black Swamps. Possibly because of tolerance to higher salinity levels, black mangroves may form almost pure stands. In some Black Swamp area in the Florida Keys salt crystals form on the surface of the soil in the dry season. At these sites the black mangroves are stunted and scrubby. The average height of trees measured in the Black Swamps was 5.8 m compared with the 12-15 m heights of some black mangrove trees in the coastal red mangrove dominated Coastal Band communities. There are few examples of Black Swamp in Dade County; a typical community was found at Card Point. No soil elevations were available in Black Swamp areas.

The Conocarpus Transition of Davis is upland of the Biscayne Bay mangroves. An example is found south of the Deering Estate in Section 35 of T55, R40. Conocarpus Transition is not common along Biscayne Bay and its location is too upland to be of significance in overall Biscayne Bay productivity.

Scrub or dwarf mangrove forests along south Biscayne Bay are predominantly red mangrove. The two types have in common that they are short in stature. They are readily distinguished however by the density of growth. The Dense Scrub grows so densely that it is difficult to walk through whereas the Sparse Scrub trees are widely spaced.

The Dense Scrub of Teas (1974) is an induced forest (Teas, et al., in this volume) growing on former freshwater marl marshlands salinized as a consequence of drainage. Aerial photographs indicate there was little Dense Scrub at the time of Davis' field studies, 1933-38. Dense Scrub is usually found immediately behind the Coastal Band along most stretches of Biscayne Bay shoreline, for example at Gables-by-the-Sea and Black Point. Dense Scrub is sharply separated from Coastal Band (see Fig. 13 in Teas, 1974). The typical soil elevation is from 23-30 cm. Dense Scrub trees are closely packed, sometimes more than 8 trees per m^2. Several groups of Dense Scrub averaged 174 cm high.

Prior to drainage, the juncus-distichlis and sawgrass communities were apparently effective competitors of mangroves under freshwater or slightly brackish conditions. When saline intrusion forced the juncus-distichlis back from the shore into former sawgrass area, mangroves began to develop in dense stands forming the Dense Scrub community. Subsurface mollusc shells found in this area are freshwater species as described by Craighead (1971) (Teas et al., in this volume). Some of these Dense Scrub communities can be dated from aerial photographs. For examples, in Section 33 of T56, R40, the heavy seeding that gave rise to Dense Scrub came after mosquito ditching in 1958-59. Dense Scrub is found on marl soil where the soil salinity may be higher than that of surface water, but the Dense Scrub is ordinarily washed by high tides. Dense Scrub is probably nutrient stressed in the calcareous soil. The Dense Scrub community typically has a high incidence of dead trees and branches, and has smaller leaves than Coastal Band. As Dense Scrub grows and becomes thinned by natural forces and accumulates litter and peat it may develop into a Coastal Band community. Some of the oldest Dense Scrub (as indicated by aerial photographs) already appear to be transitional toward Coastal Band.

The Dwarf Form or Scrub Mangrove community of Davis (1940), dominated by red mangroves (95% or more) was designated Sparse Scrub by Teas (1974). As noted by Davis, coastal scrub mangrove communities exist in two types: a form growing on waterlogged soil, often near or below the mean low tide level, and a form found high in the tidal zone.

Sparse Scrub is found principally from Turkey Point southward, landward of the taller Dense Scrub mangroves. Sparse Scrub is very clearly different from Dense Scrub; the transition is frequently sharp (see Fig. 14 in Teas, 1974). Patches of Sparse Scrub are found north of Turkey Point in the almost bare salina areas, usually where the soil is thin. Tree densities found in Sparse Scrub south of Mangrove Point were ca. 1.7 per m^2 and the trees averaged .98 m high. Some Sparse Scrub averages less than 1/10 as many trees per unit area. Examination of Sparse Scrub mangrove forests shows that the individual trees are sometimes spaced in almost a regular pattern. The Sparse Scrub mangroves from Turkey Point to Card Point and south have invaded the shore since 1900 (USDA, Soil Conservation Service, 1946), being found in areas that were formerly graminoid. Counts of leaf scars indicate that the ages of these Sparse Scrub trees are consistent with such recent origins. Sparse Scrub communities can be seen in other mangrove areas of the world. The Sparse Scrub communities along Biscayne Bay appear to be stable, i.e. there is usually little evidence of recruitment in the open areas between Sparse Scrub plants.

Sparse Scrub is found on marl soils, sometimes growing where the soil elevation is less than mean low tide level. At such sites, along Card and Barnes Sounds, on South Biscayne Bay, the soil is almost perpetually inundated and the scrub growth form is probably induced by waterlogging as suggested for scrub communities in other parts of the world by Macnae (1968) and by Chapman (1969). Other Sparse Scrub, which grows in a recognizably different form, is found at higher elevations in areas that are subjected to high soil salinities. The saline zone is reached only by the very high or storm tides. The saline bay waters evaporate and salt concentrates in the marl soil. Because the marl soils exchange slowly with surface waters the roots of these plants are exposed to hypersaline interstitial water even in the rainy season (Teas et al., in this volume; Reark, 1975). This second type of Sparse Scrub appears to be stunted because of salinity stress. It is notable that the soil salinity in a (peaty) mangrove hammock can be the same as, or only slightly elevated over, that of surface water, but a short distance away in the marl of the Sparse Scrub community the soil interstitial water can be considerably more saline than surface water. Soluble phosphate in the soil of the Sparse Scrub is lower than that in the other communities and the soil of the Sparse Scrub has the highest pH of the mangrove communities along Biscayne Bay.

The White and Mixed community of Teas (1974), which is the "Laguncularia Consocies" of Davis (1940), is made up principally of white mangroves on marl soil, ordinarily at higher elevation than the other communities, and extends upland to 55-61 cm and higher elevations. See photograph Fig. 16 in Teas (1974). In at least one area, a population of white mangroves if found landward of a salinity dike (L-31E), growing in freshwater.

In the mangrove communities monitored in this study the average height of the White Mixed community was 5.8 m; however, this figure has little significance compared to the ca. 10.7-12 m height of the white mangrove trees in some of the Coastal Band. The White Mixed mangroves were apparently seeded into former farmlands along Biscayne Bay by the high tides associates with hurricanes in 1945 and 1965 (Reark, 1975). A typical White and Mixed forest community is found in upland parts of Cocoplum.

It is obvious from field observations that the above community classification is useful, but not every patch of mangroves along the Bay falls sharply into one of the communities. Transition zones are sometimes found between some communities, for example, between Coastal Band and Dense Scrub. Also important in classification is that mangrove communities may undergo changes in character. Examples have been found (Biscayne Bay and Marco Island) of established "pure" Black Swamp that has an understory consisting of large numbers of young red mangrove seedlings, all of the same age class, likely carried in by a wind driven high tide. These seedlings may in time replace the black trees because the latter are intolerant of shading, whereas the red mangroves thrive in partial shade (Macnae, 1968).

The overall species composition of the south Biscayne Bay mangrove communities is approximately 83% red, 13% white and 4% black.

Productivity estimates

The gross primary productivity (GPP) of mangroves is the total carbon fixed. Our concern with productivity related to Biscayne Bay is with the net productivity, i.e. the amount of carbon found to have been fixed, after subtracting for respiration (R). The GPP and R can be estimated from metabolic studies that involve enclosing plants or portions of plants in plastic gas exchange bags. Measurements of photosynthesis and R have been carried out in Puerto Rico (Golley et al., 1962) and in south Florida (Miller, 1972; Carter et al., 1973; Hicks and Burns, 1975; Lugo and Snedaker, 1975). The net primary productivity (NPP) of mangroves is represented by the photosynthetically fixed carbon that is accumulated in leaves, branches, trunk, bark, roots, fruits and flowers, etc. Operationally, the compartment of net productivity which can be readily measured is the litter. Litter measurement requires periodic collections in pans or baskets during a year. The only mangrove forest trees for which there are sufficient data, including subsurface roots, for estimating NPP from litter measurements are those of Golley, et al., in Puerto Rico (1962) and Panama (1969). Golley, et al. (1962) have also provided regression data from which the annual incremental growth of wood can be estimated. Lugo and Snedaker (1975) recently have calculated a value for annual wood increments in a mangrove forest. Watson (1928) and Noakes

(1955) have provided data from which wood increase can be calculated for managed Malayan mangrove forests over periods of decades.

Alternatively, if litter component distribution data are available, litter can be estimated by harvests of leaf prisms, from leaf area index measurements, or optically by the use of photocells and conversion factors that relate percent transmission to standing crop of leaves. The annual yield of leaf material will equal the leaf biomass if leaves average one year on the tree, which has been reported to be approximately true for red mangroves Gill and Tomlinson (1971). Our studies of tagged individual leaves of red mangrove confirmed the average leaf residence time as ca. 1 year. Pool et al. (1975) calculated leaf turnover rates (annual leaf fall ÷ canopy leaf biomass) for 7 Florida sites and obtained an average value of 0.97. Sparse Scrub at Turkey Point had a rate of only 0.8 and mixed mangrove forests in the Ten Thousand Islands of southwest Florida had rates of 1-1.4

METHODS

The yield of litter (leaves, twigs, branches, flowers, fruit, seedlings and miscellaneous) was determined directly by the use of litter pans, except for Dense Scrub communities where leaf harvest was ordinarily used.

The comprehensive estimate of the areas of each of the 5 communities was made for Biscayne Bay south of Coral Gables. Aerial photography of the mainland side of Biscayne Bay was used as 23x23 cm aerochrome and false color (FCIR) transparencies with stereo coverage at a scale of approximately 1:10,000. Vegetation analysis of the mainland mangrove areas was carried out utilizing a stereo viewer. Mangrove areas on the western shores of the offshore islands were estimated from black and white photographs. Interpretation of mangrove communities was based on ground truth.

The extent of the mangrove communities was marked on a Dade County black and white aerial photographs (scale 1 cm = 36 m) and the areas of the marked communities were measured. Mangroves were classified into the 5 community types, Coastal Band, Dense Scrub, Sparse Scrub, Black Swamp and White and Mixed. Areas of open marl soil or salina were excluded since they have no or only very sparse mangrove growth. The White and Mixed mangrove community is the most variable of the five types. Toward the bay it meets the Dense Scrub and on the upland side, often well above mean high water, it intermingles with salinity tolerant shrubs, Australian pines and some hammock species. Relict mangroves upland of salinity dikes or levees were omitted from the area estimates because they could have no role in Biscayne Bay's productivity. Sparse Scrub was subdivided into density classes for productivity estimates.

Elevation determinations require sight lines and bench marks, neither of which is frequently found in mangrove swamps. Some elevations of community types were obtained by correlating elevations on topographic maps with onsite and aerial photographic analysis of mangrove community types. This method was possible in the case of the Cocoplum and ITT Snapper Creek properties where elevations were available from surveys. Elevations were known from an east-west transect along the midline of T56, R40 sections 14 and 15, provided by the Metropolitan Dade County Department of Public Works. Elevations were also available for two transect lines through the mangroves south of Mangrove Point that were recorded on a topographic survey of Toussaint and Associates. The locations of the cleared lines from this latter survey are visible on aerial photographs.

Elevations were obtained by sketching onto the above maps outlines of characteristic mangrove communities as determined from aerial photographs and ground observations. The elevations of the ground within these designated communities were then tabulated from the reference maps or transects. All elevations within an identified community were used in calculating the averages except that low points which obviously represented the bottoms of small creeks were discarded.

Soil samples for analysis were taken with a garden trowel at the surface after removing litter; they represent the top 5-10 cm. Organic matter was determined by combustion at 500 C; soluble phosphate was measured by a standard method (Strickland and Parsons, 1968) on samples dried at 70 C; pH was measured on an aqueous aliquot of the sample dried at 70 C by the procedure of Llewellyn (1963).

RESULTS

Litter production by Biscayne Bay mangrove communities is shown in Table 1. The Coastal Band is the community with the highest yield of litter at 2.93 $g/m^2/da$. These data are for litter pans that were collected every 2 weeks. The total litter values were higher for these stations than from the ones sampled less frequently. These values for Coastal Band and Sparse Scrub are in the same range as those of Pool et al. (1975) for mixed species forests in southwest Florida and Sparse Scrub at Turkey Point. The species distribution of trees in the 5 communities are from "typical" examples. Leaves made up 75% of Coastal Band litter, 66% of Dense Scrub litter, 69% of Sparse Scrub litter, 88% of Black Swamp litter and 86% of White and Mixed Community litter. Fruit, flowers and propagules were 19%, 29%, 22%, 2% and 6% respectively. Wood and miscellaneous debris made up 6%, 5%, 9%, 10% and 8% respectively. Predominantly red mangrove forests had much larger fractions of their litter as fruits, flowers and propagules (av. 23%) than did the Black Swamp and White and Mixed communities (av. 3%). The Dense Scrub has about the same species distribution as Coastal Band and is usually found at appropriate elevations for Coastal Band. The Black Swamp community in this study had a low litter fall (0.78 $g/m^2/da$) probably because the canopies of the communities sampled are relatively open. It is predicted that a dense Black Swamp would have 2 or more times the litter reported here. The distributions of leaves and total litter in Table 1 can be used to estimate the litter compartment of mangrove forest productivity from prism harvest data.

Estimation of the component of NPP that is due to wood is the most difficult of the compartments. Mangrove GPP estimates from literature are shown in Table 2. The average GPP for all examples was 6.5 gC/m^2/da. If the Sparse Scrub and the anomolous value for the Turkey Point mangrove hammock are excluded, the average GPP is 9.7 gC/m^2/da. Approximately 60% of this is respiration; the NPP is divided between wood and litter. The data are widely spread from GPP of only 1.4 gC/m^2/da for Sparse Scrub to 12.0 gC/m^2/da for the average of 3 mixed species communities in southwest Florida. It should be possible to estimate the increase in wood from the NPP and litter; however, as is noted by authors of metabolic studies (Miller, 1972; Carter, et al., 1973; Hicks and Burns, 1975), the trees used for experiments are small and not necessarily representative of the mature forest.

The R component of GPP for a mixed mangrove community in southwestern Florida was found to vary with surface water salinity that is, with position in the estuary (Hicks and Burns, 1975). These investigators concluded that the reduction in community NPP with increasing salinity was a reflection of enhanced R, which increased from 36 to 65% of GPP as the salinity increased from 4.7-16 parts per thousand. Inasmuch as this decrease in net productivity is attributed to salinity stress, it is interesting to see that Sparse Scrub red mangroves, which are stressed by waterlogging near the Biscayne Bay or by hypersalinity upland, (Teas et al., this volume) had R that equalled or exceeded the GPP in a short time experiment (Table 2). These scrub trees have smaller leaves than do normal trees and show other signs of stress. Sparse Scrub trees have so little biomass per unit area that the pro-rated increments of wood for an estimated 45 years since their seeding (Teas, et al., this volume) is ca. 26 g/m^2/yr or ca. 13 gC/m^2/yr which averaged 0.04 gC/m^2/da as fruit, flowers and propagules (Table 1). These Sparse Scrub trees are thus allocating as much of their NPP to reproductive structures as to wood.

The areas, litter fall, and calculated NPP of the south Biscayne Bay mangrove communities are shown in Table 3. The total litter production is almost 3.8x10^4 mt/yr and the NPP approaches 5.7x10^4 mtC/yr. This last number represents an estimate of the amount of carbon fixed in litter plus wood (all of which wood will ultimately become litter when the trees die).

The area south of the Coral Gables City line encompasses the great majority of Biscayne Bay's mangroves. The significant tracts which contain mangroves that are excluded from the estimate are: Interama, Key Biscayne, Virginia Key, Cocoplumm, Matheson Hammock, the ITT Snapper Creek Property, Gables-by-the-Sea, and the Dade County Chapman Field Park. The total areas of mangroves on these properties, are ca. 5-6% of the total along Biscayne Bay. The community types are generally Coastal Band, Dense Scrub and White and Mixed Communities. An approximate correction for the productivity of these mangroves would bring the Biscayne Bay totals to ca. 4x104 mt litter/yr and a NPP of 6x10^4/ mtC/yr. It should be noted that half of the mangroves of the barrier islands at the east side of Biscayne Bay are considered in the present estimates of mangrove area and productivity.

DISCUSSION

Available data indicate the NPP of these Biscayne Bay mangrove forests vary from 1.28 mt/ha/yr for Sparse Scrub to 10.7 mt/ha/yr for Coastal Band. This is low for tropical forests which are generally acknowledged to be more productive than temperate forests. Golley and Lieth (1972) estimated that tropical forests have an average NPP of 25.3 mt/ha/yr, with a range of from 13-123 mt/ha/yr. Temperate forests average 12 and 28 mt/ha/yr for deciduous and coniferous forests, respectively.

Comparison of Biscayne Bay's mangrove productivity with that of the bay's macrophytes is interesting, since the likely greater productivity of the seagrass community has been raised by Thorhaug et al. (1972) and others. The area of south Biscayne Bay as defined here is approximately 42,776 ha, the total area of mangroves is ca. 7,876 ha. A value of 2,000 gC/m^2/yr was assumed for seagrass litter production estimates (Roessler and Beardsley, 1974) and 25% cover of Biscayne Bay by seagrass was assumed (estimate of Jones, 1968). The productivity is a high value, but probably more than 25% seagrass cover is involved. The approximate seagrass litter production for the bay is 4.2x10^5 mt/yr. Roughly this means that for the whole of Biscayne Bay the average annual litter from seagrasses is ca. 9-12 times as much as the litter from mangroves.

It is notable that of the 5 mangrove communities which can be recognized as the major types along Biscayne Bay, 4 have been found to be modified by man (Teas, et al., this volume): The Coastal Band in its fullest pre-drainage development had other non-salinity tolerant species within it until reduction of freshwater flow eliminated the salinity sensitive species; the Dense Scrub is almost completely induced by man as a consequence of drainage that salinized previously freshwater graminoid marl land and allowed dense development of red mangroves; the Sparse Scrub, which was found only near the shore of south Biscayne Bay in 1900, has advanced 5-6 km inland because of drainage that reduced freshwater flow (Reark, 1975); and White and Mixed, which was seeded on salinized marl lands by hurricane high tides. Thus, most of the mangrove communities present today along Biscayne Bay are either in their present form or owe their existence to salinity induced secondary succession.

It would be useful to reconstruct a picture of the mangrove forest of Biscayne Bay before modern dredge and fill operations and compare their probably ecological function and area in pre-drainage days with those of the mangroves of today. It is possible that we have a greater area of mangroves along Biscayne Bay today than existed in 1900.

Salinity is clearly a dominant factor in the evolution and development of Biscayne Bay's mangrove communities. The effects on the biota of salinization of the Whitewater Bay area of Everglades National

Park as a consequence of opening the Buttonwood Canal has been reported by Tabb et al. (1962) and Thomas (1974). The metabolic influence of salinity on mangroves needs to be investigated. The role of root zone salinity, as opposed to surface water salinity, is critical for mangroves growing on marl along Biscayne Bay. The importance of the difference was appreciated by Davis (1940). This value was from Lugo and Snedaker (1974) which based on estimates of both ground area and leave area metabolism. Since the leave area index for these forests is not available, the magnitude of the estimate is questionable. The logistics have been worked out for such investigation. Odum and Jordon (1970) used a plastic cylinder 20 m high and 18 m in diameter for rain forest metabolic studies in Puerto Rico. Wilson and Simberloff (1969) used tents up to 18 m in diameter and 10 m high over entire mangrove islands for fumigation experiments in the Florida Keys.

The response of Biscayne Bay mangroves to freshwater upland runoff and to inorganic nutrients is important to understand. Studies of inorganic nutrient, freshwater and salinity effects on Dade County mangroves growing on marl soil are the most important aspects to be investigated. The results may well provide guidelines for the management of the present Biscayne Bay mangroves.

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TABLE 1. Litter produced by south Biscayne Bay mangrove communities

Community	Average litter g/m^2/da				Typical mangrove tree species distribution (%)		
	Leaves	Fruit, flowers and propagules	Twigs, bark, wood, misc.	Total	red	white	black
Coastal Band	2.20	0.56	0.17	2.93	79	14	7
Dense Scrub	0.82	0.36	0.05	1.23	84	6	10
Sparse Scrub*	0.24	0.08	0.03	0.35	95	5	0
Black Swamp	.69	0.02	0.07	0.78	0	2	98
White and Mixed	.99	0.07	0.09	1.15	6	94	0

* Estimated from harvest data

TABLE 2. South Biscayne Bay mangrove productivity estimates (gC/m^2/da)

Mangrove species	Forest type	Location	Gross primary productivity	Respiration	Net primary productivity			Reference
					Litter	Wood	Total	
Red	Mixed Community (average)	S.W. Florida	12.0	5.7	1.3^a	5.0^b	6.3	Hicks and Burns (1975)
Red	Hammock	B. Bay Florida	1.9	0.6	1.3^a	0	1.3	Burns (cited by Lugo and Snedaker, 1974)
Red	Forest	Puerto Rico	8.2	9.1	1.3^a	0.42	--	Golley et al. (1962)
Red	Sparse Scrub	B. Bay Florida	1.4	2.0	0.14^c	±0	--	Burns (cited by Lugo and Snedaker (1974)
Black	Black	S.W. Florida	9.0	6.2	1.3^a	1.5^b	2.8	Lugo et al. (cited by Lugo and Snedaker (1974)

a Average litter for mangrove forests, excluding scrub (Pool et al., 1975)

b By difference

c Data from Teas

TABLE 3 South Biscayne Bay mangrove productivity

Mangrove community	Area % distr.	Area ha	Rate litter* mt/ha/yr	Total community litter* mt/yr	Total NPP mtC/yr**
Coastal Band	56.7	2,192	10.7	23,454	35,181
Dense Scrub	21.5	1,628	4.49	7,310	10,965
Sparse Scrub	14.7	3,476	1.28	4,449	6,674
Black Swamp	0.1	13	2.85	37	56
White and Mixed	7.0	567	4.20	2,419	3,629
Total		7,876		37,669	56,505

* Dry wt organic matter, metric tons/hectare/yr

** Based on NPP = litter x 3 (Bray and Gorham, 1964; Golley, 1972) and litter dry wt x 0.5 = C (Golley et al., 1962)

ECOSYSTEM MODELS OF MANGROVE COMMUNITIES IN BISCAYNE BAY

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ABSTRACT

The systems view of ecological communities provides a holistic perspective for gauging the impact of human activities on natural ecosystems. This paper emphasizes the use of ecological circuit notation for the development of biologically sound mathematical models of ecosystems. The conceptual framework underlying ecosystems analysis is defined, and specific models of mangrove community dynamics are developed with reference to the pertinent literature on structure and function of this ecosystem. The models emphasize the following ecological aspects of mangroves in the coastal region: (1) productivity of mangroves is controlled by a synergistic interaction between tidal flow and fresh water availability; (2) interception and filtration of surface runoff by mangroves captures nutrients otherwise lost to the open sea, improving water quality in the process; (3) detrital production by mangroves helps fuel food chains supporting fisheries and bird populations; (4) shallow brackish waters around mangroves are nursery and breeding grounds for many estuarine dependent animals. The models concentrate on ecosystem processes within the mangrove community, and serve to point up the many processes and variables needing assessment in the Biscayne Bay area mangrove ecosystem. Successful use of the ecosystems approach for natural resource management will require careful definition of realistic management alternatives, ecologically sound models of the impact of management schemes on the region, and careful research to calibrate the models to the Biscayne Bay ecosystem.

INTRODUCTION

The term "ecosystem" was introduced into ecology by A. G. Tansley in 1935. Since that time ecosystem ecology has developed into a distinct specialty within the general field of ecology, but the term "system" has become so diluted in the general culture that its meaning has been nearly lost. In general systems theory, a system is usually defined as "an arrangement of physical components connected or related in such a manner as to form and/or act as an entire unit" (DiStefano et al. 1967) or some equivalent phrase. The essence of the definition lies in the concept of a unit response of the entire system to perturbation of any member of the collection of items. General systems theory as a discipline is directed towards abstracting the principles of organization that lend this property to collections of "physical components". To that end, systems analysis dissects functional units (systems) into a set of subsidiary conceptual elements.

Functional Categories of Ecosystems Analysis

System components

The first problem of any systems analysis is to define the system components in terms of their contribution to overall system performance. Since "performance" is usually construed to mean the process of transformation of system inputs (raw materials, energy, etc.) into outputs (products) and residuals (waste products, heat), the system components are usually defined in terms of functional contributions to input-output dynamics. In an industrial context difficulties are frequently encountered from the tendency of human organizations to have overlapping responsibilities, as for example when raw material acquisition involves a purchasing, accounting, transportation, and process control division (the latter ensuring that stocks of many raw materials are in proportion to total needs) of the same industry or firm. In ecological studies identical difficulties are encountered when, for example, energy transfer is defined as a significant process, and functional units are defined as trophic levels. It then becomes apparent that many of the species present do not fit conveniently in any of the functional categories, but may shift position according to stage of the life cycle, season, or even according to idiosyncratic preferences of individual animals.

Identification of functional components, then, is the initial task performed in any ecosystems analysis. However, the ultimate objectives of the study always strongly color this identification process. In particular, if human intervention and management of the system is contemplated, the definition of well-defined and realistic management objectives is extremely important (Thornton, 1975). Since all models are designed around a particular set of objectives, no model can accurately predict the outcome of environmental perturbations exceeding the original design parameters and topology.

Resources and environment

Additional attributes of a system include the system resources, environment, and the "goals" of the system (Churchman, 1968). The idea of system goals is sometimes disturbing to natural scientists who legitimately hold that ascribing "goals" and "goal-directed behavior" to natural systems constitutes a gross anthropomorphism. However, in the discipline of systems analysis, the description of system goals has no connotation of the conscious intentionality that is often a feature of individual human goal-directed behavior. Instead, system goals are used to describe operationally what the system in fact does in order to transform inputs to outputs, and the net result of this process. Thus in ecology, when the goals of ecosystems are described as a maximization of useful power (energy flow) (H. T. Odum, 1972), or a maximization of standing crop per unit maintenance metabolism (Margalef 1968, Morowitz 1968), what is being attempted is a general observation of how ecosystems in fact perform, a judgment that, at least ideally, is value-free. In the industrial example, the set of goals that emerge from objective analysis are frequently quite different from the goals perceived and intended by management.

A system has external environmental influences and internal resources. System resources are defined as those elements, processes, or factors that affect system performance and are under direct system control. The system environment is defined as that set of elements that affect system operation, but over which the system has no control except as feedback exchange. For example, in analyzing the ecological process of autotrophic energy fixation (particularly photosynthesis), we might consider the system environment to include sunlight, temperature, carbon dioxide and oxygen concentrations, and inorganic nutrient and water supply. System resources would include chlorophyll content of leaves, leaf and stand morphology, biochemical and genetic structure, enzyme concentrations, and local water and nutrient supplies. The processes of water inflow, outflow, recycle and conservation are a major part of many ecosystems. Their operation depends on an environmental component (rainfall, overland and subsurface transport through the system), and a resource component with control mechanisms that govern resource allocation and utilization. The interaction of water relations and energy fixation by plants is an important feature of many ecosystems and significant to any ecosystems analysis. Rosenzweig (1968) suggested that net primary productivity is linearly related to actual evapotranspiration at the biome level, and Carter et al. (1973) have adduced evidence that this is true on a more local (intra-ecosystem) level as well.

The discrimination between system environment and resource is often rather subtle, and often depends on the objectives and time scale of the analysis. For example, studies of fishery populations or benthic invertebrates in Biscayne Bay would probably treat the input of organic matter to the bay (mangrove debris, sewage, etc.) as part of the system environment, i.e. as a fixed constraint. From the larger perspective of the Bay watershed, organic input is a variable controlled by extent and vigor of surrounding mangrove forests, engineering policies vis a vis sewage plants, and other factors affected by resource decisions. Many industrial problems have been solved by sensitizing management personnel to factors that, although perceived as part of the environmental constraints of the system, in fact lie in the resource domain (Churchman, 1968).

Limiting Factors and the System Environment

The causal functions, driving forces, or forcing functions of an ecosystem constitute the system environment. The study of causal functions in natural systems has developed from the concept of limiting factors. This idea was first explicitly presented by Liebig, and was expanded by V. A. Shelford to include excess as well as deficiency of ecological factors as important aspects in the functioning of biological communities (Liebig 1840, Shelford 1913; quoted from E. P. Odum, 1971). The significance and interpretation attached to limiting factor observations depends to a degree upon the level of organization from which the system is approached. Liebig's original observation, that growth is generally controlled by short supply of a single mineral, was made in an agricultural context of focus on a single cultivated plant species in monoculture. Even at the single species level of integration, organisms cannot really be said to be completely driven by environmental conditions, and frequently modify their microclimate or so adapt (acclimate) that the limitations apparently imposed by the physical environments are considerable ameliorated. Examples of this phenomenon are provided by ecotypes (Turesson, 1922) that are strongly modified in their responses to local conditions, both in terms of tolerance of extremes of environmental factors and in their maximum growth responses to variation in the average levels of driving forces. The plasticity and 'ingenuity' of both plant and animal adaptation is so great that in some senses it is difficult to credit the idea that any individual organism is very much 'limited' in the habitats where it is actually found (Billings, pers. com.). Even a creosote bush (Larrea tridentata) in the deepest parts of a hot desert, taken as an individual, will appear to be well-adjusted and thriving in its "inhospitable" surroundings.

At a population and at an ecosystem level, the picture that emerges from study of limiting factors can be quite different. Shelford's (1913) extension of the law of the minimum to a law of tolerance helps to clarify the situation for populations of organisms. Tolerance (or rather, intolerance) of environmental extremes often strongly shapes both distribution and abundance of species populations (Andrewartha and Birch 1954). At the ecosystem level of organization, the correlation of total (above-ground autotrophic) yearly net production with evapotranspiration has already been mentioned (Rosenzweig, 1968). This relationship appears to be a result of actual evapotranspiration being a measure of the coavailability of water and sunlight, probably the two most important limiting factors to ecosystems. H. T. Odum (1971) has argued that other 'limiting' factors (e.g. mineral nutrients, temperature, etc.) are with few exceptions susceptible to successful adaptation on the part of evolving species and ecosystems. Most adaptations, however, involve a metabolic drain or cost requisite to the process of coping with environmental shortcomings of the habitat. For example, although desert plants are admirably adapted to hot deserts, their very adaptations unfit them for life in gentler environments. Sclerophyllous growth form, ability to shed leaves under water stress, ability to store substantial quantities of water: all these are liabilities in the competitive situations of mesic environments. Each such adaptation is accompanied by a metabolic expenditure vis a vis the ways mesic ecosystems deploy their energy base, and in a mesic habitat would result in rapid elimination of species possessing such characteristics from the system. An example of this process at work at the community level is shown in Table 1, which demonstrates the response of the autotrophic stratum of a mangrove ecosystem in South Florida to gradients of salinity and of the auxiliary energy support provided by tidal renewal of the soil solution (Carter et al. 1973). In this case community gross primary productivity increases as the ocean-front edge of the community is approached, but salt stress levies an increasingly greater "stress tax" on the metabolic budget. The balance of these competing processes results in maximum net productivity being attained in the midreaches of the estuary, where tidal energy and chemical water activity are in some optimal combination. In a systems context, the dispute over whether nitrogen, phosphorus, or carbon is "limiting" is perhaps to an extent resolvable by observing that all three are biologically active and important substances, but what basically "limits" the productivity of ecosystems is the size of the energy base available to cope with environmental stresses and shortcomings of all kinds. For example, the generalization that nitrogen is "the most limiting factor in estuarine systems" must be tempered by the realization that salt marsh and mangrove communities fix atmospheric nitrogen (Greene and Edmiston 1974, Kimball and Teas 1975, Zuberer and Silver 1975). Furthermore, E.P. Odum and Fanning (1973, quoted from E.P. Odum 1974) have found that salt marsh systems respond directly to the energy subsidy provided by tidal action, with a peak response at a tidal range of five to eight feet. To sum up, it seems that study of the causal functions that drive ecosystems must to some extent be conducted at the ecosystem level directly, and although mechanisms of action are to be sought at a more atomistic level of integration (e.g. in environmental physiology), considerable caution should be exercised in extrapolating physiological conclusions to the complete ecosystem.

Emergent Properties and System Topology

This problem has been expressed in capsule comments such as "the whole is greater than the sum of its parts" and "'emergent' properties dominate response patterns of whole systems". Such statements have achieved a mystical aura in the popular press, but really amount to nothing more than the observation that a list including sodium bicarbonate, flour, and eggs does not adequately express the 'emergent' properties of a chocolate cake. Emergent properties of this type are obviously real phenomena that arise to bedevil most land management programs. They are a result of the nature and intensity of functional interactions among the system components, and are only surprising or unpredictable when the system topology and its resulting constraints are ignored (Caswell et al. 1972).

Model Validation

A particularly thorny arena that has generated some friction between modelers and managers is that of model 'validation'. Our society is currently heavily committed to 'objective' measures of performance, which apparently typically measure the worth of a model by how well it fits some set of real data. Even leaving aside the question of the (usually subjective) criteria for a good fit, and the validity of the real data, there is some doubt that data fitting per se is a more than marginally useful exercise. Here we must distinguish between models that are designed only to provide information on future states of the system, and models developed from a systems theory baseline that are designed to advance our understanding of the real system (Wiegert, 1975). The epitome of the first type is the statistical model (e.g. linear regression), which is by definition valid only within a previously measured response domain. In this case the fit of the model to the relevant data is usually quite good, but its reliability as a predictor of the response of real systems to the novel situations brought about by technological environmental management policies is by definition unknown.

By contrast, models based in theory are applicable over a wider range, but can only be disproven by systematic test of hypotheses generated from the model and its initial conditions. Only a long series of failed attempts to disprove can be regarded as sufficient to induce faith in the model, and even then one crucial experiment may suffice to discredit it. In fact, poor fit of a model of this type to observed data is often a more useful situation than good fit, since parameter optimization techniques may correct the deviation and thereby suggest further or refined data collection in the appropriate area. In addition, it is often particularly significant when the optimization process fails as well, since this suggests that some important aspect of system topology is not well understood.

If the potential benefits of systems ecology to environmental enhancement programs are to be realized, some institutional means must be found of marrying politically responsible authority to regulate and control with scientifically responsible evaluation of the results of management policies. 'Models' are always approximations, useful for extrapolation of the implications of current understanding and for exposure of gaps in our knowledge. Models are useful tools that can guide our progress toward the understanding of ecosystems, but must always change and advance as understanding becomes more comprehensive and incisive. Models are by no stretch of the imagination a panacea for environmental problems, but do suggest avenues for further exploration and likely management strategies.

METHODS OF ECOSYSTEM ANALYSIS

Most of the ecosystem models of mangroves discussed in this paper use the system of ecological circuit notation developed by H. T. Odum (1971, 1972). A brief discussion of the theory underlying the notational system and the specific significance of the free-body modules is given here in order to enable the reader to follow the diagrams and evaluate the perspective governing model formation.

Energy Transfer and Mineral Cycling

An ecosystem can be defined for analytical purposes as a set of functional components, biotic and abiotic, which are coupled by flows of energy and materials whose magnitude, direction, and functional form are amenable to direct investigation. Within this definition there is a major disparity between energetic coupling and mineral flow coupling that must be borne firmly in mind. It is summarized by the distinction that minerals circulate in ecosystems; but the flow of energy is one-way through the system. Incoming energy is ultimately dissipated in heat. A major area of investigation in systems ecology is embedded within this definition, that of the nature of the interaction between these two apparently dissimilar processes.

The flow of energy and materials in ecosystems is roughtly parallel. For example, the transfer of energy along food chains occurs via the consumption of high-energy materials contained in the food. The concentration of mineral nutrients in the soil system is paralleled by a dissipation of energy in the detrital food chain. This interaction of energy flow and mineral cycling serves to organize collections of plant and animal populations into ecosystems: the population gene pools act as an information storage that establishes and maintains the range of successful interactions we see operating in ecosystems today.

Transformation of energy into useful work is the basic process governing the operation of all systems. Artificial systems serving man's purposes rely on the ingenuity of the engineer to establish useful pathways of energy flow, while natural systems employ selective pressures acting over a lengthy time span to achieve what may be similar end results. These may include the development of processes that enhance long-term stability, some set of particular resource utilization rates with a balance of throughput and recycling, and progressively greater internal control of environmental variables. In both cases the laws of thermodynamics establish the boundary conditions that constrain system operation. These laws help form the underlying guidelines for constructing system circuit diagrams for ecosystem analysis.

In brief, the first (conservation) law imposes a requirement that the energy budget be balanced, i.e., it is not possible for any incoming energy to simply disappear. This is not so trivial a point as it appears, for it serves as a means of keeping track of the completeness of a system definition: if major terms of the energy budget do not appear in the model, this can be taken as an indication that the circuit is not yet complete. The degradation of potential energy to dispersed forms (second thermodynamic law) accompanies every energy transformation. This forces systems to treat the utilization of potential as a prime resource. Perhaps a profitable way of viewing the second (entropy) law in this context is that potential represents the opportunity to perform useful work, and some of this opportunity is irretrievably expended each time it is employed (Sears and Zemansky, 1963).

These two considerations make possible the calculation of balanced energy budgets for whole systems, and lend assurance that the opportunity to transform energy to useful work must be apportioned in a systematic, regular fashion. The loss of work opportunity with each transformation forces the system to treat this eminently exhaustible commodity as its most precious resource. Moreover, it assures us that there is scant likelihood that any substantial energy consuming process is incidental to basic system function.

The circulation of mineral elements in ecosystems may act as a feedback governor that helps control the direction and speed of energy flow. A similar mechanism may be at work in economic systems, insofar as currency circulation may be said to effect changes in potential work opportunities. This feedback effect lets us define an energetic value for minerals and nutrients in terms of the energy flows they control. A similar treatment of dollar flow and energy flow may be possible as well. Dollar flow and mineral flow are in any case both accompaniments to the flow of energy and its dissipation in the course of the useful work that has developed and maintains the world as we know it. This parallelism allows preliminary comparisons of natural and artificial systems to be made in terms of a common measure of value. For example, a quantitative equivalence between currency and energy can be defined from a ratio of kilocalories of energy to the U. S. dollar, derivable from available information on the annual real gross national product and total yearly power consumption in the U. S. economy (H. T. Odum, 1971).

Ecosystem Processes and Productivity

Photosynthesis, respiration, and matter transport are the basic processes of ecosystems that account for energy fixation, utilization, and transformation; and for the cycling of crucial limiting minerals. The primary productivity of the ecosystem represents the energy available to operate all the energy consuming processes and biological work powered by organic respiration throughout the system. For this reason primary consideration must be given to direct measurement of gross photosynthesis as a most important system parameter; gross primary productivity establishes the magnitude of the organic energy budget available for all other purposes. Ecosystems may be coupled to auxiliary energy sources as well, and in some cases may be totally dependent on them (for example, benthic detrital systems). Auxiliary energy sources provided by physical and chemical environmental processes may reduce the quantities of energy the system expends in maintenance, and are often of sufficient magnitude to produce selective pressures that create ecosystems specifically adapted to utilize them. In general, these subsidies may make additional energies available for increased complexity of biological organization or increased net productivity. At the other end of the scale, physical processes often produce conditions that require a commitment of energy resources to counter destructive effects - this situation serves to define the concept of a "stress" in energetic terms.

The flow of energy through ecological systems begins with the fixation of solar energy by autotrophic organisms. The rate of storage of radiant energy in organic materials is called "primary productivity", and it is usually estimated by measuring some indirect quantity associated with energy fixation. The production process utilizes carbon dioxide, water, nitrate, phosphate, and other mineral elements as raw materials, and releases molecular oxygen as a by-product. Study of the rate of disappearance of any of these source materials, or rate of by-product accumulation, can yield information about the magnitude of primary productivity.

The production process is composed of a balance among several component processes, each of which has importance in delineating the energetic status of an ecosystem. "Gross primary productivity" (GPP) is the total rate of photosynthesis, accounting for the energy used in maintenance activities during the period over which observations are made. "Net primary productivity" (NPP) refers to the gain in bulk of stored materials within the plant tissues over an observation period. It is the net balance between gross energy fixation and the concurrent utilization of energy in the life process. Energies expended in growth, reproduction, and tissue maintenance activities are referred to as "respiratory metabolism" or "respiration" (R). These relationships can be summarized as (NPP = GPP - R).

The precise significance of each of these terms depends strongly upon the context in which it is employed.

Energy fixation and tissue growth are both complex biochemical processes that are composed of lengthy series of enzymatically controlled reactions. Each step involves energy losses in the transmission of energy via intermediate chemical species towards final storage products, and the magnitude of quantitative assessments of the rate of energy capture thus depends heavily upon which step in the sequence is chosen for study. For example, electronic excitation of the chlorophyll pigment molecule is the initial step in photosynthetic energy capture. Measurement of this step has been accomplished by numerous detailed studies of the molecular physics and chemistry of chlorophyll (Zelitch, 1971). Every downstream reaction coupled to this initial energy capture device necessarily involves a thermodynamic efficiency less than unity. In consequence, the putative "efficiency" of photosynthesis relative to impinging radiant energy, as well as the absolute magnitudes of measured energy capture rates, is greatest for this solid-state physical process of electronic excitation and declines steadily through the anabolic sequence. In this sense the significance of "productivity" measurements depends on the technique employed in measurement.

The "net production" of a plant community has varying meanings depending on the time frame used to define measurement. Over the yearly cycle or growing season, it is usually used as the net storage of organic matter after accounting for heterotrophic consumption (grazing) and mortality. On a daily basis, it is the net gain (or loss) over a full diel cycle, that is, net production in daylight hours less respiratory energy utilization during the night-time. The utility of these definitions is related to the ultimate purposes behind the measurements. Seasonal net community productivity is a concept of great agricultural significance, and in some ecosystems measures the size of storage accumulations necessary, e.g., to survive seasonal unfavorable weather and initiate subsequent re-growth from the stored reserve. It also serves to guide studies intended as estimators of the capacity of particular ecosystems to support, inter alia, the seasonal reproductive activities of dependent animal populations. Such studies are usually performed by periodic standing crop evaluations, with net production defined as the difference between yearly extremes. It should be noted that even in situations where this definition yields zero, or very low values, considerable animal populations may be supported by the daily net production, most or all of which may be rapidly consumed by grazing food chains and the production of flowers and fruits. In neither the case of a fertile pasture heavily grazed by livestock, nor that of a mature tropical rain forest, is it very useful to regard the system as unproductive; but neither shows much standing-crop change over a year's time.

The assimilation of atmospheric carbon dioxide by plant tissue has been widely used as an indicator of plant productivity. Carbon assimilation fails to account for a number of energy harvesting processes of probable importance in ecosystem energetics, especially in possible internal recycling of CO_2 as an energy carrier during daylight synthesis of enzymes, nucleic acids, and other important compounds; and in its inability to measure the true rate of daytime respiration, especially in plants in which respiration is accelerated by light (photorespiration). However, it is a technique that can be adapted to field survery work, and it measures a quantity (carbon fixation) that can be used to construct overall ecosystem energy budgets in equivalent terms (based on known fuel values of carbon compounds). In addition, carbon fixation is usually (though by no means invariably) a good indicator of the levels of availability of organic fuels to support heterotrophic ecosystem components (Table 1).

Free-body Modules

The modular components used in energy circuit notation for constructing ecosystem models are given in Figure 1. Each module represents a particular cluster of similar ecological entities, and each has a particular group of associated mathematical functions. Most ecological processes can be portrayed by combinations of these operators. Unit properties of the modules are described below.

1. a.) The passive storage module stores potential energy as the balance of its inputs and outputs. A complete definition requires a mathematical expression for the quantity of potential energy stored, and an expression of storage functions for establishing that quantity. The expression for the outflow usually is a function of the circuit connections as well as the quantity stored, that is, the flow of energy from the storage will depend on the process to which it is coupled. The input functions may also be of several kinds. For example, water stored in a tank against gravity has an energetic value related to its hydrostatic head; energy in compressed gas is related to pressure by a logarithmic function. These storages are state variables of the system, and may represent storages of water, chemicals, biological populations, air, money, information, etc. In an environmental system, with its great diversity of possible utilization pathways, there are losses inherent in any storage. Almost any concentration of a quantity constitutes an incipient energy source by virtue of its low entropy, and tends to be used by one agency or another. For example, a storage of food tends to develop chemical reactions, populations of consumer insects, etc. Work is done to protect the source if containers or some other means are used to insulate an energy source from losses. This is, in effect, a drain on the source. Leaf litter dynamics in forest ecosystems is an example of a process described by this module. The input to forest floor litter accumulation, a storage, is given by the simple sum of leaf-fall rates from the trees. Litter decomposition dynamics are usually adequately described by a rate equation based on the quantity of litter available to decomposer populations.

1. b.) The "work gate" represents a control function on the transmission characteristics of pathways of energy flow. The action of the control factor modifies the input-output transfer of energy through the block by regulating the conductivity of the contained pathway. For example, the transport rate of carbon dioxide gas to plants from atmospheric reservoirs is strongly controlled by wind driven air circulation in the forest. If the control agent is in short supply, the controlling factor can be represented as a passive storage. The dynamic behavior of the work-gate module can be shown to be a limiting factor hyperbola under these conditions (Odum, 1968). For example, photosynthetic production under phosphorus-limited conditions is controlled

by the rate of supply of phosphorus to the plant community. Phosphorus supply may be governed by the rates of accretion from exogenous sources or in situ recycling of previously generated materials.

1. c.) The "self-maintaining consumer population" symbol represents a combination of "active storage" (Figure 1.e.) and a work-gate (Figure 1.b.). In the population module, potential energy stored within the population is utilized to maintain a continuing input of new potential for growth and reproduction. Several formulations of the detailed operation of this module lead naturally to mathematical functions that exhibit "logistic" properties, i.e. populations that grow rapidly at first and subsequently reach a stable plateau of population size.

1. d.) The "pure energy receptor" symbol represents a coupling of pure energies such as sound, light, and water wave trains to an energy storage process. Chlorophyll dynamics are an example of this process. In this module incoming energy interacts with some cycling material to produce an excited or activated state, which then decays to its ground state while transferring energy to the next step in a chain of linked reactions. The kinetics of this module were first described in terms of enzyme-catalyzed biochemical reactions, generally labelled "Michaelis-Menton" kinetics. Its transfer function is hyperbolic. It is usually used in the present ecological context to depict the reception of light energy by plants in the initial steps of the photosynthetic reaction.

1. e.) This "active storage" module expresses the generation of stored potential from an input energy flow. In this case the re-storage requires that some transformation process be performed on the input stream. In this module work is being done against some resisting force, and the potential may be stored in a new form. For example, conversion of the kinetic energy of falling water to electric power in hydroelectric engineering projects can be represented as an active storage. The law of entropy requires that such conversions cannot be 100 percent efficient, thus some of the input energy is necessarily diverted to the "heat sink" of the module.

1. f.) The symbol for a self-contained subsystem (example: green plants) combines a cycling receptor module (Figure 1. d.) and self maintaining properties (Figure 1. c.). In addition, work must be done to maintain the photosynthetic machinery of the cycling receptor. All this internal organization is summarized in the bullet-shaped symbol of Figure f.

1. g.) Energy sources from outside the boundaries of the system of interest are indicated with a circle symbol. Names for this type of module from other system languages include: forcing function, driving function, environmental variable, etc. In order to completely describe the source, the nature of the energy flow (whether light, a flow of organic matter, the drying power of an air mass, etc.), and the manner of its delivery, must be specified. For example, one class of sources exert a constant driving tendency even when large flows are being delivered, e.g. the pressure from large water reservoirs, or chemical reactions taking place under conditions where reactant concentrations are maintained at constant levels. Another class is composed of sources that deliver a constant flow regardless of the utilization pattern downstream. Examples include the flux of sunlight, and water flowing past a waterwheel. Whatever the case, the delivery function must be indicated mathematically or graphically to complete the description of the source.

1. h.) Stress factors require the commitment of metabolic energies to counter their destructive effects. This symbol summarizes the process as a drain of potential that would otherwise be available for other ecological purposes. Although the rate of energy drain may be a linear function of stress intensity, the response of the system to long-term stress may show a lengthy period of minimal effect followed by an abrupt collapse. Such a pattern could emerge from the gradual exhaustion of energy reserves used in the ecosystem to weather normal intermittent short periods of unfavorable environmental conditions, such as drought. The curve for a stress factor might then follow the hyperbolic relationship of a limiting-factor work-gate draining system potential to the heat sink. The loss rate is controlled by an environmental factor entered on the opposite side of the gate.

1. i.) The gradient pump or forced diffusion module portrays a bi-directional transport of materials that may be proportional to a concentration gradient or a causal force operating the gate. The heat sink allows for conformance of the process to the second law of thermodynamics. Tidal flushing of an estuary is an example of such a process. Tidal forces move water in and out of the bay, and net concentration changes in dissolved materials are a function of concentration differences between estuarine and off-shore waters.

1. j.) Any miscellaneous transfer function appropriate to special cases is represented with this box symbol. This module is used when the function is unknown or of no consequence to the point being made. It can also be used when the mathematical transfer function is known but a specific symbol is not available.

1. k.) In a "constant gain" amplifier the input force acts as a tap on an unlimited supply source. Output dynamics are expressed as a constant increment of the input force called the "gain" of the module. The exponential growth of biological populations under completely unlimiting conditions can be portrayed with this module.

1. l.) Pathways of energy delivery are represented by the interconnecting lines of the circuit diagram. The existence of the pathway generally implies that work is done to maintain it, and this must be shown somewhere in the diagram. The nature of the causal force producing the energy flow is not automatically defined by the pathway. As in the case of the energy source, additional notation must be added to define the transmission characteristics of the pathway. However, this question need not be explored if the coupled responses of the driving agent (source) and the module receiving the energy are known. For example, in creating sets of differential equations from a circuit diagram for simulation, the time dependent behavior of each module is frequently derived by writing expressions for the balance of inflows and outflows to the unit. Each algebraic term describes a flow as a function of the causal actions.

The second energy principle requires that all spontaneous processes include a dispersal of potential energy into distributed heat of the environment, unavailable as a driving impetus for any further process. The heat sink representing this must flow from every spontaneously operating module of the energy system. When some simple system such as water flow or electrical current flow is being represented, the heat sink receives flow directly from the pathway. In complex modules that represent groups of processes, the heat sink is a miscellaneous conduit of heat dispersal from the several processes. For example, the respiration of an organism is the sum of many processes of work and heat dispersal. Respiration can be measured by the oxygen consumption or CO_2 production that accompanies these processes.

1. m.) The "digital programs" symbol, a special case of work-gate, is used when discontinuities have been identified in a conductivity control process. The design of complex switching functions used in modern high-speed digital computers has provided a thorough theoretical background to the use of this module in ecological models. Some switched responses are of a simple on-off character, but many reflect the simultaneous presence of several necessary conditions for the initiation of an ecological process. Many responses of ecosystems to environmental variables involve threshold effects. For example, the light ground fires characteristic of many southeastern ecosystems will not propagate unless standing stock of dry ground litter is greater than some threshold level.

1. n.) This symbol is used in combination with a work-gate to indicate the transport of dissolved or suspended materials by a mass flow of some carrier material.

1. o.) The "economic transactor" is used to relate the flow of energy to the flow of money, both in economic systems and at the interface between economic and ecological systems. Unlike the flow of minerals that accompanies energy flow, the parallel flow of money is in the opposite direction, as in a grocery store. The price structure and market mechanisms of the economic system regulate the conductivity and kinetics of this module. The direct heat losses of these transactions are small since the work involved generally is small, as for example in the purchase of goods in a market. However, the maintenance of complex regulatory agencies for controlling the prices of goods and services may induce substantial costs of coupling within the system.

We can summarize the useful features of the energy circuit language for compartmental modeling of ecological systems as follows:

1. Information is presented in a diagrammatic form that conveniently summarizes large quantities of data.
2. Energy flow pathways and functional interactions are presented in an explicit form.
3. Energy circuits can be rapidly transferred to a set of mathematical equations for simulation.
4. Each module implies a particular type of process describable by one of a limited set of mathematical functions.
5. Research directed toward calibration of the model and calculation of necessary coefficients for simulation can be coordinated by referring to the diagrams.
6. Circuit diagrams define system topology by the selection of a set of pathways interconnecting the components and defining energy and material exchange patterns among them.

ECOSYSTEM MODELS AND ANALYSIS OF MANGROVE COMMUNITIES

We begin our discussion of mangrove ecosystem models with a brief review of ecosystem level processes important to the place of mangroves in the natural economy of a region. Following this, we will consider system components, driving forces, and topological constraints in the context of specific models.

The largest and best developed mangrove forests of the United States occur in south Florida, where they play an ecological role analogous to that of salt marshes in the temperate zone. Although mangrove trees are of direct economic importance in many tropical countries [as timber, charcoal, tanbark, and source materials in the textile industry (Lugo and Snedaker, 1974)], in the United States the primary benefits to man have derived from the mangrove's ecological role in the coastal wetland ecosystem.

Mangroves and the Coastal Ecosystem

Substrate conditions

The coastal sedimentation environment is important in determining where mangroves can grow (Scholl, 1963). The balance between physical energies impinging on a shoreline from wave action and longshore currents, and the sediment load carried by local waters, determines the likelihood that a mangrove forest will be able to establish and maintain itself on a given site. Mangroves are generally found only on low energy, accreting shorelines, and are largely absent from eroding shorelines, although they may help stabilize marginal shoreline dynamics. Mangrove seedlings cannot take root on high energy coastlines where wave action washes out the young plants before extensive root systems can develop. On low energy shorelines, extensive mangrove forests can become established in spite of a lack of water-borne sediments that help build up soil around the root system. In the forests around Florida Bay, the mineral soils consist primarily of calcareous muds with very little admixture with sand. We can contrast this situation with conditions further up the coast in the Ten Thousand Islands. Here wave action is greater, but the area mangrove soils contain large quantities of sand derived by longshore drift from Cape Romano Shoals further to the north. A gradient in the percentage of sand contained in the soil can be discerned from the Ten Thousand Islands south to Florida Bay, indicating the nature of the balance between water movement and sediment load that must be found for mangrove communities to exist in any given locality.

Once established, the net of prop-roots and trapped debris of the mangrove fringe acts as a sedimentary weir, slowing water movement and allowing any load of entrained particles to settle out of the water column. Net production of the mangroves in excess of the remineralization abilities of detrital food chains may then result in deep accumulations of mangrove peat. Thus we are making a crucial distinction here: although mangroves can build land *up*, they cannot build land *out*.

Although mangroves do not "build land" in the sense inadvertently implied by earlier authors, they exert an important stabilizing effect on areas where they are able to grow. Artificial mangrove plantings designed to stabilize dredging spoil and other disturbed soil areas in the coastal zone have been studied in Florida including the Biscayne Bay area (Teas 1974, 1975; Teas, Jurgens, and Kimball 1975; Savage 1972); and mangroves were introduced into Hawaii (MacCaughey 1917) for the specific purpose of beach erosion control.

Zonation

Upward land building results in a successional sequence that results in a replacement of red and black mangroves with white mangrove, buttonwood, and ultimately wholly terrestrial or fresh water communities. However, it should be noted that this process has been unable to keep up with recent rises of general sea level, as can be seen from the occurrence of areas of drowned mangrove peat in Florida Bay and Biscayne Bay. Either a rise in sea level, or salt water intrusion due to drainage works and aquifer depletion, can induce a succession in the opposite direction at the landward margins of the forest. In general, although details at a given site might vary with elevation, soil structure, and seed availability, we could expect fresh water communities to be sequentially invaded by buttonwood and white mangroves and ultimately by a mature red and black mangrove forest. This idea is supported by observations of red mangroves growing on areas of white and black mangrove peat (Davis, 1943) , and by the observation of Teas, Wanless, and Chardon (this volume of red mangrove scrub expansion into formerly fresh-water areas following drainage.

Role of mangroves in the estuarine ecosystem

Mangrove forests are of considerable importance to the integrity of coastal zone ecosystems where they occur. Mangrove dominated areas are breeding, feeding, and nursery grounds for substantial populations of spectacular wading and fishing birds, sports and commercial fisheries, and help protect the coastal zone from devastation by tropical storms and hurricanes. The mangroves themselves are primary food-producing agents in tropical estuarine ecosystems, producing as much as 80% of the total organic materials available to the aquatic food chain (Carter *et al.*, 1973). The transport of mangrove derived organic materials into the estuary, and the patterns of utilization of these materials by estuarine animals, have been amply documented by Heald (1971) and W. Odum (1972) respectively. Considerable recent controversy has arisen, however, over the relative roles of the several species of mangroves in this process. The drainage basin studied by Odum and Heald was dominated by red mangroves with about a 1% admixture of white mangroves: no black mangroves were present at all. Intact black mangrove leaves are rarely observed floating in the estuary, which suggests that export of organic matter from black mangrove dominated forest zones may be predominantly in a dissolved or very finely divided form (S. C. Snedaker, pers. communication). Whether such dissolved organic materials have a substantial role in the estuarine ecosystem is an open question. Finely divided particles in transit through detrital food chains are usually exceptionally rich in protein (Heald, 1971), and dissolved compounds may serve regulatory roles within the system (Janzen, 1974). However, it should be emphasized that such possibilities are currently pure conjecture.

The internal ecological relations of the black mangrove zones of South Florida coastal forests have been examined by Tabb *et al.* (1974), especially in terms of *in situ* fish production. These authors conclude that events in this zone, although partially isolated from interchange with the lower estuary, are as important as red mangrove production in supporting estuarine animal populations. The black mangrove swamps and high marshes of Everglades Park are nursery grounds for tarpon, snook, and other juvenile marine fishes which derive their nutrition and growth from a detrital food chain based on a feeding sequence with black mangrove debris as the primary source material. This food chain proceeds through the feeding of mosquito and tendipid midge larvae on detrital materials, and heavy predation of killifish, mosquitofish, and other "forage" fishes on these insect larvae. Seasonal dry-downs of these marshes concentrate forage fishes in pockets within the marshes, which are then intensively utilized by wading birds during the rookery season. During high water periods or storm floods, considerable quantities of nutrients, including large numbers of fishes, are transported out of the marsh, providing a seasonal pulse of food nutrients to the lower estuary. This chain of events is strikingly similar to ecological relationships occurring in freshwater marsh areas of South Florida, and suggests that black mangrove swamps are intermediate in character between the red mangrove swamp, regularly washed by tide waters, and uplands completely isolated from marine influences. If this view is correct, the snook and tarpon are in a sense Florida's version of an anadromous fishery, with all the protection problems such an analogy implies.

Salinity and Forest Development

Mangroves are perhaps best known to temperate zone ecologists as an arboreal curiosity - a forest type tolerant of high soil solution salt concentrations. Halophytic tolerance is not unlimited however, and in many areas of the world mangroves in the coastal fringe are backed by land lacking any vegetation whatsoever. This phenomenon is especially common in areas of low rainfall or a pronounced wet-dry (monsoon) season. Here conditions inimical to the survival of any higher plants are created in inner segments of the coastal zone, which are washed by only the highest tides and then dry out leaving salt residues behind (Fosberg, 1961).

Although tolerant of high salinity conditions, mangroves appear to reach their best development in estuarine (polyhaline) situations. A study conducted by the U.S.E.P.A. in Southwest Florida (Carter et al. 1973) showed that maximum net primary production occurred in the mid-reach of the study zone under the most strongly polyhaline conditions (Table 1). Net production, which represents the organic fuel available to dependent wildlife and fishery food-chains, declined both towards the ocean-front and towards inner fresh water marshes. It appears that competition for space and nutrients may limit landward extension of mangrove forests, while salt stress may suppress maximum productivity under fully marine or hypersaline conditions. If this is the case, the modification of estuarine salinity patterns by upland drainage and other surface water control policies may have profound effects on the mangrove community and its associated fisheries. Community net production under fully marine conditions in the study noted above amounted to only 64% of polyhaline values, and this drop probably indicated a similar drop in carrying capacity of the area for wildlife. Accelerated transport of upland fresh water to the lower estuary may have several adverse side effects: pollutional loadings are not cleansed by passage through marshes and swamps, sharp salinity shocks are imposed on the lower estuary, the productivity and carrying capacity of the mid-reach estuary declines, and brackish water conditions that protect juvenile fishes, shrimp, etc. from predation are destroyed.

Teas (this volume) has estimated the litterfall component of mangrove net primary productivity for the Biscayne Bay area, and has compared the relative magnitudes of mangrove and seagrass litter production in the regional ecosystem. Teas, Wanless, and Chardon (this volume) have documented systematic soil salinity variations affecting Biscayne Bay mangroves. It appears that the mangrove scrub community may be poorly developed due to restricted water exchange in the marl substrates.

Research Planning Model of a Mangrove Estuary

An ecosystem model developed primarily for use as a research design and coordination tool is given in Figure 2. This model is divided into three major blocks of land area. On the left, contiguous upland terrestrial ecosystems are shown simply as a source of fresh water and dissolved nutrients flowing to the estuary. The bottom central portion of the figure represents mainland mangrove forests and salt marshes, and the upper right-hand section of the figure shows the estuarine bay ecosystem and its fringing mangroves and island mangrove forests. The Gulf of Mexico appears on the far right of the model as the ultimate sink for fresh water, nutrients, and detritus in the estuary (the model was oriented to conditions in Southwest Florida). Note that this model concentrates on the role of mangroves and benthic vegetation in the estuary, especially as this is affected by canal drainage of hydrologically connected uplands, and it neglects any mention of phytoplankton populations and grazing food chains.

As in Figure 1. n., the flow of water from the uplands entrains a flow of nutrients in proportion to the concentrations of nutrients in the water (Figure 2, process Block 1). Under sheet flow conditions, these waters and minerals enter the mainland mangrove and salt marsh zone, where they act as source terms for evapotranspiration and as a mineral nutrient supply for the photosynthetic activities of the plant communities. The "fresh water" storages in this model are intended in the sense of a dilution of sea water, that is, if pure sea water is present in the marsh it would be shown as zero fresh water, and conversely.

Marsh fresh water and nutrients are exchanged with the estuarine bay by the action of the tides (Block 2). The net exchange, as shown by the use of a two-way gate (Figure 1. i.), will depend on the relative salinities and mineral concentrations between the two water bodies and the volume of tidal exchange. Under drained conditions, the canal network acts as a switch (Block 3) that bypasses the mainland mangrove and salt marsh ecosystems and delivers fresh water and nutrients directly to the bays. In this case, delivery of upland fresh water and nutrients to mainland systems will only occur by tidal exchange from the bays, and much of it may be lost by tidal exchange with the Gulf of Mexico (Block 4). The extent of any loss of this kind would depend on the flushing rate of the estuarine bays. The mainland zones would become proportionally more dependent on rainfall inputs for their fresh water supply.

Within the mainland mangrove zone, plant production ultimately results in a production of detritus that fuels a detrital food chain. The basic sequence of litter decomposition and mineral regeneration ultimately supporting fish and bird populations is sustained by a major group of organisms summarized in the figure by the self-maintaining consumer block labelled "detrital food chain". An acceleration of the nutrient regeneration sequence is shown by a sequence of process blocks subtended to the populations of salt marsh and mangrove animal residents (Blocks 5, 6, 7 and 8 of Figure 2). Fresh water in the marshes controls the rate of incorporation of detritus into the food chain (Block 9) in the sense described by Heald (1971). Breakdown of detrital materials was shown by this author to proceed most rapidly under brackish water conditions. Detrital materials not consumed directly on the marsh are exchanged with estuarine bay systems via the tidal exchange gate shown as Block 10. Juveniles of many species ("Juvenile Sport Fishes" population) may develop within these mainland salt ecosystems where brackish water conditions protect them from predation by piscivorous adults of the same and other species. Eventually they move to the bays, shown here as the transfer pathway marked "recruitment" in Figure 2.

Within the estuarine bay and island mangrove ecosystems two distinct plant communities produce organic fuels for the ecosystem. Solar energy fixation by the mangrove fringe and island systems may be gated by the availability of water for evapotranspiration and by the mineral nutrient concentration of bay waters washing this zone (Blocks 11 and 12).

Productivity of the marine "grasses" and algal communities of the bays themselves is controlled by available nutrients in the bay (Block 13) and the turbidity of the bay waters (Block 14). The extinction coefficient of the water governs the transmission of light to bay bottom communities by the well known exponential relationship

$$I = I_o e^{-kz}, \qquad \text{(Eq. 1)}$$

where if I_o is taken as visible light input at the water surface, z as the depth of the water column, and k as the extinction coefficient; then I is the light reaching the bottom community. Turbid waters are produced within these shallow bays by the action of wind induced stirring of loose sediments from the bottom into the water column. The transfer of momentum from moving air to the sediment surface is less efficient as the depth of the water body that must first be set in motion increases. Thus, the turbidity of a given bay is an independent function of the average depth of the bay, assuming the inputs of stirring energy from wind to any two bays is the same. In this sense, the light intensity reaching bay-bottom communities is a "double" function of the depth of the bay. First, depth determines the efficiency of the wind in producing turbid water. Second, light transmission to the bottom is then a function of turbidity (extinction coefficient) and the path length of incident light energy given by the depth of the bay as in Beer's Law (Equation 1 above). This situation is summarized by the source term to Block 14 marked "wind and water depth", and the pathway notation "e^{-kz}".

Both the bay bottom plant communities and the associated mangrove communities contribute to the detritus pool in the bays. Paralleling the situation in the upland mangrove zone, energy flow into the detrital food chain may be salinity dependent (control line from "Bay Fresh Water" at Block 15). The remineralization sequence proceeds as before through the decomposition sequence of Blocks 16, 17, 18 and 19, resulting in release of minerals bound in detritus for re-incorporation into new plant tissue. Each block represents an acceleration factor in the remineralization sequence, so loss of a block does not halt, but does slow, the total process.

The bird populations that appear at the top of both the bay and mainland food chains are in many respects the same population. They have been separated in this figure mostly for the sake of clarity in the figure. These bird populations may act to transfer minerals from bays back to terrestrial mainland communities. This factor could be of some importance to counter-current inter-system mineral transfers. A possible magnitude for this process is suggested by the observation that bird rookeries can produce sufficient quantities of phosphorus in their excreta to result in phosphate rock concretions in nearby waters (Lund, 1958).

Finally, the sports fish populations of the bay are harvested by an extensive guide and tourist industry within the region. This industry is portrayed by the economic transactor module at Block 20. The economic importance and estuarine dependence of the penaeid shrimp populations and commercial fisheries are not shown. The sports fishery was used as a simple descriptor of man's dependence on estuarine ecosystems for part of his economic well being.

This model suggests a number of major questions. For example, do canal inputs substantially modify salinity and dissolved nutrient regimes within the estuarine system? To what extent are minerals merely exported to offshore waters from these bays, and to what extent are they infused into mainland marsh and mangrove ecosystems by tidal exchange? What are the relative magnitudes of detrital inputs to bay systems from the resident plant populations and from the mangrove communities? Research engendered by the concerns expressed in this model was carried out by the U. S. Environmental Protection Agency and is reported in depth in Carter et al. (1973). Results obtained suggested a strong dependence of primary productivity of mangroves on auxiliary energy sources represented by fresh water inflow into the system and tidal mixing (Carter et al., 1973, Hicks and Burns, 1976, and Table 1).

Ecosystem Model of Mangrove Communities

The causes of the decline in community vigor with loss of a polyhaline environment (Table 1) are not completely clear at this writing. The most plausible explanation appears to involve an interaction of water chemistry with the physical energies of tidal water movement within the mangrove forest. For example, tidal movement of water, alternately draining and reflooding the intertidal zone, may serve to replenish the soil solution from which mangroves derive their water supply. This renewal cleanses the soil of accumulated salts and toxic sulfur compounds, and renews the supply of inorganic nutrients for further photosynthesis. The availability of brackish water for such injection into the soil system would enhance forest productivity by reducing salt stress and salt inhibition of production. More precisely, the soil solution salt content determines the osmotic pressure gradient between the soil water and the plant vascular system, which partially controls the rate at which water can be supplied to leaf tissues to support transpiration water losses. When this water supply is deficient, the leaf stomata close to reduce the rate of water export, which also reduces the uptake of CO_2 gas from the air, and thus reduces productivity. In addition, glandular excretion of excess salts from mangrove leaves requires an expenditure of energy (Atkinson et al., 1967, see also discussion below) that would otherwise be available for tissue growth.

The model presented in Figure 3 is a formal statement of the major processes by which fresh water input and tidal mixing may control productivity in the mangrove ecosystem. This model emphasizes the contrasting physiological adaptations of red and black mangroves to a saline environment. The essential problem for both species arises from the necessary export of pure water from the leaf surfaces during transpiration, which could produce a toxic accumulation of salty residues within the leaves and other tissues of the plants. The numbers in parenthesis in the discussion below provide orientation to the encircled numbers on the diagram.

The flow of water in higher plants serves two primary purposes. First, inorganic nutrients are transported to the locus of photosynthetic activity in the leaf tissue (1). Second, the exchange of gaseous carbon dioxide through the leaf stomata can result in dessication and wilting of the leaf, with a cessation of production, if the tissues are not continually remoistened to replace water lost through the stomata. Incident sunlight provides the driving force to evaporate water from the leaves (2), as well as providing the energy source for fixation of carbon dioxide in reduced organic compounds (3). The magnitude of transpirational water losses is conditioned by two additional environmental variables, the saturation deficit of the local air mass (i.e. the ability of the air to absorb water vapor), and the velocity of local winds that remove transpired water vapor from the leaf vicinity. Regulation of transpiration magnitude is also to some extent directly controlled by the plants themselves. On a short term basis, closure of the stomata occurs when the water supply to the leaf fails, thus preventing dessication of the internal tissues. This event would also reduce productivity by interfering with uptake of atmospheric carbon dioxide. Longer-term control of water loss can be accomplished by morphological changes in the leaves, which govern the internal resistance of the leaf to the diffusion of water vapor. Bowman (1921) observed an increase in succulence of *R. mangle* leaves on trees growing in salt water over those growing in brackish water. This might imply an increased tolerance for salt in the leaves [water-storing hypodermal cells (inter alia) were larger] and/or an increase in internal diffusion resistance.

Mangroves are tolerant of high salt concentrations within the cells of the plants, but the transpiration stream (xylem sap) is close to fresh water. The salt concentration in species like red mangrove, which do not secrete salt at the leaf surface, is less than 0.3 0/00 (4).

In *Avicennia*, which actively excretes salt residues from the leaves, xylem sap concentrations are about ten times higher, or 3 0/00 (5) (Scholander *et al*., 1962, 1966). The mechanism for this separation of fresh from salt water arises from a simple ultrafiltration through the root tissues of mangroves (Scholander 1968). Since filtration continues when the tissues are killed, this apparently is based primarily on structural properties of the root membranes rather than a continuous energy consuming process. The concentration of salts in the xylem sap appears to be independent of transpiration rate. Thus, in the model, transport of chloride to the leaf tissue of black mangrove is shown to occur as a simple proportionality to the volume of water transported. The chloride in the leaf tissue is then actively secreted onto the leaf surface, a process requiring a metabolic energy expenditure (7) (Atkinson *et al*, 1967. See also Kylin and Gee, 1970, for evidence that this species possesses ATPases activated by salts). Chloride secreted onto the leaf surfaces is returned to the surface water compartment by rainfall and leafdrop (8). Although some chloride is obviously transported to the leaves of red mangrove in the same fashion, it is not explicitly represented in the model since the concentration of the filtrate is a full order of magnitude less in this species, and salt is allowed to simply accumulate in the leaf tissue as the leaf ages (Atkinson *et al*, 1967).

Soil Chlorides and Transpiration Rate

Although the activity of soil water is always greater than that of water in the mangroves themselves, chlorides in the soil solutions slow water uptake in proportion to concentration (9). For example, Bowman (1917) found that transpiration rate of *R. mangle* leaves decreased with increasing soil salinity and increased with greater soil moisture. Bowman conducted an extensive series of laboratory experiments with red mangroves (*R. mangle*) cultured on Tortugas calcareous shell sand. These experiments were designed to elucidate the affect of salinity on transpiration rate of mangrove leaves. Bowman collected 1st or 2nd year seedlings in the lower Florida Keys, transported them to the Tortugas Laboratory, and planted the seedlings in jars filled with local coarse sand. Seven dilutions of full-strength sea water were used to water the experimental series of cultures, and in each case the culture water was completely renewed daily. The transpiration rate of plants grown under each condition was determined using a method developed by Stahl (1894, quoted from Bowman 1917) that involves a measurement of the time required for complete color change of cobaltous chloride on a disc of filter paper in contact with the leaf surface. In this method the quantity of water transpired is constant, although of unknown magnitude. However, so long as the size of the filter paper used in measurement is the same, and the conditions under which the measurements are obtained do not significantly vary, a good picture can be obtained of relative transpiration rates. Bowman reported his findings, representing "about two thousand records", as percentages of fresh (rain) water and time required to saturate the test disc. These same results, transformed into relative transpiration rate as a function of chloride concentration, are given in Figure 4, with the addition of a point for 140% seawater that Bowman did not include in his main tables because of high mortality in this set of plants. Inspection of this figure reveals a steady decline in relative transpiration rate with increasing chloride concentration in the soil solution.

We can evaluate the physical process controlling this relationship from additional information unavailable to Bowman at the time of these experiments. Scholander (1968) has demonstrated that mangroves desalinate seawater by a simple ultra-filtration process through the root membranes. This process does not require continual direct expenditures of metabolic energies, as can be seen from the fact that it continues even when the roots are poisoned with dinitophenol. The driving force inducing a continuing flow of nearly fresh water through the xylem towards the leaf tissues is provided by evaporative processes at the surface of the leaves (a function of irradiance, saturation deficit, and wind speed). The concentration of salts in the transpiration stream (xylem sap) is fairly constant and is independent of the rate of transpiration (Scholander *et al*., 1966). Thus it appears that the energy barrier to water transport posed by high salt concentrations in the soil solution is the most significant factor governing transpiration rate for a given value of the driving forces. However, it will be remembered that changes in succulence, over the longer term, could change the value of the salt gradient between the external and internal milieu and thus shift the entire response curve. In Bowman's experiments the specimens tested were grown at the relevant soil solution concentrations, so that adaptation effects are presumably accounted for in his results. In these experiments the magnitude of the driving force and the quantity of work done against the gradient (amount of water transpired) were constant, and the time necessary to accomplish this given amount of work increased with increasing soil water salinity. Examination of Figure 4 indicates that a straight-line relationship adequately describes the control of transpiration rate up to perhaps 23 0/00 chloride, and that a modified relationship with an asymtote at about 25% of the maximum might be more appropriate to simulation studies of mangroves growing in hypersaline conditions. The importance of tidal exchange as a mechanism for renewal of the soil solution has been alluded to already, and is shown by a set of tidal exchange blocks in the model(10).

The work of Lewis and Naidoo (1970) has directly demonstrated the importance of this factor. Working with *Avicennia marina* in South Africa, they found that transpiration responded to morning increases of light intensity and saturation deficit. After midmorning, transpiration decreased despite favorable atmospheric conditions, but later tidal flooding produced a new increase in transpiration rate. An additional strand of evidence supporting the importance of chloride in control of transpiration can be found in the work of Connor (1969). He reported laboratory studies indicating that although maximum growth was obtained with *A. marina* grown in brackish (15 0/00) water, loss of height development was considerably more marked than loss of dry matter production with increasing salinity. Loss of height is generally an indicator of decreasing water availability.

Nutrient Dynamics

In the model, phosphorus (P) has been used as an indicator for inorganic macronutrients necessary to biological productivity (Ca, Mg, K, N, etc.). External source terms include phosphorus in overland flow (11), rainfall (12), and tidal exchange with offshore marine waters (13). An additional source term is derived from remineralization of dead plant remains, etc. via a detrital food chain. A considerable amount of literature on decomposition rates as affected by rewetting frequency, salinity, estuarine filter feeders that act to trap nutrients in the swamp, and the role of the sulphur cycle in regeneration of nutrients, is summarized for the purposes of this model by a conductivity control block indicating acceleration by brackish conditions (14). Two populations are shown as being trophically connected to the detrital food chain. The first (C_1) consists of juvenile estuarine-dependent organisms that are seeded from, and recruited to, offshore adult populations by seasonal cues. The second (C_2) population consists of adult carnivores that may move into the estuary and feed on the developing juvenile populations under high salinity conditions (16). This is a means of modeling the well-known protection from predation afforded juveniles by brackish conditions. A most important feature of this model resides in its attempt to integrate the effects of inorganic nutrition, and the metabolic (including transpirational) consequences of halophytic tolerance, with environmental forces that are frequently modified by man. Most studies of mangrove growth under varying salinity regimes have found maximum growth to occur in brackish conditions, indicating that up to a point nutritional improvements of ambient waters more than compensates for reduced water availability brought about by chloride increases, as suggested by Kuenzler (1974).

The models developed in this paper treat the mangrove community as a distinct subsystem of the Biscayne Bay regional ecosystem. These models could be used as a framework for developing research to establish the functional forms and numerical parameters needed to calibrate the models to Biscayne Bay area mangrove communities. They could be used, as well, as a starting point for the genesis of models reflecting feasable and likely management strategies for the area. Computer simulation studies using the calibrated models could then be useful as a forecasting tool for exploring the impact of management actions on area ecosystems.

It should be remembered that all models are formed from a specific set of goals and purposes. For example, one of the models presented in this paper was designed as a research guide, and the second was developed to characterize the implications of that research. Computer simulation models have been used to study the role of allocthonous nutrient sources in mangrove community nutrient dynamics (Lugo *et al*.,1975); the effects of herbicides on mangroves in Vietnam (Odum *et al*., 1974); and photosynthetic response to driving factors (Miller, 1972). Models directed at the more general questions of management of Biscayne Bay would need to consider the roles of other subsystems (e.g. seagrasses, macroalgae, plankton) and specific proposals for management of the regional ecosystem. Lugo *et al*. (1971) constructed a series of preliminary ecosystem circuit diagrams incorporating this wider perspective as a general guide to needed research activities in the South Florida region.

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TABLE 1.

Community Metabolism of Mangrove Forest in Southwest Florida (Ten Thousand Island Region)

GPP stands for gross primary productivity, i.e. total carbon fixation; NPP for net primary productivity, the net fixation of organic materials for growth of the forest and support of dependent food chains; R stands for respiration, the quantity of carbon released by the plant community in the course of maintenance metabolism. Metabolism units are in grams of carbon fixed (or released) per square meter of forested land surface per day. [Table adapted from (Carter *et al.*, 1973).]

Station	Surface Water Chloride (ppt)		Community Metabolism ($gC/m^2/day$)		
	mean	range	GPP	NPP	R
Upper Estuary	4.7	0.4	10.3	6.6	3.7
Middle Estuary	12.7	8.8	11.8	7.5	4.3
Lower Estuary	16.0	2.0	13.9	4.8	9.1

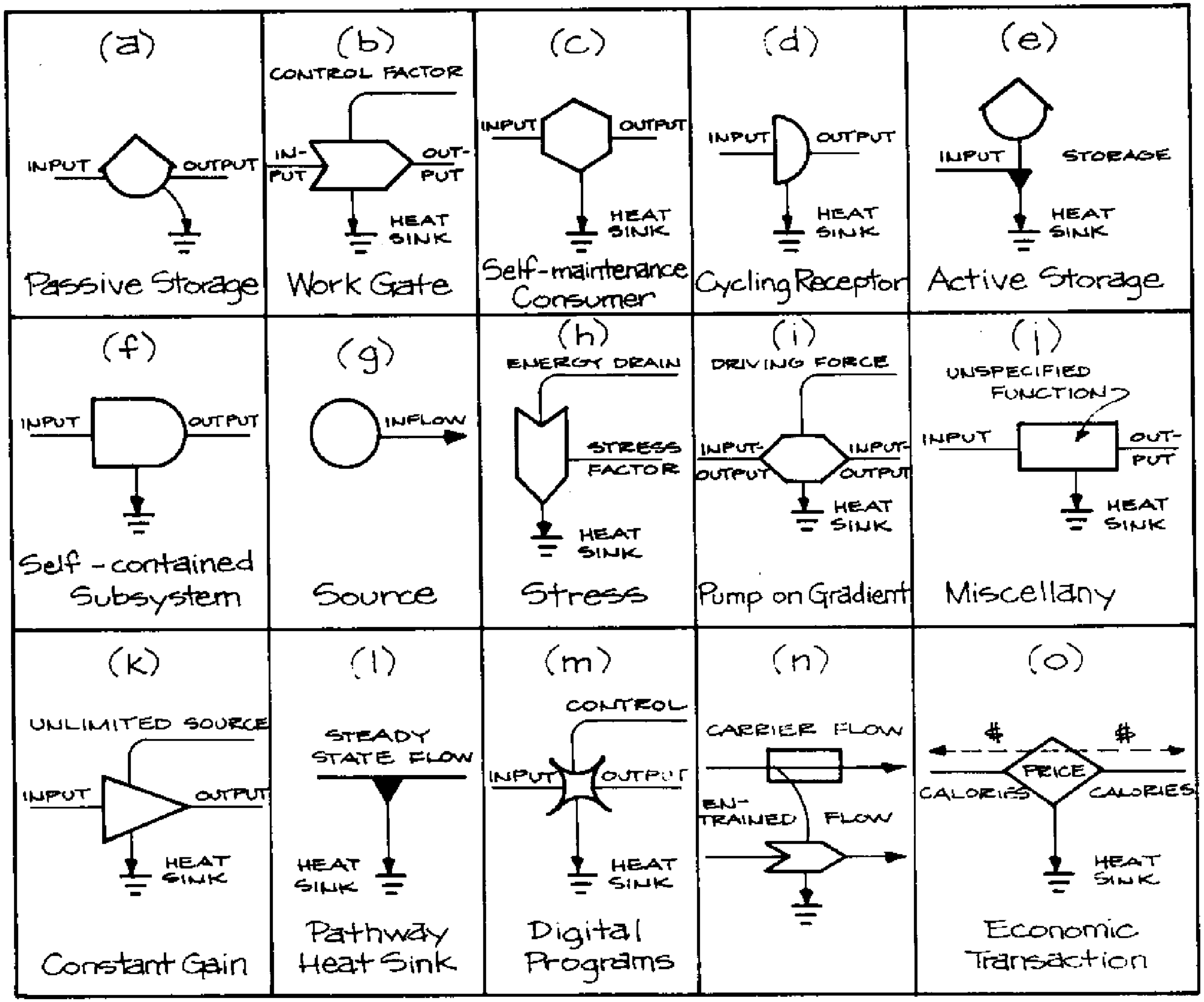

Figure 1. Functional elements of the energy circuit language. These modules are used as blocks in constructing compartmental models of ecosystems. Association of mathematical functions with compartment interactions enables computer simulation of ecosystem dynamics. Details of these mathematical relationships and derivation of some interaction terms can be found in H.T. Odum (1972).

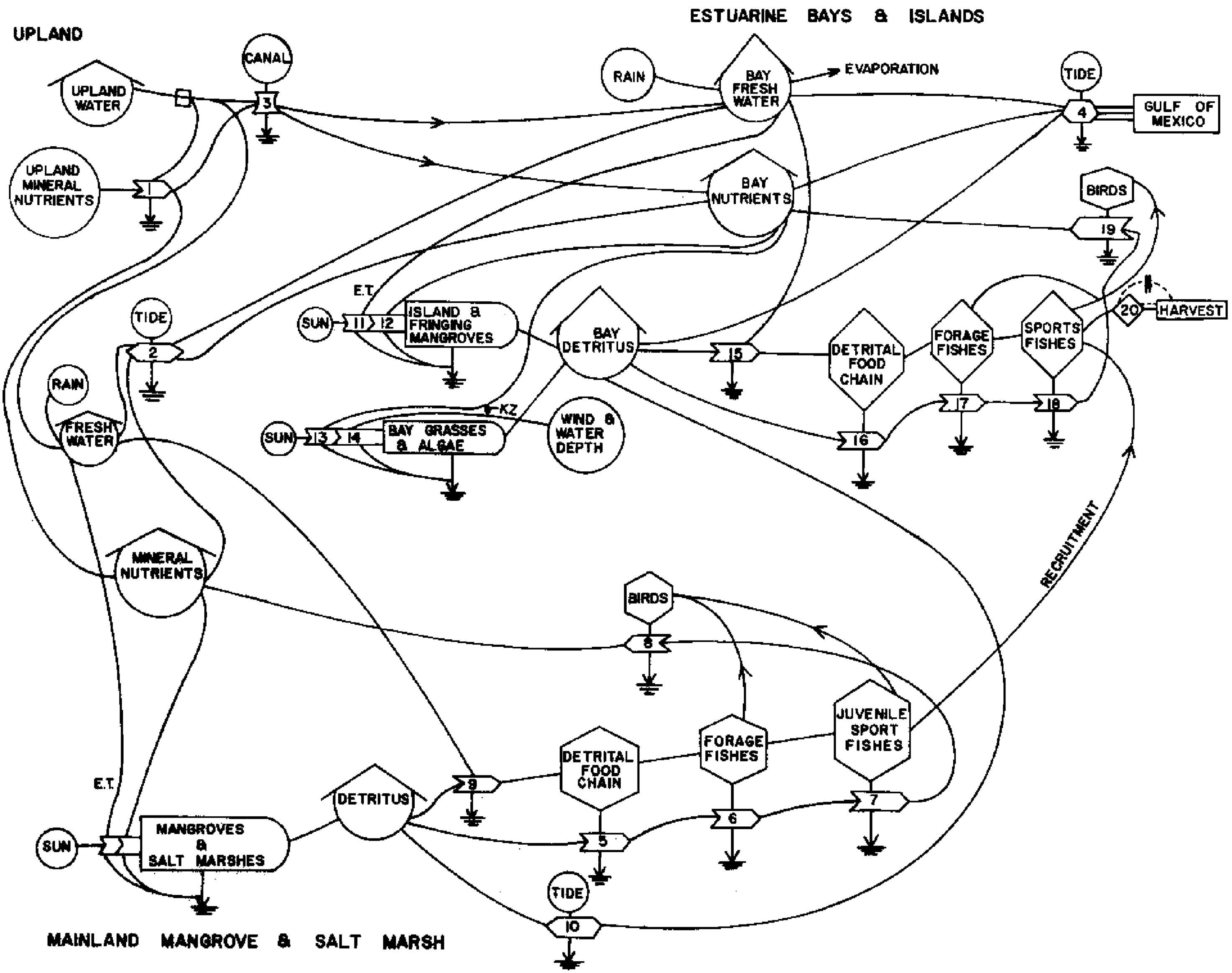

Figure 2. Research planning model of a mangrove estuary.

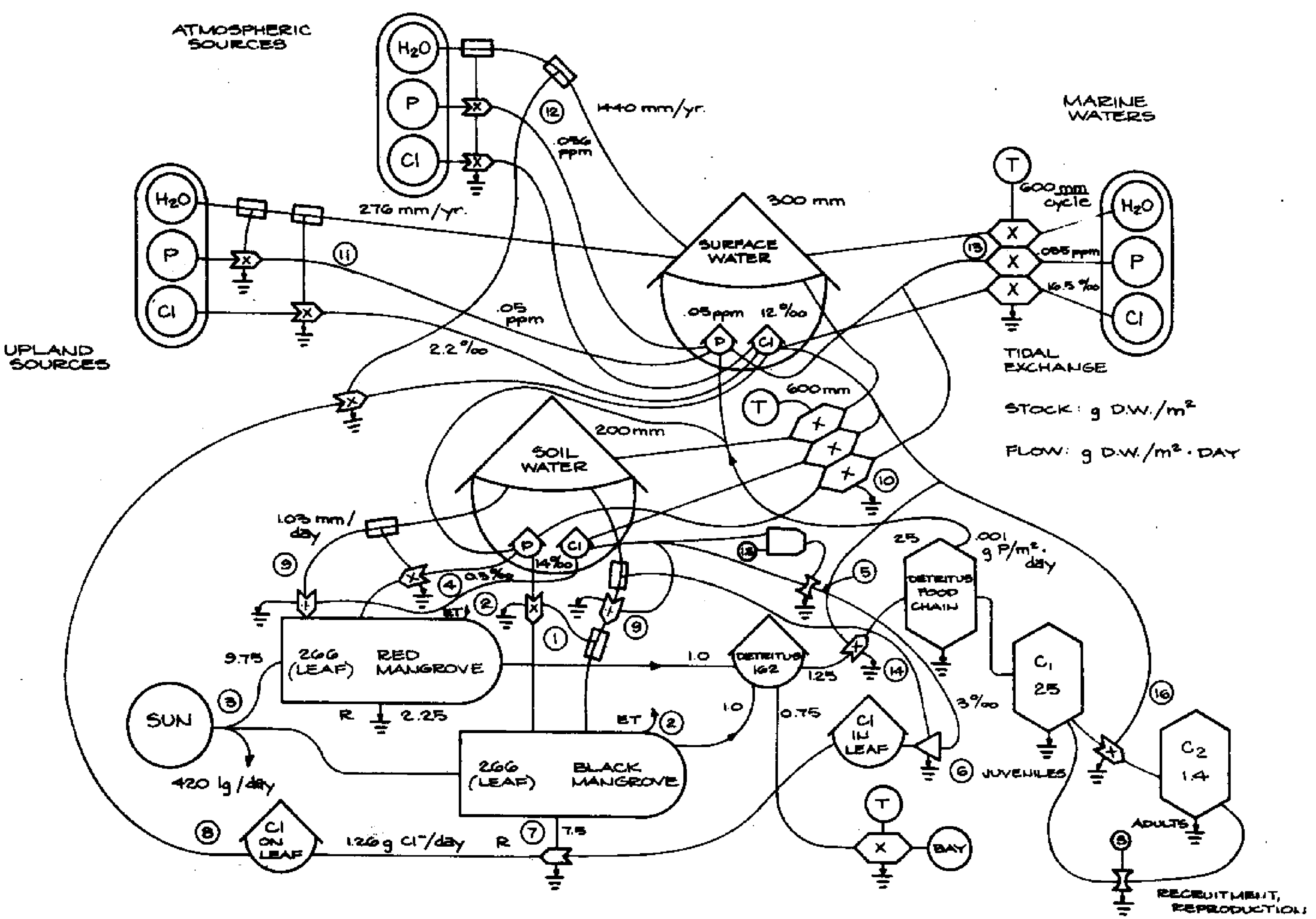

Figure 3. Model of productivity control of mangrove community by macronutrient and salt dynamics. Stocks in grams dry weight/m^2, flows in g D.W./m^2/day except as otherwise indicated. Numerical estimates for mixed stand.

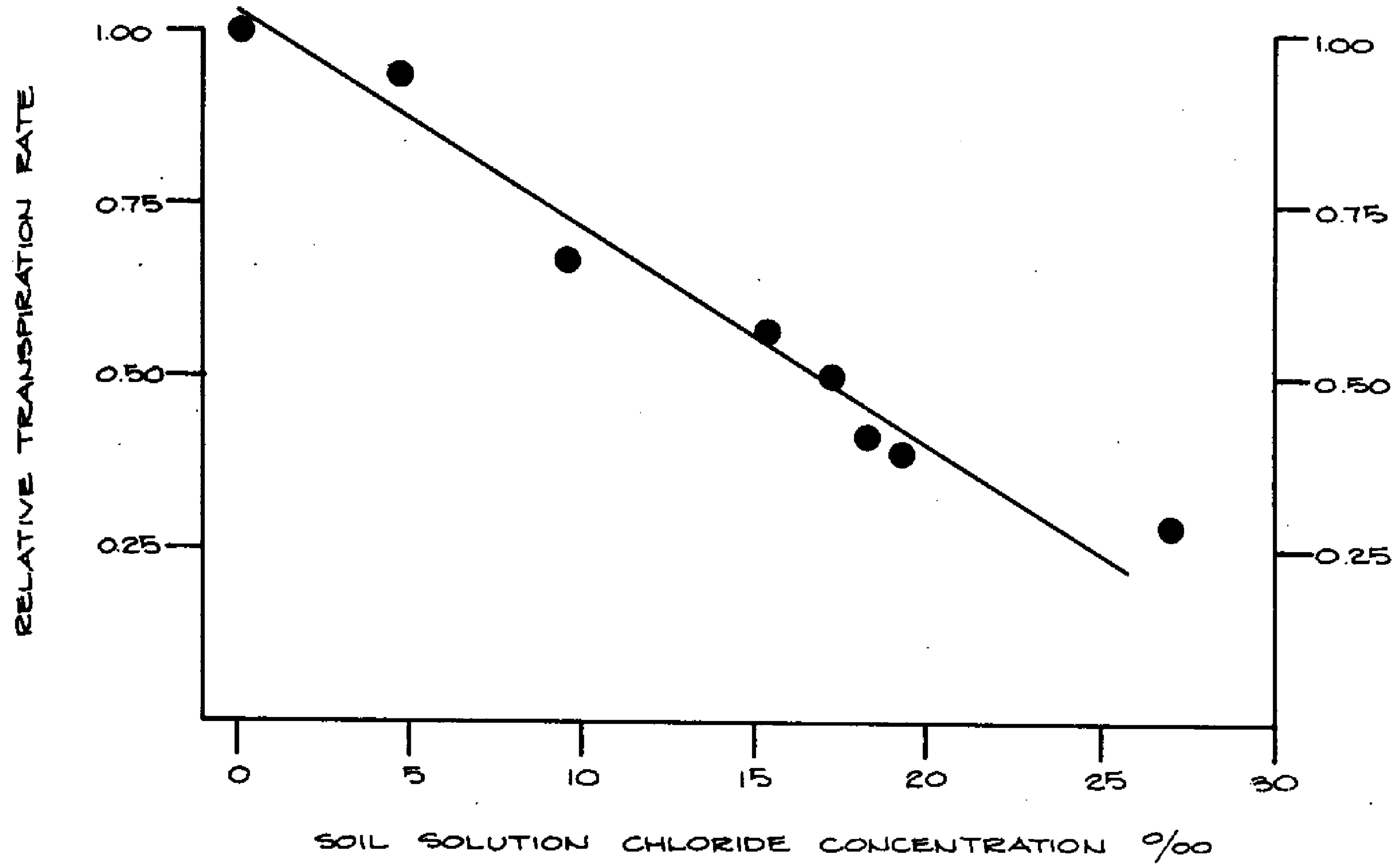

Figure 4. Relative transpiration rate of red mangrove (*Rhizophora mangle*) as related to chloride concentration in the soil solution (seawater dilution). Data recalculated from Bowman (1917). Plants were cultured on calcareous sand and watered with seawater diluted with rainwater.

EFFECTS OF MAN ON THE SHORE VEGETATION OF BISCAYNE BAY

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ABSTRACT

The shoreline vegetation of Biscayne Bay has suffered from man's activities since the turn of the century. Shore vegetation has been eliminated in much of north Biscayne Bay and has been seriously impacted even along the relatively less polluted and altered south Biscayne Bay.

A vegetation history has been reconstructed for five sites: Interama; Cocoplum; Saga; Section 33 of T56, R40; and Card Point. The study has involved on-site biological and geological investigations and made use of historical accounts, maps and aerial photographs. The effects of man are basically of two types: (a) physical, which includes land fill; vegetation removal and erosion by boat wakes, and (b) water quality and quantity factors. Drainage of the Everglades that began about 1900 lowered the water table and affected all five sites. With reduced freshwater sheet flow the high and storm tides made the marl soils saline farther upland and eliminated freshwater vegetation. Building of roads and dikes that restricted overland freshwater flow further accentuated salinity problems. Mosquito control and agricultural drainage ditches allowed saline bay waters to penetrate and seed mangroves in marl areas that had been freshwater marsh. Near Card Point the saltwater zone has extended 2 to almost 4 miles inland. One section of coastal land, Section 33 of T56, R40, has mangroves growing on more than 300 acres of former marshland because of the upland advance of salinity in drainage ditches and the elimination of freshwater sheet flow by dikes. In several areas, mangroves are currently growing on land that had been vegetable fields before salinization of the soils. It is possible, because of this invasion of marshlands by mangroves, that there is a greater acreage of mangroves along Biscayne Bay today than there was in 1900, although much of the mangrove area that has been seeded has developed into stunted, scrubby growth because of the marl soil.

Studies of the mangrove communities that have developed on marl marshlands are needed in order to learn more about their ecological role, nutrient status and potential management. Also needed are more experiments with mangrove planting and ecosystem reconstruction.

INTRODUCTION

The shore vegetation of Biscayne Bay provides a significant component of the Bay's productivity and it plays an important role in the cycling of nutrients in the course of their transfer from the uplands to the sea. Shore vegetation has been eliminated in much of north Biscayne Bay and severely impacted by man's activities in even the relatively less polluted and alterned south Bay. The changes in the shore vegetation of Biscayne Bay brought about by man involve an array of factors from the obvious destruction of habitat by dredge and fill operations to the more subtle consequences of draining the Everglades and subsequent saline intrusion. Shore vegetation as defined here covers the emergent plants and those growing near the water, but not the seagrasses and algae under the water. The shore is here considered as extending to the freshwater wetlands near the Bay. Analysis of shoreline vegetation has been carried out using aerial photographs, maps, and on-site observations. Water supply and salinity are obvious factors in the impact of man on shore vegetation.

No recent systematic review of the shore vegetation of Biscayne Bay is known, but Davis (1940) and earlier botanists have discussed South Florida flora. Teas (1974 and in this volume) has covered the mangroves.

Parker (1974) has reviewed the history of the predrainage Everglades, including information on Biscayne Bay's western shore. He reported that prior to drainage there were high water levels behind the Atlantic coastal ridge during most years and there were freshwater artesian wells near the shore of Biscayne Bay. Thomas (1974) has reviewed the relationship of freshwater table and estuarine salinities. Kohout and Kolipinski (1964) reviewed the recent occurrence of freshwater springs under the western side of Biscayne Bay. Diking and drainage of the Everglades that began in about 1900 and continued into the 1940's caused a gradual loss of freshwater head and reduced spill over the coastal ridge (Parker, 1974). Undoubtedly the streams such as the Oleta River and Arch Creek as well as the small spring or seepage-fed sloughs received less water as the inland water source was drained. Reducing the freshwater supply to the shore plant communities by lowering the water table, reducing the freshwater runoff, and shortening the hydroperiod can induce secondary succession (Alexander and Crook, 1974). Although the rise in the sea level is not anthropogenic it could be involved in some changes in shore vegetation (Alexander, 1974).

Increasing salinity plays a critical role in recent shoreline vegetational changes. Few, if any, higher plants are obligate halophytes, but many tolerate high salinities (Barbour, 1970). Saline soils and media have been variously defined as ones with salinities in excess of 2.5 o/oo (ppt or parts per thousand) by Bernstein, or greater than 1% by Kearney and Schofield (Barbour, 1970). Most crop plants are inhibited by 2.5 o/oo salt (Bernstein and Hayward, 1958). Salinity serves to eliminate or suppress competition for halophytes but there is undoubtedly a metabolic "price" for high salinity tolerance. Rhizophora mangle, which appear to prosper at seawater salinities, have been reported by many authors to grow better in brackish than in full-strength seawater, e.g. Pannier (1959). Davis (1940) stated that the best growth of mangroves was found where the salinity was 10 to 20 o/oo. Recently it has been shown that net photosynthesis of Rhizophora mangle plants is suppressed by increasing salinities beyond brackish (Carter et al., 1973; Hicks and Burns, 1975). Reductions in the level of photosynthesis or reduction in growth of halophytes subjected to increasingly saline environments has been reported for a variety of species (Waisel, 1972). Salinity imposes stresses that may alter competition between species (McMillan, 1959; Waisel, 1972). Davis (1940) pointed out that it is the soil interstitial water, rather than the salinity of the overlaying water, that is critical for plants. Buttonwood can tolerate some salinity but not high levels or continuously (Craighead, 1971). Craighead also noted that buttonwood trees can survive at 1-1.5 ft. above mean sea level in Everglades National Park, which probably corresponds to about the mean high tide level.

The type of soil has been reported to be important in mangrove salt tolerance. Clay was found to protect Avicennia seedlings from high salinities (McMillan, 1975). Calcium has been found to protect against salt toxicity in beans (LaHaye and Epstein, 1969). Interactions of soil in salinity tolerance may occur generally. Restricted salt exchange between surface and interstitial water has been reported in fine marl (calcitic mud) soils of south Florida. The slow exchange that is found probably results from molecular diffusion (Scholl, 1965). Because of the slow exchange of interstitial and surface water there can be a retention of salinity in the root zone of the soils for a substantial time after the end of the dry season. At some locations in south Florida high soil salinity continues through the rainy season (Davis, 1940; Reark, 1975; Teas, 1975).

Although salinity serves to eliminate competition for halophytes, salinity tolerant species, once established, may prosper in areas of low salinity. For example, at one site in Everglades National Park, red mangroves that were seeded several years ago by storm tides (Craighead, 1971) are growing and reproducing in a sawgrass area where the surface salinity was found to be 0.02 o/oo (Teas, 1975a). Indeed, records indicate that several species of mangroves have grown and reproduced for more than a century in a freshwater lake at Bogor, Indonesia (Ding Hou, 1958; Macnae, 1968).

In south Florida, as in other parts of the world where there is a long dry season and high temperatures prevail, "salinas" or "salterns", i.e. saline zones with little or no plant growth, are often found (Fosberg, 1961; Guilcher, 1963). Typically salinas are found upland of the mangrove band, in areas that are inundated only by spring tides. The combination of water-holding soil and high evaporation rates makes for zones with salinity levels that are too high for most plants to invade or survive. Such salinas can be seen in aerial photographs along south Biscayne Bay. Marl flats, paludal basins and shallow depressions in surface limestone are most likely to become salinas in south Florida. Study of aerial photographs suggests that such salinas have resulted from secondary succession. Clear cutting mangroves south of Bangkok, Thailand (Macnae, 1968) and herbicide killing of mangroves in parts of the Saigon River delta in South Vietnam (Teas, 1975a) are probably other examples of man-induced salinas.

The roots of mangroves typically grow in anaerobic soil. Aeration of mangrove roots through lenticels in the prop roots or pneumatophores appears to be a survival mechanism (Scholander et al., 1955). The requirement of mangrove roots for air has been used to kill them in preparation for land fill. It has been standard practice in Florida for real estate developers to kill mangroves by diking and flooding them, maintaining water levels above the pneumatophores and most of the prop roots for a few weeks. This period of root anaerobiosis is reported to kill the trees. Craighead (1971) concluded that the very extensive mangrove destruction in Everglades National Park following Hurricane Donna had as its basis the killing of the tree roots by the anaerobic conditions that followed the storm deposition of a thick layer of fine sediment.

Although Florida mangroves are killed by deep stagnant water, especially if the water has a high BOD (biochemical oxygen demand), mangroves can sometimes adapt to life without tides. The three Florida species of mangroves, Rhizophora mangle, Avicennia germinans and Laguncularia racemosa, have been grown in pots in the absence of tidal circulation. Such plants prosper and have produced viable seed after two years without tidal flushing (Teas, 1975a). A mangrove forest in Barbuda, in the Lesser Antilles, has been isolated for many years (Stoddart et al., 1973). Teas (1974) cited several cases where mangroves in Dade County were growing on dry land.

Mangroves that are cut off from tidal circulation may die, even without artificial maintenance of a high water level. As discussed later in this report, a plot of mangroves on the Interama site was cut off from tidal circulation during dredge and fill activities and subsequently reconnected. The interrupted circulation appears to have resulted in a selective kill of red mangroves.

Ditching to improve tidal circulation has been used as a means of selectively improving the growth of Rhizophora mangroves in Malaya (Watson, 1928; Noakes, 1955; Macnae, 1968). Increased tidal flushing probably favors the growth of Rhizophora over Laguncularia and Avicennia in south Florida.

Craighead (1971, 1973) has noted that fires in coastal marshes, hammocks and tree islands can initiate secondary succession, especially when they are combined with salinization. In recent years the trend in south Florida has been to control some spontaneous or arsonist fires and to carry out controlled buring (Hofstetter, 1974).

Low-lying coastal marsh and swamp lands often are breeding places for salt marsh sandflies and mosquitoes. There had been scattered early hand ditching, but in 1935 the Dade County Mosquito Control Division was created as a unit and began using machinery to dig ditches in the coastal insect breeding areas to promote drainage. The rationale was that ditches provide access for fish that eat the insects during their developmental stages and also eliminate some insects that do not tolerate salinity. The ditches that introduced tidal waters into the marshes and swamps connected with agricultural drainage ditches and, thus, at the time of high tides, brought saline water into cultivated fields as sell as the marshes and swamps. As noted earlier, salinized marl soils lose their salt very slowly to surface waters (Scholl, 1965). In addition to salinizing coastal shoreline fields, the mosquito and agricultural drainage ditches provided access whereby propagules of the Florida mangrove species could be seeded into the open land near the ditched areas by high tides.

Boat wakes can erode mangroves and other shoreline vegetation. The Intracoastal Waterway at Dania Beach, south of Port Everglades, is an area of high energy boat wakes. Red and white mangroves and Australian pine are being undercut and falling into the water. Along the north fork of the St. Lucie River, cabbage palms and woody trees fall into the river from the eroding effect of boat wakes (Teas et al., 1971).

The present study will evaluate effects of man on the shoreline and adjacent wetland vegetation of Biscayne Bay by considering detailed evidence for five sites (see Figure 1 for their locations). Much of the information on these sites is derived from unpublished sources.

SPECIFIC SITES OF IMPACT ON VEGETATION

Interama

The Interama site is a property of about 1500 acres (600 ha) along northern Biscayne Bay. This was known as the Graves Tract until about 1960. It is the location of a planned, but now abandoned, Interamerican Center for trade and cultural exchange (see Prestamo, this volume). Interama lies south of the N.E. 163rd Street (Sunny Isles) Causeway, between the Intracoastal Waterway and Biscayne Boulevard (U.S. Highway 1). The property extends southward to approximately N.E. 135th Street. The western one-fourth of the property had been farmed or otherwise distrubed before 1928. The soils are generally marl or peat. The Interama property is shown in Figures 2 and 3 (1956 and 1969).

Today, much of the southern part of the eastern two-thirds of the site has been extensively altered by ditching and by dredge and fill operations. Aerial photographs of the Interama property were available for 1928, 1940, 1945, 1950, 1956 and most years since 1960. For earlier years, various coast and land surveys provide some indication of the vegetation on the Interama site, although the degree of precision, with regard to species and their distributions, is far less than that permitted by the use of later techniques, such as aerial photograph analysis. Ground elevations were obtained from a 1955 topographic survey by Bennett (1955). Only minor differences in elevation would be expected in the marsh and swamp areas between 1928 and 1955 and, indeed, up to 1975 for areas not dredged or filled.

1765-1770

Surveys of northern Biscayne Bay were carried out in the 1760's by William Gerard DeBrahm, the British Surveyor-General for Florida. These surveys included descriptions of coastal vegetation, and were cartographically summarized by him on maps drawn in 1770 (Chardon, 1975, and in this volume). Among the vegetation types specifically distinguished by DeBrahm were mangrove, sandbeach vegetation, freshwater marsh, saltwater marsh, tall grass subject to inundation, and hammock. Unfortunately, the different types are not always clearly delineated on his maps. The section later known as the Interama tract is shown on DeBrahm's maps as mixed mangrove and marsh, but the former predominates, especially along the shore. This vegetation pattern (i.e. mixed) is portrayed from the Oleta River south, covering the entire Interama tract.

At that time, there existed an outlet to the sea by way of present Indian Creek, and this tidal inlet, about 3.5 km (2.2 miles) south of Interama, very probably increased the salinity of the waters at the site's shores. Earlier Spanish maps suggest that the tidal inlet was wider in 1743 and, since DeBrahm's 1770 maps show an unbroken belt of mangrove on the Biscayne Bay shore opposite Interama, as well as much mangrove on the tract itself, it seems reasonable to assume that red mangrove comprised at least part of the Interama vegetation, particularly along its shore, in 1770.

That other plant species existed in addition to the mangrove is indicated by the mixed vegetation pattern on DeBrahm's maps. However, close examination of the maps, and of DeBrahm's notes, does not provide a precise identification of that vegetation, other than that it included marsh types and possibly sawgrass. It would appear, therefore, that the vegetation types described below for 1928 are, in the main, applicable for 1770. Further precision does not seem possible at this time.

1870-1887

U.S. coast charts of this period generally identify only four coastal vegetation types for the Biscayne Bay area: sandbeach, swamp, marsh, and upland (in this case woodlands). By this time, the tidal inlet at Indian Creek had been closed for some years, but mangrove was apparently well established along the shore of the Interama site. Charts for the late 1870's and 1880's show a band of swamp vegetation, presumably mangrove, about 500 meters (1500 feet) wide all along the bayshore of the Interama tract. Behind this was an area characterized on the charts as marsh vegetation, with a narrow mixed transition zone between the two distinctive types. A similar pattern is indicated by land survey maps drawn in 1870, but these maps may well have been drawn by coast surveyors themselves, at least originally. Again, further precision as to species and their distribution is not attainable at this time.

1928

The borders of the three ponds (designated east, middle and west), in the southern third of the property were about 0 ft. elevation (mean sea level), and the ponds themselves were typically 0.5 to 1 ft (0.15 to 0.3m) but in some places 2 ft (0.6m) deep. There were mangrove bands at the east and south parts of the property which were approximately 700 and 2300 ft (210 and 700 m) wide respectively and were on ground elevations of from 0 to +1 ft (0 to +0.3 m). The prominent creeks that drained the wetlands and flowed northward into the Oleta River were typically 1 to 4 ft (.3 to 1.2 m) deep, but occasionally 6 ft (1.8 m) deep near the Oleta River. The marshland-swamp area between the middle part of the property and the 163rd Street Causeway was generally 0 to +1 ft (0 to +0.3 m) elevation. New spoil piles along the Oleta River along the eastern third of the Interama property in 1928 indicated recent channel dredging, probably at the time of deepening the Intracoastal Waterway.

In 1928 the mangrove forest in the middle portion of the eastern stands was predominantly red mangroves (*Rhizophora*). This conclusion is based on an examination of tree trunks along the spoil piles and the sides of relatively recently dug (1972) mosquito ditches in the area. Aerial photographs indicate that this forest had been bulldozed about 1962 and covered with fill.

In 1928 there were probably buttonwood (*Conocarpus erecta*) and cabbage palm (*Sabal palmetto*) among the mangroves at the higher elevations. This conclusion is based on the finding of buttonwood and cabbage palm trunks in the mature mangrove forest along the Intracoastal Waterway and on the south near Biscayne Bay.

Behind the about +1 ft (+0.3 m) elevation band of mangroves the three shallow ponds were probably freshwater-to-brackish according to rainfall and the time of the year. The broad band of mangroves in 1928 probably impeded tidal flow to the extent that the effective mean high water line was probably within the mangroves. These ponds were generally 1 ft deep (0.3 m) or less, with occasional 2 ft (0.6 m) depths. The middle pond was shallower than the other two. The ponds were probably bordered by cattails (*Typha angustifolia*). Adjacent to the ponds were light colored areas that were graminoids such as sawgrass (*Cladium jamaicensis*) and juncus (*Juncus roemerianus*). A recent check of a former pond area on the eastern half of the property revealed that, although the swamps and marshes had been filled, cattail and sawgrass plants were present. These plants were likely relict flora from pre-dredging and filling days. The ponds drained into the Oleta River through a maze of marshland, swamps and small creeks. Near the Oleta River and along the creeks leading into it along the eastern half of the property there were fringing mangroves and buttonwoods and patches apparently developing to solid mangroves. Along the Oleta River the western half of the property had fewer mangroves and those prinicpally as a fringe along the River and creeks. There is some direct evidence on pre-Bakers Haulover cut salinities in Biscayne Bay, the Miami River and Arch Creek. Bowman (1917) reported the following salinities from August, 1916 (in the rainy season; however, 1916 was a drought year with 43 inches (1,092 mm) of rain); Atlantic Ocean 23 o/oo; Biscayne Bay 17 o/oo; mouth of Miami River 5 o/oo; ½ mile (805 m) up the River 0 o/oo; 2 miles (1,610 m) up the River, with scattered mangroves along bank 0 o/oo; mouth of Arch Creek (south side of Interama Property) 4.5 o/oo; 1 mile (805 m) upstream 3 o/oo; and 2 miles (1,610 m) upstream 0 o/oo, thus in August of a dry year both Arch Creek and the Miami River were freshwater at the points where there were scattered mangroves along the shore; however, both of them had the more saline bottom layers which have been claimed are the reason that mangroves are able to grow so far into the freshwater zone (e.g. Bowman, 1917). Harshberger (1914) described the mangrove border of the Miami River below its fork (0 o/oo salinity) as being broken by areas of cattail (*Typha angustifolia*), and sawgrass (*Cladium jamaicensis*) with leather fern (*Acrostichum aureum*) as a conspicuous species. It is very likely that Oleta River at the middle of the Interama property, approximately 2.6 miles (4,200 m) upstream from Biscayne Bay proper, and 1.2 miles (1,930 m) upstream from the present Intracoastal Waterway, was freshwater before 1925. This is the approximate upstream extent of mangroves in the U.S. Coastal and Geodetic Survey (USC&GS) map prepared from 1928 aerial photography. This also argues that the three ponds and the marshes and swamps along the Oleta River were freshwater. The Oleta River was probably fresh before 1925 and increasingly brackish thereafter. In 1928 there were uniform density patches up to a few acres in extent south of the Oleta River and north to the 163rd Street Causeway. Some of these patches were probably brackish marsh graminoids such as *Juncus roemerianus*, *Distichlis spicata*, *Spartina alterniflora*, *Spartina cynosuroides*, *Sporobolus virginicus*, or *Monathochloe littoralis*, species listed by Davis (1940) as forming nearly pure stands in open salt marshes or enclosed areas within mangrove swamps. The fresher parts of the marsh may also have included cattail and sawgrass.

In 1935-36 mosquito ditches were dug through much of the mangrove forest band on the eastern and southern parts of the property. The bottoms of these ditches were typically -1 to -2 ft (-0.3 to -0.6 m) although some were -4 ft (-1.2 m) in 1955.

1940

The individuals or clumps of mangroves in the three ponds were more numerous than they had been in 1928. The middle pond was becoming filled in with mangroves. Much of the light-colored soil adjacent to the ponds had become dark with vegetation. There was vegetation that appeared to be mangroves, along the shore of the Oleta River and along the creeks leading into it. The irregular shaped patches of what appeared to be graminoids were more dense than they had been earlier.

1945

The mangroves that had begun to grow in the marsh areas adjacent to the ponds had become more dense. The individual mangroves in the ponds increased in size but not appreciably in number. The mangroves along the Oleta River increased in density and canopy coverage; they appeared to have extended to large areas along the shore and the creeks that drain into the Oleta River. The irregular graminoid patches near the River, especially between the River and the 163rd Street Causeway, became mottled in appearance, probably because they had been invaded by mangroves.

1950

The three ponds were still present. They still showed scattered individual or small clumps of mangroves. Much of the shallowest part of the middle pond was closing in with mangroves. The irregular graminoid patches along the Oleta River had almost disappeared and the area had begun to look like an almost uniform covering of shrubs between the higher mangroves that lined the Oleta River and creeks.

1956

The entire Oleta River drainage area on the Interama property became dense with trees or shrubs. Field studies in 1972 (Teas) showed that these trees or shrubs had grown up into solid stands or red and white mangroves. Red mangroves were generally dominant along the creeks. The irregular graminoid patches had disappeared.

As can be seen in Figure 2, the three ponds near the southern border of the property were still visible in 1956. The mangrove growth in the former marshland was more dense. The dendritic pattern of the creeks stood out clearly in the mangrove forests because the trees that lined them were larger and darker in the photographs.

The Terama property is a parcel between the Oleta River and the 163rd Street Causeway that is not a part of the Interama property. (See Figure 2). In 1956 the Terama property showed recent dredging along its perimeter. A narrow mangrove covered island about 450 ft (137 m) long and about 75 ft (23 m) wide was left between the Terama property and the Oleta River.

1963

A major fraction of the Interama property had been bulldozed and dredging and filling begun. The eastern pond had been obliterated by fill and most of the middle pond had been filled, but the western pond was still intact.

In 1963 a plot of mangroves in the shape of a triangle with rounded corners approximately 17 acres (7 ha) in area, surrounded by a peripheral ditch about 75 ft (23 m) wide, appeared near the north-western part of the filled area on the Interama property. This plot was isolated by landfill so that it had no outlet and thus no tidal flushing. In 1963 the creeks within the triangle were lined by fairly large red mangroves and on the land between them was what appeared to be dense, low mangroves, found subsequently to have been predominantly white mangroves. The aerial photograph showed that many of the red mangroves along the creeks were defoliated. By contrast, the red mangroves along the same creek system, just across the road to the north, which were still tidally flushed from the Oleta River, had dense canopies. Examination of pre-dredge and fill aerial photographs revealed no difference in mangrove growth between the triangular plot area and from there north to the Oleta River.

The narrow island at the Terama property had not changed.

In 1964 or 1965 mosquito ditches were dug through the mangroves at the western side of the property. At that time, the western pond, the only one remaining of the original three, was ditched for the first time.

The 1963 photograph showed a pattern along the Intracoastal Waterway which suggested that large mangroves had fallen into the water.

1966

The aerial photographs showed that a cut had been made re-connecting the triangular plot to a creek that drained into the Oleta River. The fringe of red mangroves along the creeks within the plot showed more defoliation and dead branches.

The narrow island at the Terama property, shown in Figure 4, appeared to be unchanged.

1969

Photographs showed that the lower end of the remaining mangrove forest at the southwestern part of the Interama property had been cut off by the causeway filling of the eastward extension of N.E. 135th Street, but two 60 inch culverts had been placed under this road to serve for tidal flushing of the remaining mangroves.

In 1969 the triangular plot showed earthwork and trenches for four culverts. Recent field check (Teas, 1975a) showed that the one culvert which was obviously functional was connected to the south; others were filled with trash and at too high elevations to be effective in drainage. In the 1969 photograph, the old creeks within the triangular plot were lined with what appeared to be dead, red mangroves. The white mangroves, which filled most of the plot between the creeks, had prospered in the meanwhile.

In 1969 the narrow idland at the Terama property was narrower and along its edges appeared to be trees that had fallen into the water. Field checks in 1972 confirmed this interpretation.

1972

Field studies by Teas (1972) in March of 1972 showed that the Oleta River and the tidal creeks were approximately one third seawater, i.e. had salinities of 11-12 o/oo. The mangroves in the area between the Oleta River and the 163rd Street Causeway were 90-95% red and 5-10% white. They were of fairly uniform height, approximately 25-35 ft (8-11 m). Borings in the area with a soil auger showed 2-5 inches (5-13 cm) of firm mangrove peat and below that a thick ooze of liquid peat that extended to rock at 5-6 ft (1.5-1.8 m). This fine ooze is similar to the "liver mud" characteristic of isolated mangrove rimmed ponds in the Everglades and is a record of a pond, now infilled, rather than an old mangrove forest. The 1928 aerial photograph showed that this area had been marsh just being invaded by mangroves.

The east side of the Interama property at the Intracoastal Waterway was also investigated. This area showed ca. 12 inches (30 cm) of compact mangrove peat with liquid peat below that to a depth of 5-6 ft or more (1.5-1.8 m) to rock. The trees were predominantly red mangroves with 5-20% whites and occasional black mangroves. These trees were generally 25-35 ft (7.6-10.7 m) high with some larger red and black mangroves 45-50 ft (14-15 m) high. A few of the larger red mangroves had trunks 18 inches (46 cm) in diameter, DBH (diameter, breast height). Approximately 800 ft (ca. 250 m) to the west of the Intracoastal Waterway, near the present eastern north-south access road, there was more than 6 ft (1.8 m) of compact mangrove peat. The mangroves in this area may have been started or been growing many years earlier when the upper Bay was saline because of a connection to the Atlantic Ocean through Indian Creek (Chardon, in this volume). False color infrared photographs taken in 1972 clearly showed many large dead red mangroves and a few live red mangroves along the creeks of the triangular plot. See Figure 6.

1973

The narrow island at the Terama property appeared "ragged" and had shortened to about 300 ft (90 m) and narrowed to a width of about 30 ft (10 m). There were fallen trees along its periphery. In 1973 it could also be seen that many large mangroves had fallen into the Intracoastal Waterway along the eastern side of the Interama property. Field checks revealed that both the tall (more than 30 ft (10 m) high) mangroves along the Intracoastal Waterway and the ones along the narrow island at the Terama property had roots heavily damaged by the boring isopod, *Sphaeroma terebrans*. Both white and red mangroves were attacked.

1975

The narrow island at the Terama property was smaller and more "ragged" (see Figure 5) and large mangroves along the Intracoastal Waterway continued to topple into the water.

The dead red mangroves along the creeks of the triangular plot were confirmed by field observations.

In 1975 the City of North Miami made application to fill 103 acres (42 ha) of the remaining mangrove and the pond and contiguous wetlands under a proposal that would set aside 138 acres (56 ha) of mangroves as a nature preserve.

In 1976, studies were made in the area of the western one of the original three ponds where the site of the 1928 pond, the adjacent marl prairie marsh, higher elevation marl to west and the original mangrove forest could be located.

The water in the pond was about 3 ft (1 m) deep at mid-tide and had a layer of organic sediment and debris at the bottom. The area adjacent to the pond that had been shallow graminoid marsh in 1928 had mangroves growing on a thin layer of peat overlying calcitic marl. This peat had propbably formed since mangroves spread into the area after 1935. The more upland portions of the marl zone had a community of stressed scrub mangroves; the soil interstitial water was hypersaline; and there was no peat present. The mature mangrove forest, which had been present in 1928 along the north side of Biscayne Bay at the Interama property, had widely spaced red mangroves almost 18 inches (46 cm) DBH and 60 ft (18 m) tall. The soil on which they were growing was deep mangrove peat. The molluscs found in the spoil piles were freshwater types (Craighead, 1971), consistent with them having been alive on calcitic marl marsh when it was freshwater or slightly brackish.

Summary of Interama Shore Vegetation Changes

Several factors were involved in the shore vegetation changes at Interama. One of the early ones was opening the cut between northern Biscayne Bay and Atlantic Ocean at Bakers Haulover. This inlet was opened in 1925 "primarily to relieve pollution in the upper reaches of Biscayne Bay" (Bakers Haulover, 1959). Opening this cut allowed ocean water to enter the Bay at every tide thereby increasing the salinity of upper Biscayne Bay. Bakers Haulover may also have increased the mean tidal levels because of the extra water from the Atlantic Ocean. Chanelizing the Intracoastal Waterway and the Oleta River would have increased salinities because of increased tidal flows. Increased salinity undoubtedly killed the cabbage palms and buttonwoods and was responsible for the advance of mangroves in the Oleta River. Mangroves are more tolerant of salt than are the graminoids so that when there was an increase in salinity the mangroves began to replace graminoids. Once mangroves are established they are successful in competition with graminoids because they shade out their grassy competitors. Red mangroves are more capable of invading marshland than whites; the latter apparently require open land to be successful as seedlings, although, as larger trees they are competitive (Reark, 1975a). The invasion of marsh by mangroves might have been aided by the extreme drought during 1927 (U.S. Weather Bureau) which probably reduced the freshwater flow of the Oleta River and thus increased its salinity. The drought may also have led to grass fires which could have accelerated secondary succession in the marshlands.

The internal ponds and marshes were exposed to Bay salinity in 1935-1936 when the mangroves along the east and south were breached by mosquito ditches that let Bay water in at every tide. The marshlands adjacent to the ponds were rapidly invaded by mangroves, chiefly reds, that could outcompete the sawgrass under conditions of Bay salinity. Invasion of the middle pond, the shallowest of the three, followed. However, the parts of the ponds that were 1 ft (30 cm) deep or deeper were invaded slowly or not at all, probably because of the difficulty of mangrove seedling establishment and early growth in water more than about 6 inches (15 cm) deep (Wanless, 1974). The west pond today, 48 years later, has few more mangroves in it than it did in 1928, although the individual tree canopies have enlarged substantially over the years.

With the introduction of saline waters into the property through the mosquito ditches, some freshwater calcitic mud marshes became salinized and seeded with mangroves by the high tides. Such marshes (for example, west of the west pond), which received tidal waters only occasionally, became hypersaline, i.e. salina-like. As a consequence of the hypersaline conditions, the mangroves seeded into these areas grew as scrub mangroves.

In the course of salinization that resulted from reduced freshwater flow and from the regular infusions of oceanwater by way of Bakers Haulover cut, the Oleta River converted from essentially freshwater to brackish water. In the process the river changed from one that was too fresh to support *Sphaeroma terebrans* to a river in which *Sphaeroma* populations exploded. *Sphaeroma* attacks are absent or scarce in freshwater or in salinities up to ca. 4 o/oo (Rehm and Humm, 1973; Conover and Reid, 1975; Estevez and Simon, 1975). The mangrove fringe along the Oleta River and the Intracoastal Waterway had a sharp edge in the aerial photographs through 1956. By 1963 some of the large mangroves along the Waterway or River appeared to be falling into the water, a symptom of *Sphaeroma* damage, especially where boat wakes provide the force to break loose damaged roots. The narrow island at the Terama property is also an area of very high *Sphaeroma* damage; both red and white mangroves are attacked. The mangroves on this narrow island have almost been destroyed by *Sphaeroma* or the combination of boat wakes and *Sphaeroma*.

The effect of cutting off tidal waters killed many of the old mangroves in the small triangular island and probably selected for a higher ratio of white/red mangroves. The small rectangular plot (ca. 16 acres, 6.7 ha) of mangroves between the Terama property and the 163rd Street Causeway is almost cut off from tidal circulation. The effect of filling the present narrow opening would probably be disastrous for the mangroves.

Cocoplum

The Cocoplum property is a tract of approximately 495 acres (200 ha), within the city of Coral Gables, that extends generally between the Coral Gables Waterway and Casuarina Concourse to the south, and from the coastal ridge at Old Cutler Road to Biscayne Bay to the east. The property includes parts of Sections 32 and 33 of T54, R41.

The history and biology of the tract has been reported by Teas (1971), Tabb and Roessler (1974), and Reark (1974 and 1975a). The following description is, for the most part, taken from these reports, some of which utilized old maps, surveys and photographs.

The western portion of the tract is an oolitic limestone ridge with thin sandy soil. Ridge elevation is 19-22 ft (5.8-6.7 m). Approximately 600 ft (183 m) to the east the elevation drops and the soil becomes freshwater calcitic marl (Perrine marl) which slopes gradually toward the Bay where mangrove peats are found near the present shoreline. At the outer edge of the mangroves there is some silica sand.

1765-1770

DeBrahm's surveys during these years indicate that the present Cocoplum tract contained a band of predominantly mangrove, specifically identified, along its entire coastline (Chardon, 1975a). This band, according to DeBrahm's maps, was relatively thin -- less than 200-300 meters (about 600-900 feet) wide. No specific type of vegetation is identified behind this mangrove border, as DeBrahm left the interior of this particular coastal section blank.

It so happens, however, that the Cocoplum site was included in another, private survey carried out by Bernard Romans in 1770, covering the mainland coast of Biscayne Bay from the Miami River south to just north of Shoal Point (Frazier, 1975; Chardon, 1975). Unfortunately, it is extremely difficult to locate precisely the Cocoplum area on Romans' survey map, as he apparently "smoothed out" the bayshore between Point View and Shoal Point (Frazier, 1975; Chardon, 1975). Romans identified the area most likely to be the Cocoplum section as a narrow belt of "Exceeding Rock marsh or low savannah ground -- Fresh water and Small Rivuletts" (Frazier, 1975). The only mention of mangrove on the Romans map is a reference to a patch of "Buttonwood Swamp", but this is located too far south to be applicable to the Cocoplum tract. Along the bayshore, the open water is described as "Shoals and Sand and Mud-flatts of Biscay Sound" (Frazier, 1975).

There exist, therefore, some sharp differences in the 1770 descriptions of the vegetation of the Cocoplum tract, on the basis of the two survey maps drawn by DeBrahm and Romans in that year. Romans shows the Cocoplum coast as freshwater marsh, while DeBrahm describes the coast as bordered by a band of mangrove. For reasons explained elsewhere (Chardon, 1975), it is believed that DeBrahm's maps are generally the more accurate portrayal and, on the basis of this and later evidence, we may be reasonably certain that there was a predominant band of mangrove, about 250 meters (800 feet) wide, on the bayshore of the Cocoplum tract in 1770.

Since DeBrahm leaves the area inland from the mangrove belt blank, it may well be that there, as later, was a freshwater marsh-type vegetation, but of this we cannot yet be sure. Romans' "Small Rivuletts", though not precisely located, appear to have existed on the Cocoplum property. Inland from these, Romans indicates (and DeBrahm describes in his notes) a rocky ridge (i.e. the east side of the coastal ridge), which Romans mentions as a "Very High and very Rocky Pine Barren" (Frazier, 1975).

It is unfortunate that descriptive geographic differences exist between the only two maps of this part of Biscayne Bay of which we so far have knowledge. But both DeBrahm and Romans each seem to have accurately, if the latter somewhat confusedly, described some of the main vegetation elements of the Cocoplum tract, as they appeared on coast charts about 100 years later.

1878-1904

Various coast charts published by the U.S. Coast and Geodetic Survey clearly delineate three broad vegetation complexes for what is now the Cocoplum site. The first, along the coast, is portrayed as primarily swamp, presumably mangrove, though this is not specified. This band ranges in width from about 600 meters (about 1800 feet) at the northern edge of the site, to a maximum of about 1300 meters (about 4000 feet) along the present Casuarina Concourse. There is no indication of a strand, later described (see below), of coastal hardwood, but this may simply be due to the fact that the surveyors did not differentiate between the various species found in what they represented as "swamp" on the charts.

To the west of, and behind, the mangrove belt, was a narrow band of freshwater marsh, reaching to the east side of the coastal ridge, which is in turn identified only as having a third, distinct, upland (but undifferentiated) woodland vegetation complex. The freshwater marsh is less than 200 meters (about 600 feet) wide along Casuarina Concourse, but broadens to 500 meters (about 1600 feet) at the northern boundary of the Cocoplum site. Just to the north of the site, mangrove (or at least "swamp") disappears, and marsh vegetation (probably freshwater) reached to Biscayne Bay itself.

1922

Parker et al. (1955) reported that before drainage of the Everglades there had been almost continual spring flow along the east side of the coastal ridge but that by 1930 the flow had ceased. A 1922 aerial photograph of the Cocoplum property shows flow meanders bordered by scattered trees which indicated at least spring-like seepage of freshwater had occurred. The upland approximately one half of the property was under cultivation at that time. The fields were drained to the Bay by hand-dug ditches. The land was farmed as late as 1948, at which time salt intrusion forced abandonment of the last fields (Reark, 1975).

The mangroves formed a band behind a strand of coastal hardwood forest that included cabbage palm, gumbo-limbo (Bursera simaruba), poison wood (Metopium toxiferum), seagrape (Coccoloba uvifera), buttonwood, strangler fig (Ficus aurea) and others. In places the strand was 200 ft (60 m) wide. The mangroves formed a band of mature red and black trees that varied in width from approximately 325-650 ft (100-200 m) (Reark, 1975). There was a freshwater marsh between the coastal ridge and the farmland. Ground level photographs taken about this time indicated that much of the strand vegetation had been cleared as a beach. This strand clearing left the shoreline vulnerable to hurricanes, including the very destructive one in 1926.

1935

The Dade County Mosquito Control Division dug ditches through the mangroves and former farmland beginning in 1935 or 1936. These canals provided access for saline waters into the property and red and white mangroves began to grow along the edges of mosquito ditches.

1945

A major hurricane with 150 mph (242 kph) winds struck the shore in September, 1945. The storm washed away the strand at Cocoplum and an artificial beach that had been created, and killed some of the large mangroves. Saltwater 6-9 ft (2-2.8m) deep covered the marl soil for hours. Among the flotsam deposited on the now salinized marl soils must have been large numbers of white mangrove seed which are ripe at that time of year. Recent ring counts of white mangrove trunks in the marl ex-truck crop fields showed ages that correspond to 1945 seeding (Reark, 1974 and 1975a). The white mangroves of the 1945 seeding were scattered and developed into low-form multi-forked and trunked trees. Some of the marl zone seaward of the ex-farmed area became thickly seeded with red mangroves that grew up as "Dense Scrub" community (Teas, this volume).

In each case, the salinized calcitic marl soil inhibited growth of ordinary field weeds and upland trees and shrubs that might otherwise have competed with mangroves. Checks of mollusc shells in soil samples showed freshwater species as listed by Craighead (1971) to be present in the areas where they were expected from the 1922 aerial photographs.

1965

In September of 1965 Hurricane Betsy struck Biscayne Bay and caused 10.5 ft (3.2 m) tides. A reconstructed beach at Cocoplum was again destroyed. Following Hurricane Betsy white mangroves were seeded which developed into a thicket-like crop of tall almost unbranched trees that were so dense in places that some of the stands are still difficult to walk through. It is notable that white mangroves of apparently the same two age classes and growth form (i.e. 1945 and 1965 seedings) were found in some parts of the Interama property (Teas, 1972), on marl soil near old fields.

The shoreline at Cocoplum has probably receded several hundred feet as a result of storm erosion (Tabb and Roessler, 1974). Mangrove tree stumps can be found as much as 82 ft (25 m) offshore at low tide (Reark, 1975a).

Summary of Cocoplum Vegetation Changes

The effects of man on the shoreline vegetation at Cocoplum are many and complex. They include the loss of freshwater flow that was cut off by Everglades drainage. The natural strand was cleared for use as a beach and eroded away by hurricanes: the unprotected mangroves were then susceptible to storm damage. The interruption of freshwater flow from the upland probably helped weaken the remaining mature mangroves; the mosquito and agricultural drainage ditches allowed upland penetration of Bay water; and storm tides seeded the salinized tomato fields well above the mean high water level with white mangroves.

Saga

The Saga property is irregular in shape and covers ca. 2800 acres (1135 ha). It extends between Old Cutler Road and Biscayne Bay from S.W. 196th Street to S.W. 232nd Street. The Saga property includes at least parts of Sections 2, 3, 9, 10, 11, 14, 15, 16, and 17 of T56, R40. There is a natural creek, Crab Claw Creek, that opens to Biscayne Bay at about the line between Sections 11 and 14. Ecological investigations of the Saga property have been carried out by Teas (1974, 1974a, 1975). Aerial photographs from 1928, 1938, 1940, and several years since 1960 were available. The soil is Perrine marl.

1765-1770

While the accuracy of DeBrahm's map of this part of the Biscayne Bay shoreline has so far only been partially ascertained (Chardon, 1975, 1975a), there nonetheless appears to have been a very different vegetation pattern in 1770, from that which existed in both the late 1800's and certainly in 1928, on the Saga tract. DeBrahm's map clearly and unequivocally shows, and specifically identifies, a freshwater marsh lining the entire length of the bayshore at the Saga site (Chardon, 1975a). Further north, this marsh was separated from the Bay by a narrow mangrove strip, also specifically marked and delineated by DeBrahm; the southern extremity of this mangrove strip lay at least one kilometer (0.6 miles) north of the Saga site.

On these points DeBrahm, who anchored right at the shore in this section of Biscayne Bay (Chardon, 1975a), displays no hesitation in either identifying or delineating the extent of the two vegetation complexes. His evidence therefore strongly suggests that, in 1770, there were no significant mangroves or woodlands anywhere along the bayshore at the Saga site. The implication is that mangroves or other woodlands, identified here later, must have developed after 1770. Vegetation changes may have been accompanied by actual changes in the shoreline itself, in the northern part of the Saga tract, although further research is needed to resolve this question.

Assuming DeBrahm's map to be accurate for the Saga site, he shows a freshwater marsh from Biscayne Bay inland, varying in width from about 1000 meters (0.6 miles) in the northern part of the Saga tract, to some 3300 meters (2 miles) in the south, just north of Black Point. The composition of the marsh is not further specified, but undoubtedly consisted of grasses; there may have been some isolated trees whose presence, if they existed, DeBrahm would probably not have noted on his map. Beyond the landward edge of the marsh, DeBrahm identifies no vegetation, as was his custom, since he was concerned primarily with coastal surveying. Evidence from later military expeditions in the 1830's suggests that the upland vegetation, just to the north around Cutler, consisted largely of pine and palmetto; perhaps this was also true of the upland portions of the Saga property.

1870-1878

U.S. coast charts for this period indicate that trees had become established along the bayshore of the southern portion of the Saga tract, but not along its northern shore. There, "marsh" was represented as extending to the water's edge. The band of trees, or "swamp", was narrow -- not more than 600 meters (about 1800 feet) at its greatest width. It terminated, and the coastal marsh at the bay edge began, 4.1 km (2.6 miles) north of Black Point. Inland from the swamp, marsh extended along the entire area behind the trees, and averaged at least 2000 meters in width. The marsh was widest where the trees ended (i.e. 4.1 km north of Black Point), and the inward curve of the coast, which may have been eroded some time in the preceding 100 years, narrows the marsh progressively to the north. Unfortunately, the coast charts do not specifically indicate the landward border of the marsh; they represent it nebulously fading, in one place as much as 3 km from bayshore, into blank mainland areas.

1928

There was a canal that entered Biscayne Bay near the north end of the property. In addition there were three agricultural ditches that apparently drained the upland fields into the marshland toward the coast. There were plowed fields on the Saga property less than three quarters of a mile (ca. 1200 m) from the shore.

In 1928 there were meandering lines of trees that probably represented freshwater springs or seepage flow from the uplands along a slough. These trees may have been only relicts of earlier times when there were freshwater springs.

A 1928 photograph was interpreted to provide map annotation for the vegetation at the time. The USC&GS map showed a strand of deciduous trees 300 to 900 ft (90-270 m) wide, beginning at the Bay in the position of the Coastal Band mangrove community of today. The map, which was made from the 1928 photographs, raised an obvious question because shoreline forests in south Florida are generally evergreen, not deciduous. Hammocks known to have contained buttonwood (because of still standing fire-killed buttonwood trees (Reark, 1975)) were shown on a USC&GS map of the shore south of Turkey Point from the same year as "deciduous hammocks". Davis (1940) noted that in 1938, a drought year, the buttonwoods and associate hardwoods lost their leaves. In the Coastal band mangroves in 1975 there were dead cabbage palm and buttonwood stumps and trunks. The 1928 photographs for map interpretation were taken in April of that year, before the rainy season began. The previous year, 1927, had been one of extreme drought in which there was only 33.7 inches (856 mm) of rain, slightly more than half the average amount (U.S. Weather Bureau). The present investigators concluded that in 1928 the band of trees along the coast had a substantial fraction of buttonwood and other tropical hardwood trees which had lost their leaves because of the 1927 drought. This conclusion is consistent with the somewhat open, mixed forest appearance of the area in 1938 aerial photographs.

Behind the coastal strand and mangrove fringe was a slough that was represented as grasses (graminoids) with occasional mangroves. Inland of the slough was shown on the USC&GS map as sawgrass. On aerial photographs this latter area appeared the characteristic white of the Perrine marl soil seasonally replenished by new calcitic mud precipitation by periphyton (Wanless, 1974).

Near the northern end of the property in the freshwater-sawgrass zone behind the mangroves there were three prominent tree islands which probably contained tropical hardwood species. These tree islands from north to south were approximately 1800 ft (550 m), 1500 ft (450 m) and 1350 ft (410 m) west of the shore.

1938

There was a recently dug ditch connecting the agricultural area to the Bay and there were several ditches parallel to the shore connecting to the two ditches or canals that connected to Biscayne Bay. The three tree islands were clearly visible, but all three had had recent ditches cut through them. Most of the calcitic marl marsh that had been graminoids had become dark colored probably from development of scrub red mangroves, although somewhat salt tolerant shrubs such as salt bush (Baccharis sp.) may have been involved. The trees in the band along the shore appeared to be a mixed population.

1940

There were additional ditches that drained into the slough area that extended from Black Point northward through the basin of Crab Claw Creek, almost to the northern end of the Saga property. Two of the three tree islands had changed their texture, and the third had disappeared. The land that had earlier been freshwater marl marsh seeded with mangroves was more densely covered with mangroves (Dense Scrub community of Teas, in this volume). The density of the mangroves growing on the marl appeared to be enhanced in a pattern which suggested that fertilizer nutrient runoff from agricultural drainage was stimulating their growth. Salinization of the agricultural area was probably not yet advanced in 1940.

1963

Beginning in 1957 mosquito ditches were dug at Saga through the coastal strand and mangroves to Biscayne Bay (Heidt, 1976). By 1963 there were 5 more such ditches than in 1940. In 1963 three ditches had been cut into Crab Claw Creek from the upland, which cross-connected with other ditches leading into the Bay. Also, there was a ditch almost a mile long (1610 m) through the coastal band of vegetation from ca. 100 to 400 ft (31-123 m) west of the Bay. This ditch had 8 separate new openings to the Bay. There was also a north-south ditch ca. 2200 ft (670 m) long about 1000 ft (305 m) west of the Bay.

The three tree islands noted earlier had disappeared.

Much of the area that had been white freshwater marl marsh in 1928 photographs was now uniformly covered with Dense Scrub red mangrove community. None of the fields on the Saga property was being farmed; however, some of Campbell Fields just north of Saga were still being cultivated. The latter fields were provided with pumps at the seaward side to maintain drainage and retard salt water encroachment. It has been reported that the fields closest to Biscayne Bay were abandoned because of salinity in 1964. The aerial photograph for 1963 suggests that the last cultivation of the Bayward fields may have been before 1963.

The coastal band vegetation had become more uniform, as mangroves became dominant.

1967

In 1967 less white marl area showed on the aerial photo than previously, i.e. the scrub mangroves had grown more dense. Recent field investigation showed that some of the white areas still evident on the 1967 photograph were rock outcrop with thin soil sparsely vegetated with mangroves. The high salinations in the dry season make this a salina. The canopy of the coastal band community was more dense.

None of the fields on the Saga property were being farmed. The transition from Coastal Band to the scrub mangroves was sharp. Dense Scrub dominated the slough area behind the Coastal Band. Soil borings have shown that in general the dense scrub community is growing on calcitic marl, whereas there is peat under the coastal band.

Molluscs in marl spoil piles from mosquito ditching and from soil auger samples were freshwater types as listed by Craighead (1971) in Dense Scrub and marl upland areas (Teas, 1975).

1975

A proposal was made by the Saga developers that the Coastal Band and the old slough from ca. 1200 ft (365 m) to 2100 ft (640 m) wide be left undeveloped as a Crab Claw Creek natural area.

There has been little erosion of the Saga shoreline since 1930 as judged by the positions of two 1930 benchmarks (Campanile, 1975), and by scaling the position of the Biscayne Bay shoreline with respect to the mangrove islands in the lake at Crab Claw Creek (Teas, 1975a).

The mosquito ditches on the Saga property can be efficient in carrying water from Biscayne Bay to the uplands. During the dry season the authors have obtained salinities of 28 o/oo at a distance of 2400 ft (732 m) from the Bay shore.

Rainy season surface water salinities in drainage ditches along a transect eastward toward Biscayne Bay from Galloway Road are shown in Table 1. The line was south of the Saga Property.

The effect of rainfall is event from the lower salinities near Galloway Road. The area of the transect had been cultivated fields and sawgrass marl marsh in 1928. As confirmation of this we found living sawgrass plants near Galloway Road. Near the transect line, in an area that had been a cultivated field but had grown up with sparse scrub mangroves, the surface water had a salinity of 16 o/oo and the soil water was 34 o/oo, high enough to inhibit all but very tolerant halophytes. High soil salinities in marl of scrub mangrove areas apparently are to be expected. Davis (1940) reported a soil salinity of 84 o/oo in a scrub mangrove community. However, the salinity of soil water within a small mangrove slough at the east end of the transect was 20 o/oo and surface water was 20 o/oo. The difference between the soil salinity in the slough compared to that in nearby marl soils is obviously due to the porous peat soil of the slough through which interstitial water can exchange readily with surface water. In the present case Galloway Road played a role in the increased salinities in the region by forming a barrier to superficial sheet flow of freshwater from the west.

Summary of Saga Vegetation Changes

Drainage of the Everglades had reduced freshwater flow on the property. By 1938 the freshwater calcitic marl marsh area had become heavily seeded with red (and some white and black) mangroves, from trees that were already in the coastal slough area. The mosquito ditches let saline Bay water inland toward the northern part of the Saga property and into the coastal slough from the upland side. Saline intrusion was evident in some parts of the property by 1940. In 1957-63, when the mosquito ditches were extended, the marl soils of the cultivated area became salinized and the graminoids of the marl prairie were killed as were tree islands and meandering lines of upland trees along old sloughs.

There is, however, evidence that no coastal mangroves existed on the Saga tract in 1770, and that they had begun to establish themselves in the southern coastal portion of the tract by the 1870's. Apparently, natural environmental conditions were such as to induce a change in the coastal vegetational pattern prior to significant human settlement in the area.

The Coastal band of mangroves that is found today at Saga was a strand of mixed tree species until after 1940. The strand existed at the site because it received freshwater from the uplands. Later, as the mosquito ditches regularly flushed the Coastal band with saline Biscayne Bay water, mangroves developed and the strand of handwoods died off.

Section 33 of T56, R40

Section 33 of T56, R40 is south of Black Point and immediately north of Fender Point. Within Section 33 is the outlet of Canal-102, which extends from Biscayne Bay westward through north-south levee (L-31E) that forms the salinity dam. Immediately to the west of L-31E is Canal-107 of the Central and Southern Florida Flood Control District. Within the property on C-102 is a Flood Control District water control structure.

A handprobing transect by Wanless (1969, 1974) shows that the 2 mile wide swamp and marsh margin at Fender Point is underlain by an irregular Pleistocene limestone surface that gradually rises from -3.5 ft (from mean low water) beneath the Bay shoreline to an intersection with the oolite limestone ridge of the Miami Formation (Figure 7). Core borings through the narrow mangrove coastal band encountered mangrove peat to bedrock. Cores through the marsh behind contain calcitic mud (Perrine marl) with freshwater snails from the surface to the bedrock surface. Directly adjacent to the oolitic ridge the calcitic mud yielded to a non-marine organic-rich soil. The calcitic mud is precipitated in a freshwater marsh environment in association with blue-green algal mats that carpet the surface (Gleason, 1972; Barron, 1975). Gleason has noted that calcitic muds are forming in areas of the Everglades drainage system where calcium carbonate charged freshwater is flowing off of exposed limestone topography. The calcitic muds are a striking contrast to the aragonitic and magnesian calcite muds forming in the adjacent marine environment. A calcitic mud accumulation such as this is a record of prolonged and persistent occupation of a algal-mat carpeted freshwater marsh environment along with active seasonal freshwater discharge across (or through) the oolitic limestone.

The U.S. coast charts from 1870-1887, USC&GS maps from 1928 photography, a 1938 photomosaic, and 1963, 1972 and 1975 photographs were studied.

1870-1887

U.S. coast charts of this period do not show soundings very near the shore, except at the tip of Fender Point; this fact may place the accuracy of the vegetation shown along the bayshore in some doubt, though probably in the main the complexes portrayed are probably reasonably accurate. The location of three creeks and two strings of ponds behind the coast, tends to suggest that the surveyors either surveyed the shore themselves, or that they had access to detailed maps of that part of the mainland; the authors have so far not been able to determine which.

The central portion of Fender Point itself is shown as composed of "swamp", with flats or marsh between the trees and the Bay, especially along the Point's northern shore. North of the Point is a strip of "swamp", very likely mangrove; this strip ranges from less than 300 feet (100 m) wide at the southern border of Section 33, to a width of 1800 ft (600 m) at the northern edge of Section 33 where, at the juncture of this section with Section 34, a small rounded cape juts out into Biscayne Bay. In between the northern and southern borders of Section 33, three creeks are shown flowing into the Bay. Inland from these, both to the north and to the south, lay two small north-south trending strings of ponds. The southern string was about 400 meters from the bayshore, while the one north of the creeks lay about 2500 ft (800 m) from the shoreline.

Behind the coastal mangrove strip, marsh is shown as extending all along Section 33, though it came to an end, merging into mangrove, west-southwest of Fender Point, in Sections 4 and 5 of T57, R40. In Section 33, the width of the marsh varied between 4500 to 6000 ft (1500-2000 m). As in the Saga tract, the marsh, in the northern part of Section 33, disappears into a blank area on the charts, about 6300 ft (2100 m) from bayshore. In the southern part of Section 33, however, a clump of woodland, 1200 ft (400 m) wide, is shown beginning about a mile (1800 m) from the shore.

A summary of Section 33 in the 1870's therefore indicates a thin strip of mangrove along the shore, with three creeks flowing into the Bay. Two strings of small ponds existed, one 400 meters, the other 800 meters, inland, within a band of marsh. This marsh was about 3000 ft (1000 m) wide in the south, but widened to 4500 ft (1500 m) in the north of Section 33. The marsh lay behind the thin strip of mangrove. Finally, an isolated woodland is identified, about 4200 ft (1400 m) from the shoreline, west of Fender Point.

1928

In 1928 Section 33 had a relatively narrow fringe of Coastal band community mangroves along the shore and sparsely along 5 small creeks. Between the creeks and to the west was shown as sawgrass (graminoids). Extending northwest to southeast near the southwest corner of the property was a meandering seepage line marked by upland trees that did not meet the mangroves. The western origins of this slough were upland (west) of the section line. Lands shown as cultivated fields extend to within 2400 ft (730 m) of the Bay in the northern half of the section.

In 1928 there were east-west ditches or canals at the northern and southern borders of the section and on the three quarter section that lies between.

1938

In 1938 the pattern of ditching in the northern half of Section 33 had been extended to within 1500 ft (457 m) of the Bay. This ditching was for mosquito control.

The land between the creeks and between the Bay and the western section line was light colored indicating that it was probably graminoids on calcitic marl. This area showed a fine dark pattern from some invasion of plants near the shore, possibly more salt tolerant graminoid species. In the upland area the calcitic marl showed upland plants. The mangroves had not extended appreciably up the creeks from their position in 1928 and the meandering line of trees on the upland did not appear to meet the mangroves. Near the center of the section in the marl marsh was a teardrop shaped tree island about 300 ft (90 m) long that was not continuous to the bay.

1958-1959

During this period the agricultural and mosquito ditches were extended to the south border of the property. The center of the teardrop hammock, which fell between two north-south mosquito ditches, was ditched. The prominent creek near the north border was ditched as was the meandering tree line and creek across the southwest corner of the property.

1963

In this year the photograph showed that the area between the creeks and their flood plain areas had become invaded by Dense Scrub mangroves. Australian pine (Casuarina equisetifolia) were well established on the higher parts of the property. The mangroves along the creeks and ditches were more prominent.

1968

The growth of scrub mangroves had become more dense. Canal 102 had been dug across the property, and Canal 107 and levee 31E were completed. The teardrop tree island had become "diffuse". There were some areas with salt tolerant graminoids juncus and saltgrass (Distichlis spicata), and sea daises (Borrichia sp.) and buttonwood.

Mangroves had replaced the upland trees in the meandering tree line across the southwest part of the property. The teardrop tree island had become relatively tall mangroves. The greater growth of mangroves in the teardrop areas and the meandering tree line than on the former marl marsh is probably because on these sites of former upland hammock trees organic matter had accumulated which served as a better substrate for mangrove growth than did the marl.

1972

The narrow bands of Coastal band mangroves along the shore and the creeks and old east-west ditches had become prominent, and between the creeks and for about half a section to the west the land was developing a stand of Dense Scrub, principally red, mangroves. The scrub mangroves had grown up more dense. Most of the mosquito ditches had been re-dug.

1975

Field studies showed that the teardrop had become tall red and white mangroves with a few buttonwoods. The Dense Scrub area had become more dense. There was still a small area of saltgrass and scrub mangrove where the mangrove had not completely covered. There were dead buttonwoods and a few survivors. Field studies of the mosquito ditch system in March (dry season) on an incoming tide showed salinities as expected. They ranged from 4-11 o/oo near L-31E at the western side of the property to 28-33 o/oo in ditches in the middle portion. Biscayne Bay salinity was 35 o/oo (Teas, 1975a).

The extent of vegetational change in Section 33 was assessed by comparing patterns in 1938 and 1975. The Coastal band of mangroves along the shore and the creeks in 1938 was marked on the 1975 aerial photograph and the areas of the major present plant communities on the property estimated. In 1975 the land area of Section 33 (after subtracting the part in Biscayne Bay, Canal-102 and roads) was 508 acres (206 ha). Approximately 102 acres (41 ha) of that was dominated by Australian pine. It was estimated that a maximum of 89 acres (36 ha) of Section 33 had been mangrove in 1928. Thus, there are approximately 317 acres (128 ha) of what had been agricultural fields, sawgrass and other graminoids which has been invaded by mangroves as a consequence of saline intrusion. A substantial fraction of the ca. 110 acres (45 ha) that had been cultivated fields in 1928 has become mangroves.

Summary of Section 33 Vegetation Changes

Drainage of the Everglades probably was responsible for reduced flow of water across the Section 33. Later the barrier of L-31E restricted surface freshwater flow. Agricultural and mosquito control ditches allowed saline waters to penetrate the property at high tides which salinized the marl soils. Sawgrass was eliminated, dense stands of mangroves were seeded and upland hammock vegetation was killed. On higher ground where there was less salinity, Australian pines invaded the area of previously cultivated fields.

Card Point

The Card Point study involved an area north and west of Card Point and south of the Florida Power and Light Co. Turkey Point Power Plant cooling canals. Involved are at least parts of Sections 25 and 26 of T58, R39, and Sections 28, 29, 30, 31, 32 and 33 of T58, R40.

A hand probing transect (Wanless 1969) across the swamp and marsh environments west of central Card Sound (along Model Land Canal 5) showed the Pleistocene limestone bedrock surface to be about -10 ft (3 m) (below mean low water) at the mangrove shoreline and then rise rapidly to -2.5 ft (76 cm) 0.5 miles (805 m) inland (Figure 8). To the west the bedrock surface becomes deeper and irregular over the next 2 miles and then rises onto an extremely flat surface at about -1 ft (19 cm) for the next 2-4 miles to the low oolitic limestone ridge of Miami Limestone.

Core borings through the narrow mangrove forested margin of Card Sound encountered mangrove peat from the surface to bedrock (Figure 8). This indicates that the mangrove swamp (which accumulated peat on an intertidal surface) has persisted in this area for several thousand years (see Wanless' paper on sedimentary environments, this volume). Core borings at the inland edge of the mangrove forest penetrated calcitic mud beneath 2 feet (61 cm) of mangrove peat. This documents the gradual expansion of the peat producing mangrove fringe across the freshwater swamp. Calcitic muds (Perrine marl) form nearly the entire recent sediment package inland from the mangrove margin. As described in an earlier section, the calcitic muds are a record of prolonged and persistent occupation of an algal-mat carpeted freshwater marsh environment in an area receiving active seasonal freshwater discharge from the Everglades across exposed limestone.

The USC&GS map (T-4576) prepared with the use of 1928 photography was utilized for general features of the shore in this region. Photography from 1969 to 1972 and from 1975 was available. Teas (1974) and Reark (1975) have studied the area. The 1928-1973 account is from Reark's 1975 study.

1870-1887

U.S. Coast charts for these years are the earliest yet found. They show only mangrove for the entire area around Card Point, which at that time was connected to the mainland. Mainland swamp is shown as a steady strip 3600 feet (1200 meters) wide all along the mainland coast, and including Card Point. The mainland swamp, however, grades into areas left blank on the charts, and all that can be said for the moment is that the entire mainland coast for the area here described was very probably mangrove in the 1870's and 1880's.

1928

There were mangroves or grassy slough along the shore and mangroves for a short distance along some of the creeks. To the west the shore was shown as "sawgrass", "sawgrass on rock" or "deciduous hammock". As indicated above, the deciduous hammocks represented buttonwood and other trees that lost their leaves during the drought of 1927-28. At several points the 1928 map showed "sawgrass" less than 800 ft (245 m) from the shore and hammocks within ca. 2,000 ft (610 m) of the shore. Some of these exist today as mangrove hammocks.

1969-1973

The aerial photographs showed that Dense Scrub communities had developed behind the narrow coastal band near shore and behind that there was Sparse Scrub that extended for one mile (1,610 m) or more inland. Reark (1975) has investigated vegetation types and surface and interstitial soil water salinities at a series of points from ca. 2.6 miles (4,000 m) to 300 ft (91 m) from the shore. The stations samples were not on a straight line. The data from May 12, 1975, during the dry season, are shown in Table 2. (See next page).

It can be seen that the scrub mangrove near the shore (Stations 11 and 12) is growing on peat where the soil interstitial water salinity is not greatly elevated compared to surface water. However, inland from there the zone of dwarf or scrub mangroves (Stations 6-10) is generally one of hypersaline marl soils, but not necessarily of hypersaline surface waters. The Sparse Scrub community (Teas, this volume) is made up of plants that are small and exhibit signs of physiological stress such as dwarf size (usually under 3.3 ft (1 m)), few leaves, reduced leaf size, poor leaf color, and precocious fruiting. There is no evidence of litter accumulation on a scale large enough to stain the soil a darker color. The stations for scrub mangrove vary in their relationship to canals and surface drainage. Juncus and distichlis areas (Stations 4 and 5) showed lower salinity than mangrove areas. At the sampling date there was no surface water at the sawgrass Stations (1-3); the soil salinity was no more than 9 o/oo.

Reark noted that in 1975 the sawgrass freshwater marsh (upland of the sawgrass) zone was to be found at least 3.7 miles (6,000 m) from the shore; that the juncus-distichlis band had grown from a narrow ribbon to more than 3,280 ft (1,000 m) wide and had moved inland from the shore by 16,500-18,300 ft (5,000-6,000 m). Hammocks reported as "deciduous" in 1928, and which contain remnants of cabbage palm and buttonwood, are now composed of nearly 100% red mangroves that grow much larger than the nearby stressed trees on marl soil. The soils in these ex-hammocks contain considerable leaf mold (to 4 inches (10 cm) thick). These sites are drained and soil salinities are not much higher than surface salinities.

Fire has played a role in the successional changes of the flora at Card Point. Dead trees are notable features of the study area. Close examination shows that fire has killed many buttonwood and also red and white mangroves. Conocarpus has not re-established except well upland in the freshwater marsh. A series of red mangroves growing in old burns were dated by leaf scars (red) and by ring count (white). Estimates for both species indicated that the fire had been 5 years earlier, which fits with the 1970 drought year (44.7 in., 1135 mm)) during which there were many fires in south Florida.

Construction of canals and roadways polderized low-lying land and led to disruption of the existing flora by altering the fresh water flood regimen. The rapid dryout of the polderized sawgrass wet marsh has permitted invasion by Australian pine and buttonwood.

The zone of white soil at Card Point that is visible in satellite photographs of south Florida is the sparsely growing scrub mangrove zone on the almost white, almost organic free, Perrine marl soil that formed from the earlier freshwater marsh. This is the salina or saltern zone. There are few plants other than the very stunted mangroves that grow in the salina area. In the 1975 Rader photograph of the area from Turkey Point to Card Sound road the relationship between diking (from canal digging) that inhibits freshwater drainage from the uplands and the white salina areas is very clear. Salina (white soil) is seen in the zone between that or ordinary high tides and equinoctial high tides. The land rises so gently (ca. 10 inches per mile, 15 cm per 1,000 m)) that saline waters at high tides soak into the soil.

The whiteness of soil is increased between the Turkey Point cooling canals and the regularly tidally flushed shoreline, where upland freshwater drainage has been cut off. In the area south of the cooling canals where some freshwater runoff is available (from the area up to the Model Land Canal S and Levee 31-E) the salina zone is not so prominent. The area near the Bay between the Model Land Canal S and the south border of the Turkey Point cooling canals has been cut off from all tidal waters for several years but is also cut off from freshwater overland runoff. This area appears to be less of a marl soil salina than is seen to the north or south.

Summary of Card Point vegetation changes

Drainage of the Everglades lowered the water table, and barriers to water flow reduced freshwater runoff. The result has been salinization of the soils. This has been responsible for the elimination of sawgrass or its replacement with salt tolerant types, the elimination of hardwood hammocks and their replacement by mangroves, the creation of a broad salina area of Sparce Scrub mangrove in what had been a sawgrass zone, and the invasion of dried out marshland by Australian pine.

DISCUSSION AND CONCLUSIONS

The effects of man on shore vegetation are basically of two types: (a) physical, which included land fill, vegetation removal and erosion by boat wakes, and (b) water quality and quantity related, which includes reduction in freshwater and increases in salinity.

While there is much evidence for man-induced vegetation changes during the past 80 years, there is also historical (and coring) evidence that vegetational changes were taking place, at least on some of the sites, prior to human settlement. The Interama tract was partially influenced by a tidal inlet in existence during the 1770's and into the 19th century, but which closed as a result of natural events. When Baker's Haulover Cut was opened in 1923-24, however, salinity of the upper Bay waters increased greatly--probably to higher levels than had existed in the 1770's. Historical evidence at the Saga site suggests a coastal vegetation succession from freshwater marsh at the bayshore in 1770, to partial mangrove colonization along the shore (southern part) and possible coastal erosion (northern part). By the 1920's, the marsh was separated from the Bay by mangroves.

The five sites selected for this report show a variety of responses to human involvement. Interama has lost several hundred acres of shore vegetation by filling; and mangroves are stressed by high energy boat wakes. A plot of mangroves at Interama was severely stressed by diking. Cocoplum has lost shore vegetation along the Coral Gables Waterway from filling and has lost mangrove shoreline because of strand clearing and consequent storm erosion.

Drainage of the Everglades lowered water tables and affected all five sites. Australian pines probably invaded freshwater marshlands at all sites as the water tables were lowered. Fires became more prevalent in drying marshlands. Salinization of the Oleta River brought heavy infestation of red and white mangrove with a root parasite, Sphaeroma.

Physical barriers to overland flow of freshwater were obvious at Card Point and Section 33, but may have been involved at the other sites as well.

A sudden increase in saline water occurred only at the Interama site from opening Bakers Haulover inlet.

The saline intrusion on marshlands resulting from connecting them to the Bay with mosquito or agricultural drainage ditches eliminated the freshwater marsh plants making these areas unsuitable for any but halophytes. Interama, Cocoplum, Saga and Section 33 have become salinized by drainage ditches. At all four of these sites mangrove seeding that followed gave rise to stressed scrub red mangrove development well across calcitic marl marshes. Seeding of white mangroves on the more inland salinized marl soils occurred inconnection with major Stepember storms. At Card Point the salinization of freshwater marsh resulted from draining the Everglades and from construction of barriers that cut off overland flow of freshwater from upland.

A large area of salina was created at Card Point by salinization of marl soils that are wetted only by spring or hurricane tides. The freshwater marsh plant zone has retreated 2.3-3.7 miles (5-6 km) since the year 1900 (Reark, 1975) most of it since 1928: during this century mangroves have advanced inland about the same distance from the shore. Actually, because of mangrove and salinity encroachment, the total area of mangroves along Biscayne Bay may be greater today than in 1900.

Sphaeroma damage to red and white mangrove roots as a result of salinization was noted at Interama and probably occurred also along creeks at Saga, Section 33 and Card Point.

The major portion of Biscayne Bay's shore vegetation has been stressed and altered. There appears to be little likelihood that saline intrusion can be reversed. However, some reversal of the shoreline mangrove habitat loss may be possible by revegetation of built up shorelines. For example, appropriately placed riprap outside existing concrete bulkhead might be suitable for mangrove planting.

RECOMMENDATIONS FOR FUTURE STUDY

The productivity and ecological role of the scrub mangroves needs to be investigated. There are large areas of stressed scrub mangroves that are making small but unknown contributions to Biscayne Bay's ecology. Inorganic nutrient cycling in mangroves needs to be studied. Techniques for improving the value of these stressed mangroves to the Bay would be valuable. Also the related role of seagrass and algal wrack in the development of mangrove and shore communities needs to be investigated.

Techniques for revegetation of shorelines with mangroves and marsh graminoids need to be developed. *Spartina* planting has been accomplished by Woodhouse et al. (1974) and mangrove planting experiments have been started in Charlotte and St. Lucie Counties and elsewhere in south Florida (Teas et al., 1975, 1975b).

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TABLE 1. Salinities of surface water in drainage ditches along transect from Galloway Road eastward (August 22, 1975).

Distance from Galloway Road		Salinity
ft	m	o/oo
20	6	0, 3, 4
900	275	4
1650	500	10
2100	640	16
2550	777	18
2700	825	14
3300	1000	22
3600	1100	20

TABLE 2

Salinities of soil and surface water near Card Point (Reark, 1975)

Station No.	Distance from shore (ft)	(m)	Plant Community Type	Salinity o/oo Surface	Soil
1	13500	4000	Sawgrass	-	4
2	12500	3810	Sawgrass	-	8
3	9750	2975	Sawgrass	-	9
4	7500	2290	Juncus	5	7
5	7000	2130	Juncus	8	15
6	7000	2130	Scrub mangrove	27	41
7	6000	1830	Scrub mangrove	31	60
8	4500	1370	Scrub mangrove	46	63
9	4000	1220	Scrub mangrove	29	50
10	3500	1070	Scrub mangrove	31	66
11	500	150	Scrub mangrove, near Bay*	31	43
12	300	90	Scrub mangrove, near Bay*	37	39

* peat soil

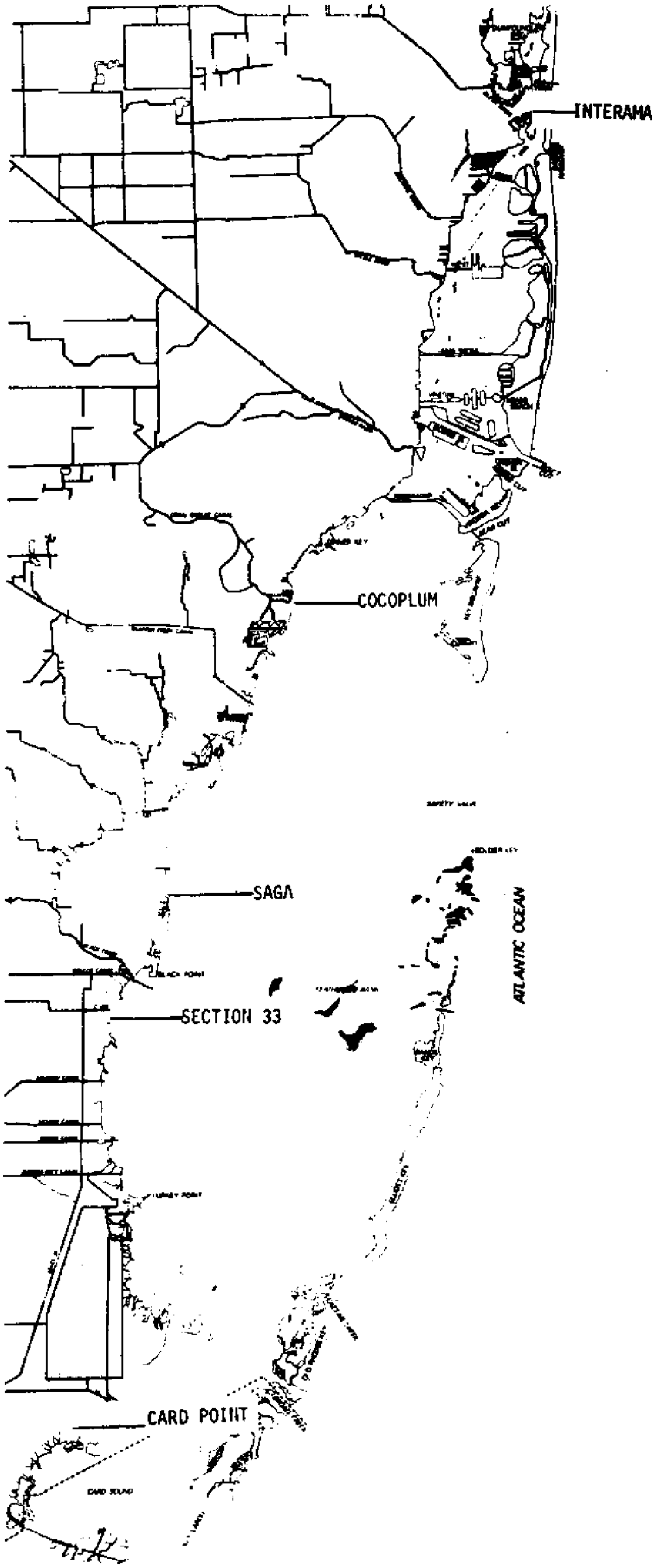

Figure 1. Map of Biscayne Bay area showing general locations of the five study sites.

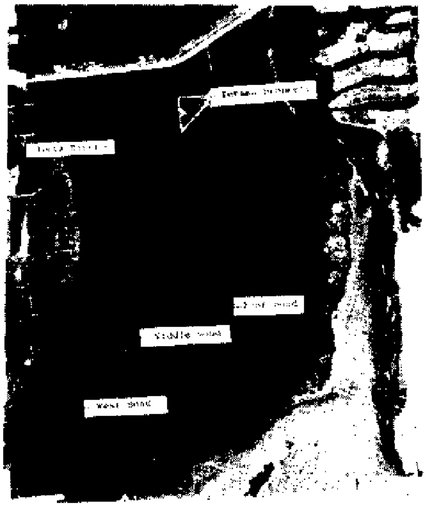

FIGURE 2 Interama property in 1956, before dredge and fill.

FIGURE 3 Interama property in 1969, after dredge and fill.

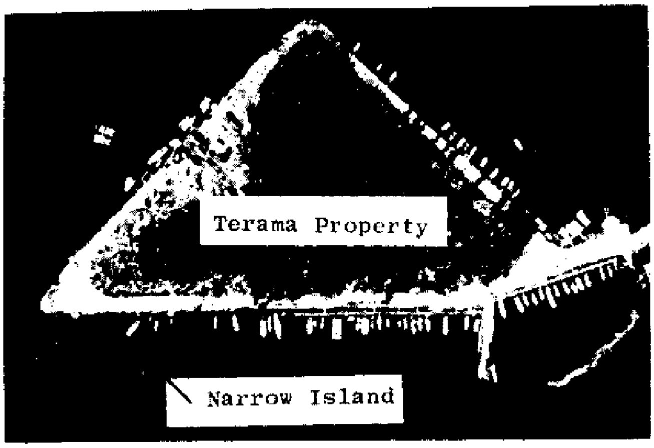

FIGURE 4 Narrow island at the Terama property, 1966.

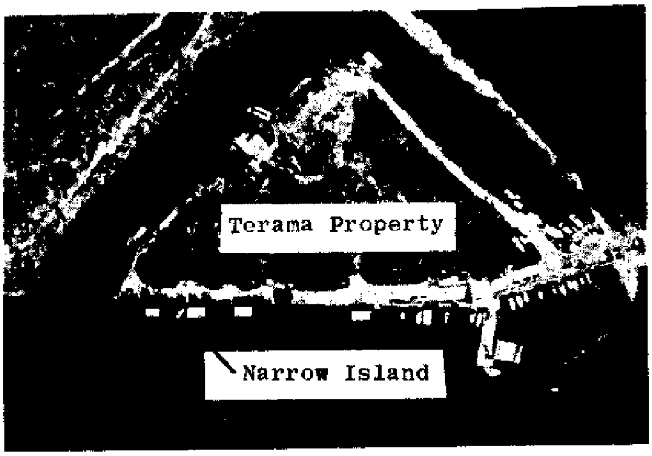

FIGURE 5 Narrow island at the Terama property, 1975.

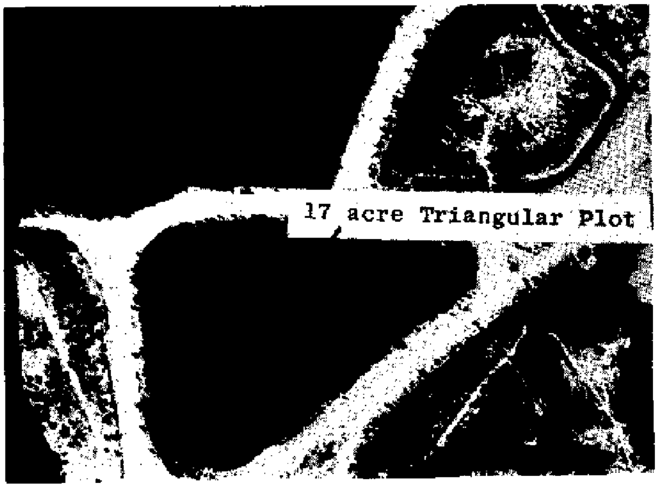

FIGURE 6 Seventeen acre triangular plot, 1972.

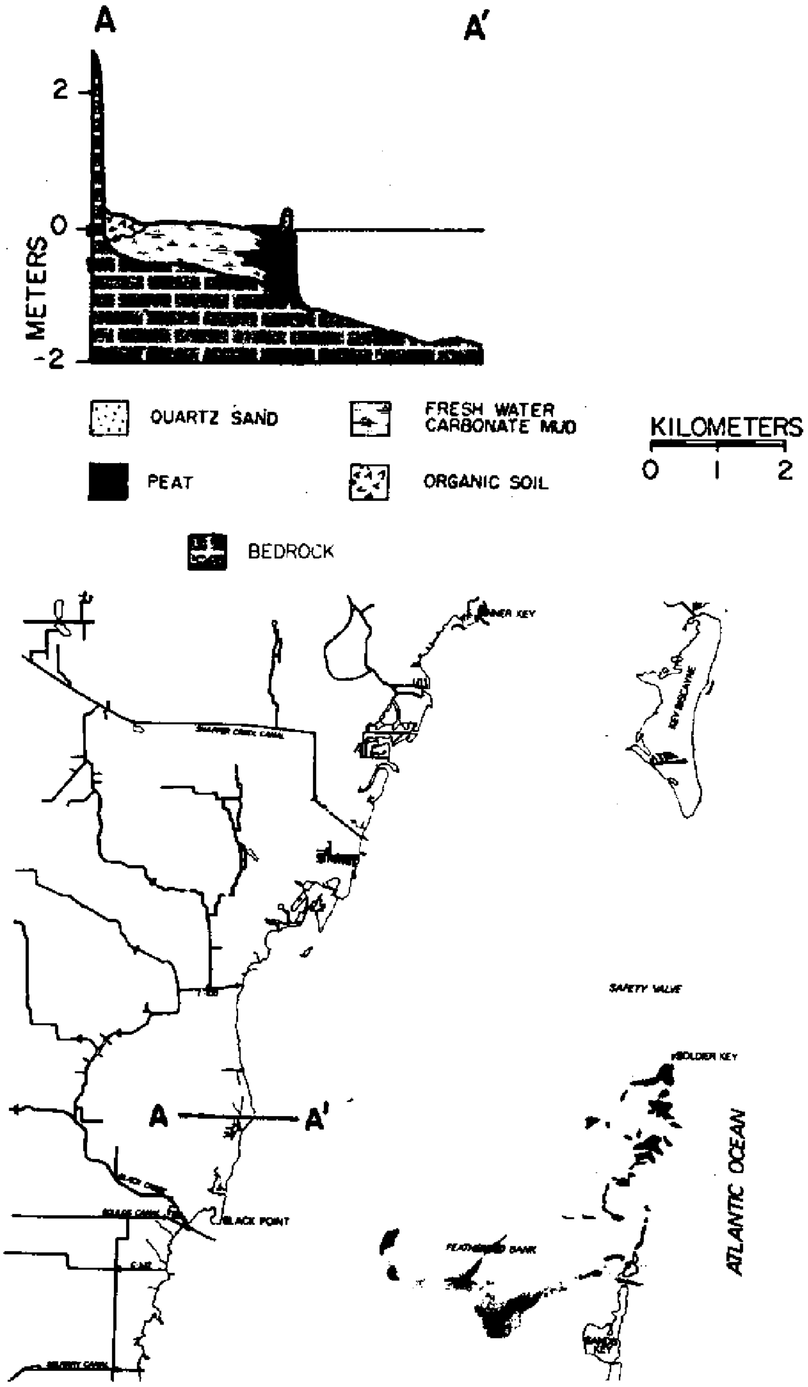

FIGURE 7 Cross-section of Recent swamp and marsh sediment accumulation in Fender Point area. Bottom line is limestone rock surface. Dots show variation in bedrock depth as determined by hand probing at each station. Sealevel datum is mean low water. See Figure 1 for location. Vertical exaggeration x 1000. Modified from Wanless (1969).

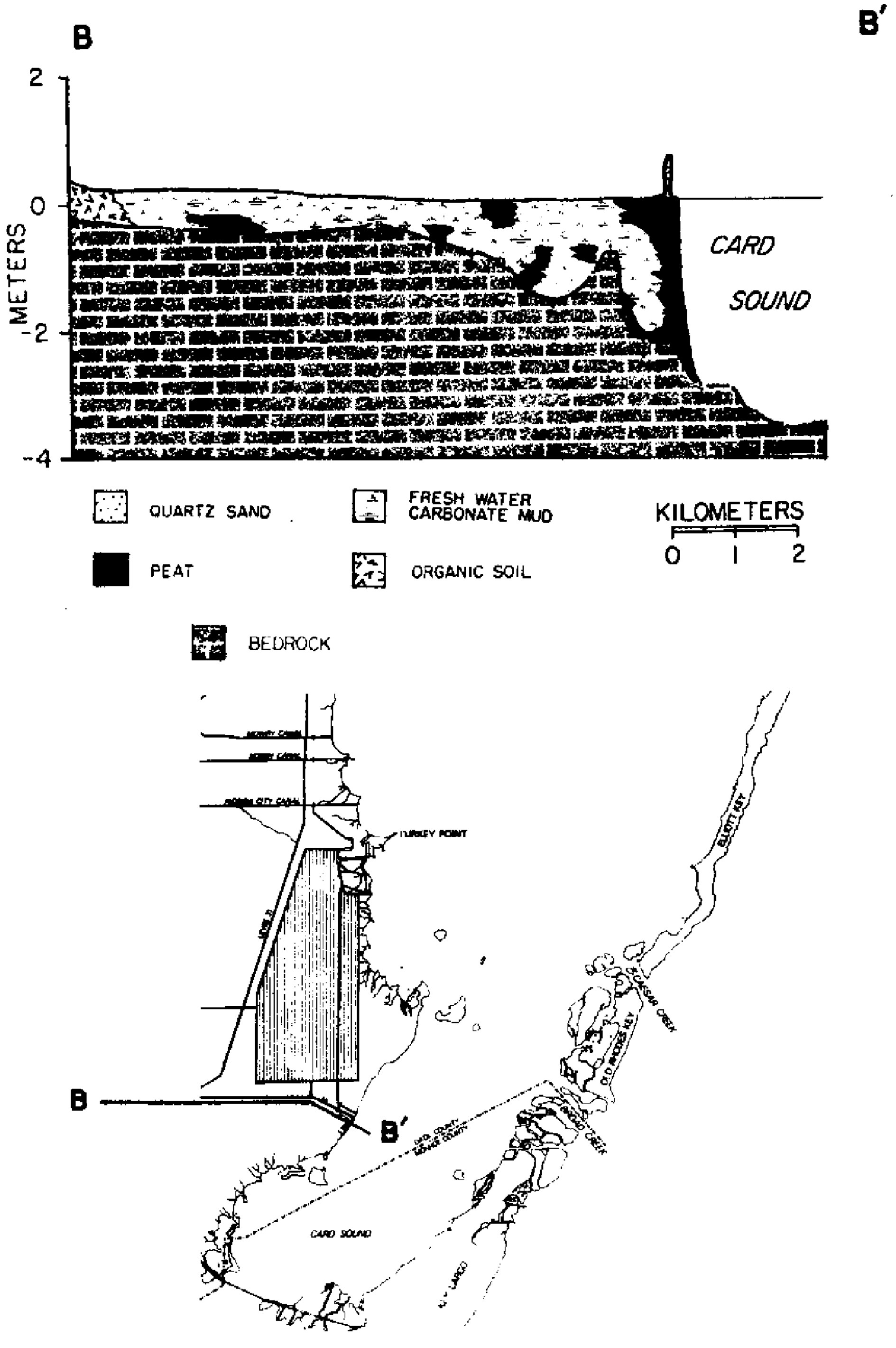

FIGURE 8. Cross-section of Recent swamp and marsh sediment accumulation adjacent to Model Land Canal 5 west of central Card Sound. Bottom line is limestone rock surface. Dots show variation in bedrock depth at each hand probing station. Sea level datum is mean low water. See Figure 1 for location. Vertical exaggeration x 100. Modified from Wanless (1969).

THE STUDY OF FUNGI IN BISCAYNE BAY - A SYNOPSIS

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ABSTRACT

Fungi have several roles in nature: as parasites, saprophytes, pathogens, and as fungal-algal composites (lichen-like associations). This paper briefly reviews these roles, emphasizing the available information in Biscayne Bay. A variety of fungal research projects have been undertaken during the past twenty years in the Bay; however, three aspects are considered of primary importance to the ecology of the Bay: (1) the possible use of fungi as indicators of sewage and land drainage pollution; (2) the sponge blight which has had a severe impact on the sponge industry; and (3) the role of fungi in the decomposition of submerged and intertidal plants such as mangroves, sea "grasses" and algae. In this decomposition process, the fungi convert inedible plant materials to microbial proteins that are consumed by a variety of small animals. This process provides a basic food source for the fishes and invertebrates that inhabit Biscayne Bay and the adjacent reefs and near-shore regions.

Considerable research is required on the sponge blight and plant decomposition; stressing the mechanisms of the processes and the effects of natural and abnormal environmental pressures. Studies of fungal pollution indicator species should be coupled with other standard and experimental pollution programs.

INTRODUCTION

Fungi are generally microscopic organisms that range in appearance from unicellular cells to highly branched filaments. In addition, their major characteristics consist of a chitin or cellulose cell wall; distinct nuclei; and a lack of chlorophyll. This combination of characteristics separates these organisms from the bacteria and algae. The fungi are capable of growing on a wide range of substrates and they exist in virtually every conceivable ecological niche. Their success is due to their rapid growth and reproduction rates; their numerous mechanisms for aerial and water spore dispersal; their ability to utilize a variety of simple and complex carbon compounds as well as organic and inorganic nitrogen compounds; and their capacity to withstand extreme environmental conditions such as high osmotic pressure, low pH, dessication and a wide range of temperatures. There are certain limitations to this success; in particular, fungi do not fix atmospheric nitrogen; they do not assimilate CO_2, as do green plants; and they are not capable of significant growth and reproduction in the absence of oxygen.

Fungi have several roles in nature; they may be pathogens, parasites, saprophytes or they be commensally associated with algae. For the importance of these roles in terrestrial environments, the informative and non-technical book by Large (1962) is highly recommended. For detailed discussions of these roles in marine environments, the reader is referred to the technical reviews of Johnson and Sparrow (1961) and Jones (1976). The purpose of the present paper is to briefly summarize these roles with specific reference to the existing knowledge of Biscayne Bay.

Pathogenic fungi

Fungal diseases of marine plants are not well known, although a dramatic event was the wasting of the eel grass, *Zostera marina*, along the coasts of North America and Europe. In the early 1930's the majority of the eel grass beds disappeared. The fungus *Labyrinthula* was implicated, but the causative agent of the disease was not determined. Because of the important role of the grass beds in marine food webs, the loss had a severe economic impact.

Orput *et al.* (1964) observed a fungal infection of the turtle grass *Thalassia testudinum* in Biscayne Bay in April 1963. Necrotic symptoms were observed on *Thalassia* similar to those found on terrestrial grasses attached by various fungi. Infected tissues of the host blades contained numerous fructifications which belonged to a fungus that the authors described as a new species, *Lindra thalassiae*. Orput *et al.* reported an extensive decomposition of *Thalassia* beds to a depth of about one meter and that the disease symptoms developed approximately 7-10 days after spring tides.

An additional potential pathogenic condition was indicated by a disease outbreak in *Thalassia testudinum* seedlings maintained in laboratory conditions during the planting program of A. Thorhaug (Univ. of Miami). The artificial conditions, including overcrowding, probably provided environmental stresses conducive to developments of this disease. The meristem area of the seedling was badly infected with bacteria, the fungus *Phytophthora vesicula* and an organism thought to be a colorless alga, *Leucothrix mucor*. The causative agent was not determined nor has the condition been observed in nature.

Creger (1962) and McMillan (1964) reported a fungal pathogen, *Cercospora rhizophora*, that produces leaf spots on red mangroves. The initial observation was at Fairchild Tropical Gardens, although subsequent studies revealed its distribution throughout South Florida. McMillan reported that the first indication of the infection appeared in the form of chlorotic spots which slowly increase in size and often reach a diameter of 5-25 mm. The leaves would often have several spots which would coalesce to involve larger areas and then the leaves would become severely chlorotic resulting in premature leaf drop. There was no indication that the disease was of significant detriment to the red mangrove systems.

The only important known fungal disease in fish is produced by the serious pathogen *Ichthyophonus hoferi*, which develops systemic infections in the heart, viscera and lateral somatic muscles. Infected animals include mackerel in England, rainbow trout in Germany, and herring and mackerel in Canada. It has been postulated that this disease may be the most important single limiting factor in population growth of herring in the western North Atlantic (Sinderman, 1970). As far as we are aware, there have not been any reports of fungal diseases in fish in Biscayne Bay.

Diseases in invertebrates are considerably more abundant on a world wide basis (for a review see Alderman, 1976). Examples include parasitism of eggs of the blue crab by the fungus *Lagenidium callinectes*; the mottling disease of lobsters on the Maine coast caused by an undescribed chytrid fungus; the economically important disease of oysters caused by *Dermocystidium marinum*; and diseases of prawns and shrimps caused by phycomycete-like fungi (Johnson and Sparrow, 1961; Sinderman, 1970). Similar diseases probably exist in Biscayne Bay, but they have not been studied and hence not reported.

The most important fungal disease of invertebrates in Biscayne Bay is the sponge blight. Sponge fishing has been an extremely important industry in Biscayne Bay to the extent that there was considerable interest in sponge culture in the late 1800's (Munroe and Gilpin, 1966). Blight that struck the Bahamas and Florida in 1938 and 1939 had a severe economic impact on both regions. An extremely interesting thesis on the history of the Florida (including Biscayne Bay) sponge industry and the effects of the blight was prepared by Shubow (1969). The only research on the disease was by Galtsoff (1942) who examined the pathogenicity of the fungus, *Spongiophaga*. Galtsoff concluded this to be the causative agent of the disease, which has been described by Johnson and Sparrow (1961) as follows: "The first externally visible symptom on all invaded animals is a 'bald' patch on the black, horny 'skin.' Beneath the bald areas is a mass of greenish, rotting tissue. Although the 'skeleton' of infected sponges may be destroyed, spongin itself is not affected. Internally the damage done by the invading organism is manifested by disintegration of the flagellated chambers and the linings of the canals, cystolysis of mesoglea, and breakdown of the ground substance. In some specimens, the central cavity is partially filled with a 'plug' of disintegrating fibers that is usually lined with a tough membrane of mesogleal cells. This membrane supposedly forms a resistant layer of tissue effectively preventing causal organism spread throughout the body of the infected animal. Infestation is confined to a narrow marginal zone around the lesion (internal to the 'bald' spot) between the healthy and affected tissue. Invaded tissue invariably has in it long, very slender (0.8 μ diameter), aseptate filaments, but none occurs within the obviously 'normal' tissues external to the lesion border."

Another fungal disease of invertebrates in Biscayne Bay was studied by Newell et al. (1976). These authors found that certain fungi (oomycetes of the genera Myzocytium, Haptoglossa and Gonimochaete) attack nematodes, internally invade the animals and subsequently consume them. These fungi were found associated with animals in decomposing plant material. The abundance of the fungi is not known; however they have the potential of affecting nematode population levels. This becomes significant due to the importance of nematodes in plant detrital food chains.

Certain fungi are closely associated with warm-blooded animals and are often pathogenic to humans. Because of this association they are common constituents of sewage and other runoff waters. In a study of the yeasts of Biscayne Bay, Fell et al. (1960) found an abundance of the pathogens Candida tropicalis and C. parapsilosis. Subsequent unpublished studies demonstrated the prevalence of the more virulent species, Candida albicans, which is the causative agent of candidiasis. The yeast was abundant in areas subjected to heavy densities of swimmers and bathers, particularly at the wading lagoon at Matheson Hammock. The presence of these pathogens is probably not a problem in dissemination of infections because these species are normal constituents of the human body. Infections are usually associated with some other physiological body disorder. However, the presence of these species in the Bay is an indication of the degree that these waters are polluted. Pollution indicator species of yeasts have also been demonstrated by other investigators in various parts of the world (reviewed by van Uden, 1967) and by the subsequent studies of Combs et al. (1971) in Long Island Sound, Buck (personal communication) in New England, and by Spencer et al. (1970) in an aquatic environment (S. Saskatchewan River).

Studies have not been undertaken to determine if other human pathogenic fungi, other than yeasts, occur in Biscayne Bay, although the possibility exists. Dabrowa et al. (1964) studied tidally washed coastal areas of southern California and isolated numerous species of fungi (Hormodendron compactum, Sporotrichum schenckii, Monosporium apiospermum, Scopulariopsis brevicaulis, and species of Aspergillus, Candida, and Geotrichum) that produce a variety of cutaneous, subcutaneous and systemic infections. (For a review of medical mycology, see Emmons et al. (1970)).

Parasitic fungi

The distinction between parasitic, saprophytic and pathogenic fungi in marine systems has not been carefully examined. As a working definition, parasites infest living organisms, but do not harm the host; saprophytes inhabit the dead material; whereas, pathogens infect living material to the subsequent detriment to the host. The majority of the available information on fungal parasites concerns those associated with plants.

A parasite that possibly inhabits Biscayne Bay (but has not been studied there) is the fungus Plasmodophora diplantherae. This particular parasite is known to attack Diplanthera wrightii, a common seagrass. This particular fungus produces a hypertrophy of the inner cortical internodal cells but does not appear to have any effect on the development of the plant nor does it affect the populations (Johnson and Sparrow, 1961).

Lichen-like associations

Fungi may be associated with algae in lichen-like partnerships in which the two are always found together and appear incapable of surviving independently. Such an association is common in Biscayne Bay in the alga Cladophora. Hyphae of the fungus Blodgettiomyces do not penetrate alga cells, but can be observed ramifying between them. Close examination of other algae in Biscayne Bay would probably reveal a more widespread occurrence of this type of association.

Saprophytic fungi

Undoubtedly the most significant role of fungi in Biscayne Bay, and similar locales, is their important contribution to detrital food webs. In general, food webs are of two basic types: grazing and detrital. The grazing food web initiates with green plants that are fed upon by herbivores which in turn are eaten by carnivores. In the detrital food web, dead organic material is decomposed by microorganisms which are consumed by detrital feeding organisms that are then eaten by carnivores. In tropical and subtropical estuarine systems, particularly marshland and benthic bay communities, detrital food webs are the most important mechanisms of sustaining the large populations of animals that are characteristic of these regions.

In south Florida, particularly Biscayne Bay, the major detrital producers are the shoreline plants, the mangroves and juncus, and the estuarine marine "grass," Thalassia. Organic production by these plants has been measured in various parts of the world, at 750 gms dry wt/m^2/yr for Juncus roemerianus, 1300-2250 gms for Thalassia and 47-730 gms for Rhizophora mangle (reviewed by Odum et al., 1973). Based on their environmental habitats it is probable that the three plants have different and yet overlapping roles in maintaining a stable, productive estuary. It is evident that there is little direct grazing of these plants and that they become useful as food sources during the degradation process (Odum et al., 1973).

The basic role of plant detritus in supporting food webs is essentially the same in terrestrial, freshwater and estuarine areas, hence the mechanisms observed in Biscayne Bay are not unique to the system. Most of the available information on food webs comes from research in terrestrial and freshwater regions, not wholly dissimilar from inland Dade County, which eventually drains to the coast. A generalized overview of how detrital systems function is depicted in Figure 1. There are essentially three components in the leaf degradation system. The decomposing leaf with the associated microbial and small invertebrate (meiofaunal) populations; the leaching soluble organics; and the detrital particles. When the leaves senesce they usually fall into the water where they are rapidly attacked by microorganisms, including bacteria, fungi and a variety of meiofauna. In most systems, the leaf material is not readily utilizable by animals in its original form, hence the role of fungi is the conversion of leaf components, mostly carbon compounds, to utilizable proteins. These proteins are consumed by meiofauna, which in turn are utilized by secondary consumers such as the commercially and recreationally important fishes and invertebrates. The types of fungi associated with the decomposition process will vary with the substrate and state of decay, i.e., degrading juncus will contain different species of fungi than decaying mangrove leaves and similarly the fungi on mangrove leaves in early stages of decay will differ from those in latter stages of decay. The same types of statements can be made for the associated meiofauna, particularly in reference to the type of substrate.

With decay the leaves become fragile and break into detrital particles that are transported by water movements. The detrital particles, per se, are not a nutrient source for most animals; instead it has been postulated by Fenchel (1970), from his work in Biscayne Bay, that the particles are coated with microorganisms that degrade the particles. These particles, with accompanying microbes are ingested by the animals. The microbes are digested and serve as the food source while the particle is defecated intact for subsequent microbial colonization and animal consumption.

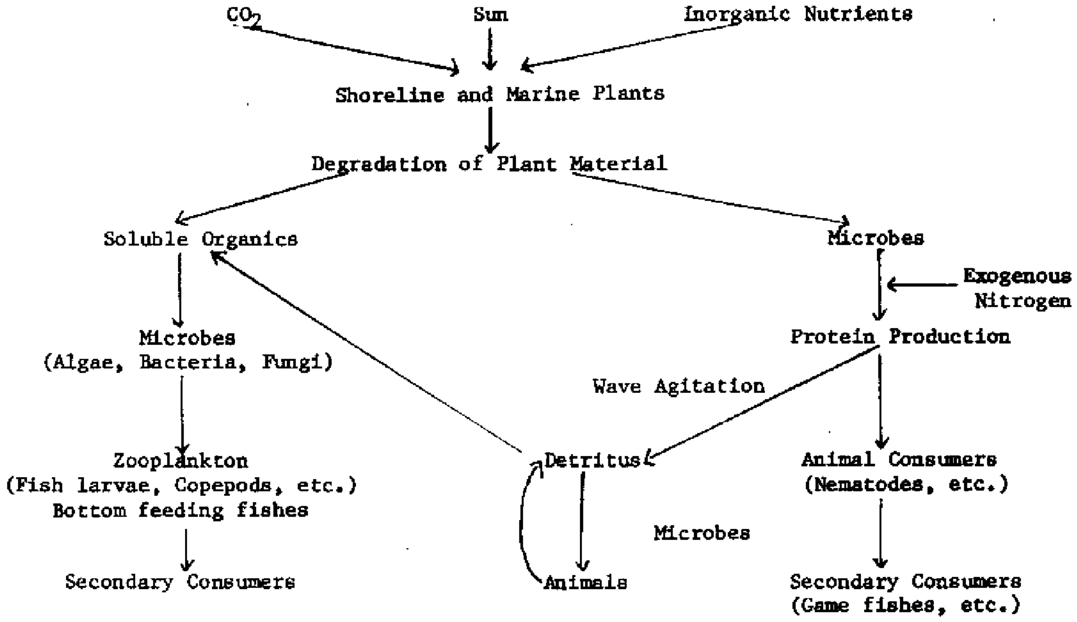

FIGURE 1. Possible Pathways of Energy Flow During the Degradation of Plant Organic Materials

Many of the soluble nutrients that leach from the leaves can be utilized for growth by heterotrophic microbes such as diatoms, fungi and bacteria. These organisms reside in the sediments and the water column and are an important food source for a variety of adult larval fishes and invertebrates. In contrast, some of the organics that leach from plant materials are not utilized for microbial growth and may, in fact, inhibit growth (Cooksey, personal communication).

Because invertebrates, such as shrimp, utilize microbial-detrital complexes in their natural diet, Newell and Fell (1975) experimented with the production of artificial feeds for mariculture. Fungal fermentations of agricultural by-products were used and the results indicated the feasibility of such techniques for the husbandry of a variety of commercially important animals.

Decomposition studies in Biscayne Bay

The early decomposition studies were directed to the breakdown of manila cordage and wood, a problem of considerable economic significance, particularly in tropical and subtropical regions. These studies included the distribution and taxonomy of the fungi involved (Meyers, 1953; Meyers, 1969; Meyers, 1957; Moore and Meyers, 1962; Reynold and Meyers, 1957; Meyers and Reynold, 1960; Meyers, 1971a; Meyers and Moore, 1960; Moore and Meyers, 1959; Meyers *et al.*, 1964; Meyers and Reynold, 1958), and various aspects of the physiology and biochemistry of the degradation process (Meyers, 1971b; Meyers, 1968; Meyers and Simms, 1967; Meyers and Scott, 1968; Meyers and Reynold, 1959a; Meyers and Hoyo, 1966; Meyers, 1968; Meyers and Reynold, 1960; Sguros *et al.*, 1962; Sguros and Simms, 1963; Sguros and Simms, 1964; Meyers *et al.*, 1960; Meyers and Scott, 1967; Sguros and Simms, 1963; Meyers and Reynold, 1959b; Meyers and Reynold, 1959c). These studies were not only important in the evaluation of the decay of cordage and wood, but also are of significant interest, in a comparative sense, in the examination of the degradation of naturally occurring plant materials.

Other studies in Biscayne Bay, at about the same time, were directed to determining the presence of fungi in waters and sediments. These studies included yeasts (Fell *et al.*, 1960, Capriotti, 1962a, b, c; Van Uden and Kolipinski, 1962; Fell and Van Uden, 1963; Van Uden and Fell, 1967), filamentous fungi (Roth *et al.*, 1964) and some of the physiological properties of the organisms (Ahearn *et al.*, 1960; Ahearn *et al.*, 1962; Ahearn and Roth, 1962; Ahearn, 1964; Ahearn and Roth, 1966; Ahearn *et al.*, 1968; Buck and Greenfield, 1964). These studies are also important for comparative background data.

Thalassia decomposition

In an extension of their research on cordage and wood, Meyers and his collaborators undertook studies of fungi associated with the decomposition of turtle grass. Orput *et al.* (1964), as previously discussed, observed what they considered to be a disease of *Thalassia* by the fungus *Lindra thalassiae.* Unfortunately, they did not quantitate the destruction. In a subsequent paper, Meyers *et al.* (1965) were of the opinion that *L. thalassiae* was a secondary invader of *Thalassia* leaves and only became established following physiological degradation of the plant tissues by associated microbes. They also suggested that a different microorganism, *Labyrinthula*, had a possible role as a primary invader. Meyers *et al.* observed considerable variation in the species inhabiting different plants within an area or even on the same blade. They also reported that there is seasonal variation and that certain fungal species were regularly associated with *Thalassia* throughout the Bay. Meyers (1968) elaborated on these findings and demonstrated that fungal populations on submerged wood are distinct from those on *Thalassia*.

Studies of the primary consumers in the *Thalassia* decomposition processes in Biscayne Bay (Hopper and Meyers, 1966a and b; 1967; Meyers, 1971) were directed to nematode populations. These animals are extremely abundant in the sediments in *Thalassia* beds and on the decomposing grass blades. By the use of some unique field and laboratory experiments (Meyers *et al.*, 1963; Meyers and Hopper, 1966; 1967; Meyers *et al.*, 1970; Meyers, 1968) nematodes were shown to feed directly on fungal mycelia. While certain fungi did not support animal growth, others, especially the fungi *Dendryphiella arenaria* and *Halosphaeria mediosetigera*, were extremely effective. Utilization of the mycelia by the animals varied with fungal species and ranged from 100 animals/mg of mycelia to 5000 animals/mg mycelia. While some nematode specied fed directly on the fungal mycelia, the role of other nematodes was suggested to be a more complex interrelationship. Initially the fungal degradation of cellulose and other plant components occurs followed by the utilization of these fungal by-products by other microbes, such as bacteria and protozoans, and finally the subsequent consumption of these organisms by the nematodes. This concept is extremely important as it is probably via this indirect method that a considerable portion of the plant material is utilized in many plant degradation systems.

Mangrove degradation

Three mangrove species inhabit Biscayne Bay: the red mangrove, *Rhizophora mangle*; the black mangrove, *Avicennia nitida*, and the white mangrove, *Laguncularia racemosa*. Of these, only the red mangrove degradation system has been studied in detail. This is unfortunate; although the presence of information has deservedly fostered concern regarding preservation of the reds, the lack of knowledge has resulted in the assumption that whites and blacks have little value. Red mangroves are usually continuously tidally inundated; whereas the black and white mangrove regions, under many circumstances, are only submerged in high or storm tides. This results in a continuous outflow of organics from red systems, with periodic to sporadic pulses from the whites and blacks. The continuous flow is important in maintaining the estuarine ecosystem; however, the pulses may be equally important both in restoring organic balances and in coinciding with other important biological activities such as the life cycles of various animals (Snedaker and Fell, 1975).

The following information is based on the red mangrove system. The degradation of mangrove leaves, seedlings and woody tissues, initiates food webs that sustain a considerable portion of the marine animal populations that inhabit the coastal region. This role of mangroves has been documented in the various publications by Heald and Odum (Heald, 1969; Odum, 1970; Odum and Heald, 1972; Odum *et al.*, 1973). Although their research was conducted in the Everglades National Park, their results are applicable to Biscayne Bay. These authors reported that fallen leaves are converted by microbial activity to detrital particles and the latter support large populations of detrital consumers such as amphipods, nematodes, polychaetes, small crabs, shrimps and fishes. In turn, these consumers are a primary source of food for game and commercial fishes, such as tarpon, snook, grey snapper, sheepshead and spotted seatrout. Odum and Heald observed, during the degradation of the mangrove leaves, a significant increase in the relative amount of protein similar to that observed by Kaushik and Hynes (1971) in freshwater systems due to fungal activities. Odum and Heald conjectured that the fungal protein is an important food for the detrital consumers.

The dynamics of the mangrove degradation system are being investigated in Biscayne Bay and are presented in the publications of Fell and Master (1973; 1976); Fell et al. (1967), and Newell (1973; 1976). The general outline follows that as depicted in Figure 1. Following leaf senescence, the leaves fall in the water, and are rapidly attached by microorganisms, including bacteria, fungi and a variety of small invertebrates. The fungi, as in other systems, convert the leaf compounds to utilizable proteins. There is a sequence of fungal populations correlated with the state of leaf decay and the composition of the residual organic compounds. In the early stages of decay, the readily utilizable carbon compounds are consumed by fungi such as the phycomycate Phytophthora; whereas in advanced stages of decay when only the complex organic compounds remain, the fungal communities are characterized by a variety of lignolytic and cellulotic species. An indication of the conversion process is indicated by an increase in absolute nitrogen during the decay sequence. Some of the chemical alterations (particularly changes in amino acids) during this process have been examined by Casagrande (1970). One of the limiting factors is an apparent lack of nitrogen in the surrounding water. Experimental laboratory and field studies have demonstrated that a substantial amount of nitrogen may be contributed from N_2 fixing bacteria (Taylor, personal communication). A portion of the fixed nitrogen is probably utilized by fungi for protein synthesis.

In addition to the utilization of leaf components for formation of microbial proteins, there is an initial rapid loss of materials through leaching into the surrounding water. Within the first two weeks there is a loss in excess of 1/3 of the dry weight. Combined leaching and weight losses, due to microbial activity, increase to approximately 60% around 16 weeks. A considerable proportion of these losses can be attributed to a loss in carbon. The rates of these losses will vary with environmental conditions, such as temperature, period of submergence, wave agitation, etc. However, at the approximate 16-week period, the leaves are fragile and easily break into detrital particles.

During the decomposition process a variety of meiofauna inhabit the surface and eventually the internal layers of the leaves. The animals attach to the leaf surfaces within the first few hours of leaf submergence. As decay progresses, the animals reproduce and attain numbers of 40-70 animals/sq cm of leaf surface. The majority of the animals are nematodes and copepods, although numerous other meiofauna are present such as polychaetes, foraminifora, ciliates, flatworms, insect larvae, mites, oligochaetes, ostracods, tardigrades and testacids.

The interdependency of organisms in the decay process as described in the flow diagram, suggest that any perturbation that would alter the functions of one member or step could disrupt the entire process. Such perturbations can be the result of natural environmental fluctuations or can result from man's interference (Hopper et al., 1973). Therefore, careful consideration must be given to the types of domestic and industrial effluents that are allowed in the Bay.

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VIRUS STUDIES IN BISCAYNE BAY

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ABSTRACT

We have recovered viruses from the Bay and from marine fishes. Most of the time these were viruses originating from human excrements--raw sewage discharged into the sea. Many of these are capable of causing human disease. When sea food becomes contaminated with these viruses (and some shellfish, in fact, concentrate them) it becomes a potential hazard to human health. We have also found viruses which originate from fish and which are probably a health hazard to them. The basic question is how much of a risk do all these viruses present to the Bay? To fish? To the users of the Bay? And to the consumers of sea food? The magnitude of the problem cannot be defined at this time and must be subjected to more intensive study in the light of newly discovered aspects of virus distribution, stratification in layers of water, binding to solid particles and inactivation by substances produced by marine organisms (invertebrates, algae and bacteria). Above all there is a great need to improve the methodology for recovery of viruses from the Bay and from other marine waters.

INTRODUCTION

In a recent workshop sponsored by the Institute of Food and Agricultural Sciences at the University of Florida at which we reported on the vicissitudes of virus isolations from the sea there was a consensus that the voids in knowledge about viral pollution are the major obstacle in the path of decision making, policy promulgation and law enforcement in the area of safeguarding the environment and protecting human health. At this conference and at others held in the United States and abroad, virologists, engineers and policy makers invariably reach the same conclusion--that more information is needed about the many aspects of pollution, in general, and the presentation, distribution and survival of viruses in water, in particular. While it is usually not too difficult to find viruses in waste water, methods in current use do not permit recovery of all viruses present in an effluent at any one time or the determination of the exact amount of a particular virus at different times. The problem is more complicated with viruses in ground waters or in soils and it is extraordinarily complex in the marine environment.

Virtually every community on the Eastern Seaboard has used the ocean as a receptacle for its waste waters. This practice was dictated by many considerations. It was the cheapest way of getting rid of sewage, and sometimes the only way. The vast size of the ocean, hence the immense dilution factor, coupled with the movement of waters was considered to be a safety device against the dangers that would otherwise result from substances discharged into the sea. The growth of the population and the movement of large groups of people toward the coastal areas has resulted in this practice assuming major proportions whereby hundreds of millions of gallons of waste water are being discharged into offshore waters. This has evoked two reactions: 1. A concern about dangers to human health and to the survival of marine animals including commercially valuable fish and shellfish and 2. an immediate disagreement as to the magnitude of the danger and the course of remedial action to be taken. The problem of health hazards has brought about ordinances declaring certain waters unsafe for swimming or other recreational activities. Outbreaks of hepatitis traceable to the consumption of raw or improperly cooked oysters and clams have led to condemnation of large stocks of seafoods and prohibition of harvesting from large estuarine areas. The recent increase in the incidence of disease and death among fishes in Biscayne Bay may signify an effect or effects of noxious substances and/or infectious agents released into the sea. The considerations of economic losses to the fishing and food processing industries have been potent shapers of opinions. Concern over economic losses has often outweighed the fears about the risk to health. There have been demands for complete cessation of discharges into the sea. Theoretically and even technically it should be possible to render waste water suitable for drinking but the costs of such technology are prohibitive. The most practical solution to waste water disposal in areas such as Dade County based on demographic, geologic, and economic considerations is construction and utilization of modern, secondary treatment plants which include terminal disinfection.

Since the practice of discharging waste water into the sea is bound to continue it behooves all interests, governmental, commercial and private citizens to create the means of recognizing and monitoring the extent and intensity of factors (microbial, viral and chemical). There is an overriding need to use advanced methods and instruments for the gathering of data and facts to assure safety and productivity of the marine environment. This information is vitally needed to counteract the extremes of propaganda which either tend to create a overreaction to pollution or bury any hazard under the sea in the hope that it will never surface.

Our main objective is therefore to develop in collaboration with industrial groups, mechanical devices and techniques for the improvement of recovery and quantification of viruses from the sea. This presupposes not only work on different instruments, membranes, fractionation procedures, etc., but also investigations on the factors which facilitate or hinder detection of viruses. Inherent in this objective is the necessity of recognizing and isolating viruses indigenous to the sea as these may be even more important to the survival of marine species.

METHODS

Since the number of viruses present in a given volume of water may be small, it is necessary to concentrate the specimens sometimes as much as 500-fold. In order to assay for viruses in tissue culture, viral particles must remain infective, and thus whatever method is used for concentration it must be sufficiently gentle as to maintain virus viability.

Three methods, each based on a different principle, have been used in our laboratories with at least some degree of success in virus concentration and are described below:

1. Flocculation with polyelectrolyte 60 (PE-60 , Monsanto). This involves mixing the specimen to be analysed with a proportional amount of PE-60 (50 mg polyelectrolyte 60 per liter of sample) at low pH followed by incubation and elution with high pH buffer (3 ml per liter of initial volume). This method

is fairly effective for concentration of acid/alkali resistant enteroviruses.

2. Adsorption and elution from epoxy-fiber glass filters. The sample is acidified to pH 3.5 by injection of HCl prior to filtration through fiber glass cartridge filters and epoxy-fiber glass membrane filters in series, followed by elution with low volumes of glycine buffer pH 11.5. The Carborundum Company has manufactured a unit that operates on this principle. It consists of a series of three clarifying pre-filter cartridges and three epoxy-fiber glass (2 cartridges, one membrane) filters in series. Acidification of the sample is accomplished by in-line injection of HCl. The sample is pumped with a centrifugal pump at the rate of 1 gallon per minute. After the desired volume is processed, viruses are eluted from the last three filters by injection of glycine buffer pH 11.5. Pre-filtration is necessary when working with heavily sedimented waters (i.e., sewage effluent) but if the water sample is clear, the first three filters may be eliminated. While this method is somewhat similar in principle to the PE-60 flocculation procedure, it has the advantage that larger volumes of water may be processed (up to 50 gallons). It now appears that in both methods elution may be accomplished by the use of protein solutions (peptone or albumin) without resorting to high pH.

3. Ultrafiltration. A Millipore Pellicon Cassette system fitted with a PTGC membrane was used. This system is a thin channel device operated with a peristaltic pump to minimize disruptive shearing forces which would probably decrease the number of infective viruses during concentration. In experiments in the laboratory, distilled water was spiked with known amounts of poliovirus (1 to 100,000 viruses/ 10 ml) and 100% of the virus was recovered upon concentration from 4 liters to 100 ml. While the volumes of water that can be processed with this device are comparatively small, this method has consistently given the best overall recoveries of viruses in artificially spiked water samples, and thus is the most promising approach for future work.

Viral Assays

After concentration, the samples were treated with antibiotics to eliminate bacterial contamination and inoculated into tissue culture. During the course of this investigation a number of tissue cultures have been tested for sensitivity to infection with enteroviruses. These cultures are Vero, a cell line derived from African green monkey kidney; MK, primary Rhesus monkey kidney cells: HEL, primary human embryo lung cells; HEK, primary human embryo kidney cells; and BGM, a Buffalo green monkey kidney cell line. Viral isolates from seawater have been obtained using the last three types of tissue culture.

All specimens were inoculated in quadruplicate and in amounts of 0.1 ml per tissue culture tube. The cultures were incubated horizontally at 37°C and observed for cytopathic effects (CPE) daily for 6 days. Viral isolates were identified according to the NIH procedures for using the Benyesh-Melnick serum pools for typing enteroviruses.

RESULTS

The results presented on Tables I and II indicate that viruses capable of causing human disease are being discharged into the sea. Positive recoveries of viruses were obtained in ten instances. The frequencies of isolation range from 1/20 to 6/13. We believe that the differences reflect the degree of treatment at the plant. It should be noted that only one positive isolate was obtained from the outfall of the Virginia Key plant, which seems to indicate that treatment of sewage at that facility is fairly effective in removing viral contamination from sewage effluent. In contrast, when raw sewage is discharged one can detect human enteric viruses with a relatively high frequency i.e., 46% in North Miami Beach and 50% in Miami Beach. Several attempts were made to isolate viruses at various distances from the outfalls. One positive isolate was obtained from the vicinity of Baker's Haulover Beach. The frequency of isolations from water distal to the outfall has been relatively low and we ascribe this difficulty partly to the inadequate sensitivity of the methods for viral concentration. The efficiency of sewage treatment on the removal of viral contaminants was further corraborated in experiments at the Virginia Key plant, where Echo virus was isolated from primary sewage effluent prior to chlorination, but no viruses were demonstrated in 50 gallon samples obtained at the plant after chlorination. It must therefore be concluded that treatment of sewage effluent with chlorine plays an important role in the elimination of possible viral pathogens from sewage effluents discharged into seawater.

DISCUSSION

Our primary concern has been the detection of human viruses in seawater. Some of the viruses recovered are known to cause infection of the human intestinal tract. In many instances these infections are inapparent; nonetheless, they may be associated with paralysis, meningitis, diarrhea, fever, and rashes.

Using methods based on principles of electrostatic adsorption and desorption we have demonstrated intermittent presence of virus in the vicinity of ocean outfalls. Why intermittent? Were there periods when virus was not being discharged? Probably not; rather, the intermittency was most likely caused by the inadequacy of methodology. The lack of capability to apply virological techniques has resulted in declarations that viruses/are absent in certain areas receiving waste waters. It must be remembered at this juncture that viruses cannot proliferate in the absence of living cells and are often lost during the process of detection and isolation due to technical factors. Treatments such as low pH required for virus adsorption, high pH for elution, shearing forces, etc. can inactivate viruses and make them undetectable. It is not difficult to imagine a situation where 10 million virus particles are discharged in an hour. If these were evenly dispersed and evenly distributed along all radii there would be no major problem. However, they are not evenly distributed or homogeneously dispersed and it is a matter of chance whether one happens to make the water collection at a position where the viruses are abundant. Scientists in one Government regulatory agency have been recommending that safe water must be shown to be free of virus to a point of less than 1 virus particle per 100 gallons. These are better than 400,000 to 1 odds, since there must be at least 1 infectious virus particle in 1 ml used for inoculation of tissue cultures. At this stage it is not known whether this stringency is justified. In any event, previously used methods fall far short in capability to achieve a concentration factor of 400,000.

At present it is not possible to make precise recommendations because of the vast amount of unknowns and variables. Unfortunately, while the benefits of pollution abatement are obvious the risks are not fully known. Economists and engineers talk of trade-offs but here we run up against the recurrent question--what are the stakes? There is no information about the magnitude of the problem in general and the extent or intensity of viral pollution in particular. To reiterate the studies done to date, partly under the auspices of Sea Grant of the University of Miami, have provided answers to the effect that human infectious viruses can be detected in the vicinity of ocean outfalls. In fact, we have found viruses at sites distal to the outfalls, such as Baker's Haulover. These viruses could have come from pollution by boats, or they may have been transported from the outfall by the currents and tide. Some of the results obtained by us also indicate that there is a correlation between frequency of detection of viral pollutants and treatment of the waste water. Thus, viruses were isolated frequently from the outfalls of North Miami Beach and Miami Beach, but only on one occasion from the outfall of Virginia Key which has been subjected to 21 separate tests. The first two discharge raw sewage while the latter applies partial treatment with chlorination. This treatment apparently suffices to reduce the level of viral contamination to a subdetectable point but even here there is no assurance that dangerous infectious viruses are not being released. Moreover, these are only crude correlations as there are no precise methods of quantification at hand. We can say virus is present or virus is not detectable. But no one using the current methods of virus detection can tell how much virus is present at a given site. This deficiency is universal and has been aired repeatedly at international, national and regional meetings. Furthermore, even if assuming that peak efficiency of operation of treatment plants would reduce the risk of viral and bacterial pollution, there is the ever present problem of inefficient operation, breakdowns and bypasses resulting in discharges of infectious or toxic materials. Moreover, increased levels of chlorinated hydrocarbons with potential carcinogenic capability have been recently demonstrated. Some of these arise from the action of chlorine used to disinfect waste water. This may necessitate modifications in treatment procedure including changes in concentration of chlorine and perhaps substitution by other disinfecting agents.

While these human viruses are probably not pathogenic for fish, we have demonstrated that oysters, conchs and other invertebrates may concentrate human enteroviruses in water. Furthermore, this concentration process is very efficient, and thus marine invertebrates may serve as vectors for infection when used for human consumption. As a spinoff from these observations, work is now in progress on the use of conchs as "sentinels" in areas of suspected viral pollution. Briefly, conchs are to be placed in and around the area of the boil and in canals discharging into the sea. At periodic intervals, some of the conchs will be sacrificed and virus extractions will be performed on the gut and other tissues, to assess the number and type of human enteroviruses they may have collected. This is strictly an experimental approach, yet it may become the best method for monitoring viral pollution in suspected bodies of water.

Very little is known about true fish pathogens of viral nature. One reason for this is the lack of appropriate fish and marine invertebrate tissue cultures that are needed to grow and isolate marine viruses. An attempt is being made in our laboratories to raise shrimp tissue cultures. These cultures, in conjunction with the already developed grunt fin tissue cultures will be used for screening of fish pathological specimens which may be suspected of viral infection. It is hoped that the combined approach of monitoring for human enterovirus pollution and for detection of viral pathogens in marine organisms will be of help in assessing the role and importance of viruses in the marine environment.

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Table I

Isolation of human enteroviruses from seawater

Sampling site	# of samplings	Virological finding	Method of concentration*
Virginia Key Ocean Outfall	21	18 negative	P
		1 positive	C
		2 atypical	P
Miami Beach Ocean Outfall	6	3 negative	P
		2 positive	P
		1 atypical	P
North Miami Beach Ocean Outfall	13	7 negative	P
		6 positive	P
Pompano Beach (boil)	3	3 negative	C
Virginia Key Plant Effluent			
a) prior to chlorination	1	1 positive	C
b) post-chlorination	3	3 negative	C

* P = flocculation with PE-60
C = Carborundum instrument

Table II

Virus Identification (from Table I)

Sampling site	# positives	# identifications	Type
Virginia Key Ocean Outfall	1	1	Polio 1
Miami Beach Ocean Outfall	2	1	Echo 12
North Miami Beach Ocean Outfall	6	1	Echo 24
Virginia Key Plant Effluent	1	1	Echo 7

THE INVERTEBRATES OF BISCAYNE BAY

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ABSTRACT

The marine invertebrates of Biscayne Bay are living under stress over most parts of the bay, and many populations have been decimated through shoreline changes, reduced flushing, sea grass destruction, and various forms of pollution. Comparisons between life on natural rocky shores, in rip-rap, and on vertical bulkheads show that the latter is the least desirable as a man-made structure. The sea grass communities are the richest known and their removal through various causes has greatly reduced invertebrate numbers in the bay.

Recommendations for the revitalization of the bay include shoreline restoration by natural landscaping and rip-rap, increased flushing by widening channels through the causeways or construction of new water flow channels, and replanting of barren bay bottom with marine grasses. Pollution must be continually reduced, as no known tolerance levels of bay invertebrates can be used for determining safety criteria. Pesticide problems in south Dade canals must be resolved. A broad scale survey of the invertebrates of the bay is required as baseline studies for proper bay management.

INTRODUCTION

Biscayne Bay lies at the meeting place of the tropical West Indian Faunal Province and the temperate Carolinian Faunal Province. As a result it has a very rich invertebrate fauna. Despite its unique position its fauna has never been adequately surveyed and no species inventory is available. A review of the older accounts of Biscyane Bay and the surrounding region reveals nothing of importance concerning the invertebrate fauna, and even taxonomic lists prior to the establishment of the University of Miami yield no information on distributions and numbers.

As a result, we are forced to rely for information about the original fauna on rather general statements in the early literature, especially on the ecological conditions then existing. Recently, for instance, it was suggested at a public hearing that the north end of the Bay was formerly a freshwater marsh and that perhaps the recovery of the north Bay area would be aided if this part of the Bay cound be returned to its supposed freshwater condition. Fortunately, this statement cannot be substantiated. The earliest reports known on the Bay show that the north end was lined with dense stands of mangroves, which cannot live in fresh water. In 1881 Dumbfoundling Bay was a mangrove-lined brackish water mud pond with mud so deep that it was almost impossible to pole across it (Pierce, ms.). Biscayne Creek was a narrow mangrove lined estuary which entered into the north end of the Bay beyond which the entire nature of the water changed. From there southward the aspect was of beautiful sea green waters of the old unpolluted Bay and the Keys. The bottom varied from white or gray marl supporting meadows of marine grasses to hard rocky bars on which grew a large variety of sessile organisms including sponges, small corals, alcyonarians, and other residents of clear, clean seawater.

Hobart Smith (1896) surveyed Biscayne Bay as the possible site of a government fish hatchery and experiment station and stated "The water of Biscayne Bay is exceedingly clear. In no part can one fail to clearly distinguish objects on the bottom when the surface is not especially rough. It seldon becomes roily, and the amount of muddy water brought down from the Everglades is too small to have any noticeable effect on the clearness of the Bay."

In the early 1900's the first of the dredgings occurred which brought the fresh waters of the Everglades into Biscayne Bay. These had detrimental effects upon the fauna almost from the beginning. No one has documented these but besides bringing in a continuous flow of freshwater, the waters brought with them sawgrass rootlets and hairs. These sink to the bottom and form dense mats which smother the bottom forms and infauna. A case of this occurred in Lake Worth in 1946 when the high waters in the Everglades brought in such a load of rootlets and hairs that the bottom life in the lower end of the lake was killed off for several years. It slowly came back only as the fur-like matting was finally flushed out to sea.

Other factors which have effected the numbers and distribution of invertebrates in the Bay have been the construction of the various channels for vessels, the erection of large islands in the Bay, and the building of the major causeways , all of which have resulted in severe reduction of water flow and the resultant reduction of the flushing rate. This is especially true in the northern half of the Bay where the most drastic effects can be seen. The accompanying vertical concrete seawalling of the shoreline has eliminated the natural filtering of the land run-off and increased turbidity. This in turn helped in the extensive reduction of the shallow-water marine grass beds which afford one of the richest invertebrate habitats known. Finally, sewage and pesticide pollution of the Bay waters accomplished what all of the other activities could not; they removed large segments of the Bay from habitation by useful and desirable life forms. Many of the changes have been documented by Thorhaug in this symposium.

The first studies of the distributions of marine life in the Bay and descriptions of life zones were by Pearson (1936) in conjunction with his undergraduate course in marine biology and dealt with the kinds and numbers of brittlestars. This was followed by a similar paper by Deichmann (1938) on the sea cucumbers and Smith (1943) on the corals. In 1948 Weiss published the results of his studies of the seasonal occurrence of sedentary fouling organisms in the Bay. The first ecological study was that of Smith et al. (1950) which dealt primarily with hydrography and chemistry and secondarily with plankton numbers. Stephenson and Stephenson (1950) touched upon the Bay in their basic study of the ecology of the Florida Keys. In 1955 Voss and Voss published their study of the ecology of Soldier Key which has served too often as the basis for comments upon an unpolluted Bay area. D. Moore discussed the fauna associated with turtlegrass (1963). McNulty et al. (1962a, 1962b) reported upon the level seabottom communities of the middle part of the Bay south of Rickenbacker Causeway, while in 1967 O'Gower and Wacasey published upon the animal communities associated with turtle grass and shoal grass. Voss et al. (1969) prepared a report on the waters of the proposed Biscayne National Monument which included all information obtainable to that time on the invertebrates of the southern portion of Biscayne Bay. This included a list of the species known at that time from the region. Since 1969 numerous reports and preliminary reports have dealt with the invertebrate fauna of various portions of Biscayne Bay from various aspects as the need has arisen in in conjunction with industry and development. Some of the findings are of excellent quality; others are of dubious value. It can be definitely stated, however, that at present no solid baseline studies of the invertebrate fauna of any part of the Bay have been conducted with sufficient expertise and with a sufficient variety of sampling gear to give an adequate picture of the invertebrate fauna of any region. Even McNulty's pollution studies (1970) were not based upon sufficiently diverse gear to give the results which are now needed for an assessment of the invertebrate life of the area studied or its total change.

DISCUSSION

It will probably be more useful to survey the faunas from a zonation and habitat viewpoint. This will also permit better understanding of the problems and priorities. Later changes can be reviewed from the standpoint of what has caused them and how they can be overcome or reversed.

Intertidal Fauna

Rocky. The tidal range in Biscayne Bay averages 1.9 feet with a spring range of 2.3 feet. This is a rather typical tidal range for tropical areas and greatly reduces the amount of living space for intertidal animals in contrast with areas in high latitudes which may have mean ranges from 12 to 30 feet, or open coastal areas where wave action may widen the band (Voss and Voss, 1960). Thus the vertical range of intertidal life is restricted to these figures except where wave action in the bay may extend them upward slightly.

Under natural shoreline conditions in Biscayne Bay, however, this vertical range was supplemented by the slope of the shoreline. On Soldier Key, for example, the lower platform extends outward and was exposed for up to 12 feet. Behind the lower platform is an eroded platform face which is narrow and vertical and which occupies much of the vertical range, followed by a very gently sloping upper platform which in some areas extends shoreward 20 to 30 feet and is covered by water at high tide. Thus on a natural rocky shore the intertidal area available for attachment or safety of the fauna was a band varying from perhaps as much as 10 to 50 feet. This was occupied by a wide variety of animals. It included numerous bryozoans, hydroids, tunicates, anemones, gastropods, chitons, mussels, sponges, echinoderms, crustaceans, and others. Also, numerous swimming forms such as shrimp lived in large numbers in the small tidepools existing in the eroded limestone. This type of habitat is densely inhabited. Counts of the animals occurring on a meter square surface ran into the hundreds per species, especially among such forms as mussels, barnacles, and false limpets.

Another type of rocky intertidal habitat is shown by a boulder shore exemplified by the jetties inside Government Cut and areas along the MacArthur and Venetian causeways. While the vertical range is smaller in parts because of a more protected location, the volume is great because of the extensive crevices, holes, and caverns found among the boulders in these structures. These afford not only greater attachment space for sessile animals but security for smaller invertebrates for brooding eggs or depositing them and protection for the eggs until hatching.

These two types of rocky shores may be contrasted with the vertical concrete surfaces of seawalls which are so prevalent throughout the Bay, especially in the northern half. Two areas were recently surveyed by the writer: Fair Isle south of Rickenbacker Causeway and a seawall in Biscayne Creek just north of the 163rd Street Causeway.

At Fair Isle the northwest seawall, which is protected from wave action, has a band of sessile organisms extending from the foot of the wall, just below mean low water, to above the high water mark covering a bond about 3 feet wide. This zone is composed mainly of barnacles, a few common oysters near the low tide mark, and some algal mats and mats of bright orange sponge below the low tide mark. Scattered among the barnacles were a few false limpets *Siphonaria*, the small *Nerita*, and above the high water mark the snail *Littorina angulifera*. Running over the face of the seawall were hundreds of the isopod *Ligida*, and a few Grapsoid crabs.

On the southwest end there was more wave action and the number of animals increased. *Nerita* was less numerous and its place was gradually taken over by the snail *Thais*. *Littorina angulifera* disappeared but its place was taken by *L. ziczac* which prefers a more exposed habitat. There were also a few horse conchs.

The offshore side of the seawall was more exposed and the zone here was expanded to a height of about 5 feet. All of the previously listed species were present except *Nerita* and *Littorina angulifera*. The growths of sponges and attached algae were denser and the oyster population larger.

A similarly constructed seawall in Biscayne Creek had an active intertidal assemblage occupying a zone only about 2 feet high. The vertical face was composed of solidly compacted oysters, *Crassostrea*, with a narrow band of the false limpet *Siphonaria* intermixed with large numbers of the small, black shell-less mollusk *Onchidella*. A few snails, *Littorina angulifera*, were found adhering to the wall above the high tide mark and a few isopods ranged over the face. The area is entirely protected and the band represented the tidal range.

Mangroves. Much of the original shoreline of Biscayne Bay, especially in the northern end and south Bay, and back of the Sand Keys, was fringed with mangroves. It might be well to point out here that the presence of mangroves in an area now does not necessarily mean that the area has long had them. When the first settlers came to Lake Worth in the mid-1870's there were no mangroves on its shores. It was not until an inlet was dug by shovel in the 1880's that mangroves appeared, but by 1930 much of the shore of the lake was heavily covered with mangroves so that recently it has been suggested that the lake originally was surrounded by mangroves.

Mangroves not only offer a substrate for attachment and a refuge for a host of animals but they also contribute to both the enrichment of the Bay by decomposition of their leaves and to the filtration of ground water run-off into the Bay. The prop roots of the red mangrove in the southern part of the Bay are typical of the growth that may be found in relatively unpolluted areas and consist of not only the prop roots proper but also massive accumulations of algae and sessile and crawling animals, the mass of the roots being increased several times by their accumulated life. In the south end of the Bay and especially along the seaward side, the growth on the roots consists of masses of red algae, tunicates, sponges, several kinds of oysters, barnacles, the snail *Littorina*, false limpets, *Nerita*, the crabs *Pachygrapsus* and *Sesarma*, several species of isopods, melampid snails, hydroids, and bryozoans.

In the northern part of the Bay, the major invertebrates found on the roots of the red mangrove consist mainly of the oyster *Crassostrea*. Most of the other forms named are missing except for the boring gribble, *Sphaeroma tenebrans*, which is present in considerable numbers.

Sandy and Muddy Shores. Under normal conditions these shores contain numerous burrowing animals such as the fiddler crab *Uca*, various marine annelids, and several common mollusks. Few of these beaches are left in the Bay and most of them are artificial in that they have been formed by dredging. Most occur in south Bay on the landward side and along Rickenbacker Causeway. They are not highly productive of invertebrates except for the microscopic meiofauna occupying the interstitial spaces in the sand. These have not been well studied in the Bay.

Shallow Water Benthos

Grass Beds. Originally most of the Bay was covered with grass beds, primarily of the turtlegrass *Thalassia* but with mixtures and small pure stands of the other tropical species. In order for these to grow, they must, however, be within the zone of illumination. In clear unpolluted waters, turtlegrass may grow to a depth of at least 30 or 40 feet. Before dredging, the depth of the Bay in no region was too deep for the growth of these grasses. At present the distribution of turtlegrass is becoming rather limited in the Bay, especially in the northern part where channels and borrow areas have lowered the bottom below the zone of light penetration and particularly the compensation depth which itself has become shallower because of the greatly increased turbidity of the water. In the middle and northern parts of the Bay, turtlegrass does not generally grow in depths much below 5 or 6 feet and even then it is rather sparse.

The diminution of the grass beds has had a dramatic effect upon the numbers and kinds of marine life. Studies in the 1960's by the writer assisted by Dr. D. Moore and Mr. R. Work were directed toward determining the kinds and amount of life in the turtlegrass communities of Biscayne Bay. Our studies tended to show that the turtlegrass community was one of the richest, if not the richest, marine community in the world, both in the diversity of life and its numbers. The proliferation of broad, thin leaves greatly increases the available attachment surface for sessile organisms; the leaves and stalks form a refuge for innumerable swimming and crawling forms; the deep root mass binds the substrate and forms further refuge for burrowing animals. The leaves serve as sediment traps and aid in the clarification of the water. The total assemblage forms such a rich source of food, that the grass beds are nursery grounds for many of our most important food and game fish.

No final count can be given here of the number of species found inhabiting this community but Dr. D. Moore(unpublished data) found over 20,000 specimens of only three species of mollusks per square meter of turtlegrass bottom near Matheson Hammock. The well-being of this community of animals is important to the security of the bait shrimp and spiny lobster fisheries as well as those of many sport fish.

Hard Bottom Communities. The hard bottom areas north of the MacArthur Causeway have largely been covered over by silt, and the turbidity is such that life conditions are not good. Those south of the Rickenbacker Causeway are still in fairly good condition, even as far north as Mashta Point. The growth on these rocky or hard bottom bars consists primarily of sponges, alcyonarians, various inshore corals, red and green algae, and many and varied species of invertebrates which live in, on, and around the others and in rocky holes and crevices. Among these are the stone crab and the spiny lobster.

Our 1969 survey showed that this habitat was under stress on the western side of the Bay as indicated by numerous alcyonarians with partially exposed skeletons overgrown with algae and similarly half-dead sponges. On the eastern side near Elliott Key these same species seemed to be healthy and growing more luxuriantly; no missing polyps were noted and little infestation with algae was seen. Whether the condition noted on the western side was due to the hot water run-off from the Turkey Point Power plant, the effluent from the drainage canals, or pollution in general, could not be determined in the scope of our study.

Soft Bottom Communities. Studies conducted during the 1960's by personnel of the University of Miami included sampling the faunas of the level sea-bottom communities in Biscayne Bay. Reports by McNulty *et al.* (1962a, 1962b) showed that the level sea-bottom communities, consisting mainly of infauna, in the middle part of the bay and opposite Bear Cut and Cape Florida channel were comparable in numbers, types, and associations with those described from other areas of the world by Gunnar Thorson and his disciples. These communities were quite rich and were found in the open marl bottom. These types of bottom do not seem today to be as rich around the areas of Mercy Hospital and Fair Isle, but this bottom has been disturbed by dredging.

A soft bottom area was studied in Biscayne Creek. It was found to be greatly improverished in species, and only the golden tube worm, *Cistenides*, was present in any numbers. Two grab samples revealed only one tube worm and several minute crustaceans.

This brief survey of the general condition of the invertebrates of Biscayne Bay may now be useful in looking at some of the changes which have occurred, and in trying to determine their causes.

Pesticides

It is difficult to assess the effects of pesticides upon the invertebrates of the Bay. No monitoring has been done at canal mouths for anything but fishes; fish kills have often been reported at the mouths of drainage canals in south Dade County. These have been directly associated with the practice of rinsing out spray trucks and tanks, and even the discard of pesticide sacks into the canals from the adjacent farm lands. For some peculiar reason, most of the concerned agencies seem to think that only fish warrant their attention, and no invertebrate worker is ever alerted when a kill is announced. Partly this is due to the fact that dead fish float and are more visible, while invertebrates, having no swim bladder, sink. The Hoover Committee report of 1969, drew the County's attention to the pesticide problem in south Dade and asked that the area be put under surveillance. The problem still exists but in a somewhat different form. There is no reason to think that the invertebrates have not been as seriously affected as the fish.

When the State of Florida sprayed Dade County in the 1960's in an effort to eradicate the Mediterranean fruit fly, the spray planes started their work at the water's edge. Within minutes of the passage of the first plane along the Bay shore, complaints began to come in of heavy mortality of young tarpon and pompano. Within a few hours the ocean beach from Miami to Palm Beach had a windrow of dead sand fleas, *Emerita*, about 2 feet wide and several inches deep that stretched in an unbroken line the entire length of the beach. Sand fleas were almost completely exterminated from the beaches for several years with a resultant decline in the sport catch of pompano and other fish which feed upon these invertebrates and for which they are used as bait.

One has to assume that most of the invertebrates killed by pesticides are then eaten by predators, probably with further ill effects along the line. It is entirely possible that the poor condition of the alcyonarians and sponges on the west side of the Bay, noted in the Biscayne National Monument report, could have been due to this cause. We have, however, no proof of the causitive agent.

Dredge and Fill

Many of the problems we now encounter concerning the invertebrate life in Biscayne Bay are due to dredge and fill activities, either directly or indirectly. Direct effect, of course, is the removal of the animals and the bottom in which they live, the covering over of the bottom and the animals, smothering of adjacent areas by the sediments, and the erosion of the fill areas before stabilization. Indirect effects have been the constriction of water flow by artificial islands and causeways, thus reducing flushing, and creation of stagnant bottoms in channels and borrow pits. These are too deep to be flushed by wave action and the bottom is too deep for the growth of marine grasses. It is these direct and indirect effects which have done much to lower the viability of the north end of the Bay and will harm the south end if permitted to occur under the plea of social exigency.

Bulkheading

Almost without exception the type of bulkheads used in Biscayne Bay have been of the conventional vertical concrete design. These of course are equivalent to rocky shores but they have the distinct disadvantage that, being vertical, they afford the least possible living space and refuge for animal life. Of the three types of hard substrate shores described above (seawalls, boulders, and natural rocky shores) the concrete vertical wall offers the least space for colonization, living, and refuge. In addition, these bulkheads reflect wave action stronger than any other type and thus assist in keeping sediments in suspension, thereby further preventing grasses from colonizing and proliferating and deterring growth in colonial forms of invertebrates.

Sewage and Industrial Pollution

Sewage pollution was a major problem in the middle and north Bay area until the City of Miami installed the new sewage treatment plant on Virginia Key and tied the city sewer system to this, closing the many outfalls. Prior to this, in the 1950's and before, the sewage of the city of Miami was dumped without treatment directly into the Bay or into the Miami River. McNulty *et al*. (1960) reported upon their studies showing the ecological conditions at that time and the distribution of coliform bacteria in the Bay. In 1960 McNulty resurveyed the benthos of the Bay and published his results (1970). His studies, carried out mainly by grab samples, showed that considerable changes had occurred. Some of these are interesting as they apply to standing crop and diversity.

On soft bottom in one area there were 21 species with pollution while there were at the same station

14 species without pollution, a dramatic change. However, on the basis of numbers of individuals per square meter it only changed from 88.6 individuals to 81.4, hardly a noticeable difference. In another soft bottom area there were 4 species with intense pollution and 4+ without while there were 9.0 individuals per square meter with pollution and 10.5+ without. An important observation was that with pollution some of the stable members of the community were missing, their places taken by non-community immigrants.

On hard bottom at one station, some distance from an outfall with pollution, there were 46 species compared with 25 without, while the numbers of individuals were 651 and 108. At an area close to the main outfall there were 5 species with pollution and 9 without, while the number of individuals was 18 with pollution and 126 without.

These figures show that while it is true that some fertilization of the waters aids the growth of invertebrates, an excessive amount inhibits it. The question then arises: How much fertilization can an area withstand and still be viable? A further question, and one of far greater importance, is the quality of the epi- and infauna. Are the faunas composed of desirable species which are important members of the food cycles of larger animals or are they themselves undesirable and are indicators of a polluted environment? Often an area may contain large numbers of undesirable species which are not suitable for food or for sport and which do not support such other species.

Great reliance seems to be placed today on the index of species diversity. While some scientists have begun to suspect that not only has this been overworked but is often misleading, many government agencies are still impressed by these figures and in fact require in some instances that species diversity be calculated and included in reports. The question, however, seems to be, with what level of species diversity will we be impressed? Because the species diversity is higher in one area than in another indicate that the area with the higher species diversity is in better shape ecologically than the other? Or does it mean that a large number of pollution-tolerent species have moved into a formerly unpolluted but impoverished area? The natural sequence of such a philosophy is that we may be, and in fact now are, apparently protecting some polluted areas from being cleaned up because they have a reasonable species diversity index. The numbers game can be dangerous if the ground rules have not been properly established.

Restoration

It seems clear, insofar as the invertebrates are concerned, that a much broader and more detailed study of the fauna is required both for baseline studies and for an understanding of the causes of the diminution of populations. This should be done by undertaking a series of transects across the Bay covering all major segments and reaching from the intertidal to the intertidal on each shore. A variety of sampling gear should be used to obtain as complete a picture as possible of the faunas involved. For best results, transects should be started at each end and worked toward the middle, thus affording early comparisons of areas under heavy stress with relatively unpolluted and unchanged areas.

It is obvious from the review that the changes in the shoreline have had serious effects upon the numbers and distribution of intertidal and near shore life. The review clearly shows that rocky shores have great advantages over vertical seawalls. Since it is impossible to restore natural rocky shores, efforts should be made to replace the seawalls with rip-rap which affords the next best habitat. Extensive rip-rap shorelines would also assist in the spread and increase of the spotted spiny lobster which in the Bay area has only been found in this type of habitat. Where possible the shoreline should be landscaped back to a combination of sandy beaches, mangroves, and rocks both for environmental improvement and aesthetic qualities.

Flushing restrictions in the north Bay are serious. The hydrography of the Bay should be studied and Federal assistance obtained to open up the causeways where necessary in order to increase flow and flushing.

The Bay bottom has been partially denuded of marine grasses by dredging. The feasibility of replanting these areas with sea grasses should be examined and, if plausible, planting should begin as soon as possible. Replacing the seawalls with better structures, increasing flushing, and continued efforts to decrease pollution should provide better clarity of seawater, thus encouraging growth of the grasses. As these become better established, they also will serve as filterers, and turbidity in the Bay should be reduced.

All these actions combined should begin the reversal of the trends which have been described here and eventually bring the invertebrate faunas back to a higher level throughout the Bay. It is impossible to return the Bay to its pristine condition or back to full productivity. However, with nursery grounds reestablished over much of the Bay, a change in the macro-fauna should take place and the overall environmental conditions be more conducive to the health and welfare not only of the invertebrates but to that most important of all vertebrates, man.

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FISHES OF BISCAYNE BAY, FLORIDA

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ABSTRACT

Biscayne Bay is a logoon-like estuary with at least 512 fish species recorded from it from a variety of the Bay's habitats. Tropical fishes prevalent in the summer are partially replaced in the winter by temperate species. Their ecological relationships are also associated with the freshwater runoff from western Biscayne Bay. Little is known about how the adult fishes of the Bay relate to their physical environment, to the fishes and invertebrates with which they associate, or about how man-made activities affect their ecological stability or population dynamics. The relation and contribution of these fishes to the Bay ecosystem are presently unknown.

INTRODUCTION

It used to be commonly advertised by promoters of Florida angling that Biscayne Bay is one of the world's great places to fish. Among local anglers, however, there are some who more than agree, while others flatly state that there are no fish in Biscayne Bay. In fact, Biscayne Bay has no less than 512 species of fish, and thus the dedicated angler has a wide range of fishes to seek. And because they range in length from several inches to over 10 feet, these fishes offer a potential thrill to the angler wishing to test a variety of tackle.

The total economic and aesthetic values of Biscayne Bay's fishes to man probably can never be adequately documented. The economic (dollar) value of the commercial fishery in 1972 was calculated at $100,000 (U.S. National Marine Fisheries Service, 1974), while the value of the sport fishery of the bay was estimated as being worth at least $3.1 million, with a capital value to anglers of not less than $75 million (Stroud, 1962; Routa, 1968). Although several fish species common in Biscayne Bay are valuable as bait to sport fishermen, no dollar estimate is available. The waters along Key Biscayne, Soldier Key, and Elliott Key are also visited by persons collecting small and brightly colored reef fishes and the young of some larger fishes for personal aquaria and also to supply the popular commercial aquarium trade, though the extent and value of this activity is unknown. And the fishes of Biscayne Bay are valuable both economically and aesthetically to the increasing number of snorkelers and scuba divers who derive pleasure from watching and photographing them. Scientifically, these fishes are worthy of study because they represent a mixture of temperate and tropical species in a unique part of the world and whose composition changes in response to environmental factors, because they interact with organisms along the reefs adjacent to the bay, and because they certainly must be an important part of the ecosystem that is Biscayne Bay.

PURPOSE

The purpose of this paper is to summarize what is known about the kinds of fishes occurring in Biscayne Bay and where and when they occur. Emphasis is placed on how little is known about (1) the interrelationships among these fishes and with other organisms, and (2) how they are affected by environmental changes, both natural and man-induced.

Paradoxically, even though we can document generally what kind of fishes live in the bay and can determine, sometimes, where they live, only seldom can we determine when and why they occur there, and how these fishes interact with their environment. Paramount, too, is the question of how the fish fauna, or kinds of species, has changed since man first began to modify the bay through his many activities.

Among the first scientists to describe the waters of Biscayne Bay was H. M. Smith who wrote in 1896 that "the water of Biscayne Bay is exceedingly clear. In no part can one fail to clearly distinguish objects on the bottom..." Now, of course, one sees the bottom clearly only in parts of the southernmost part of the bay, where man's activities have had the least impact. As late as 1920, Simpson wrote that there were mangroves 100 feet high and 4 feet across at the mouth of the Miami River. These have, of course, long disappeared. While historical quantitative data are unavailable, there are many observations of a qualitative nature which attest to man's modification of the bay's water quality (see Romans, 1775 and Moore, 1910).

The lower east coast of Florida represents a disjunct faunal zone (Low, 1973), with the fauna north of Cape Canaveral being temperate and that from the Florida Keys being essentially tropical. While the bay is saline because of free tidal exchange with the sea, low salinities are sometimes found in the western and even central parts of the bay following heavy rains or the opening of canal flood gates. The result is that the fish fauna of Biscayne Bay is predominantly temperate and continental in the winter and tropical to subtropical in the summer, with species which may be euryhaline or which may comprise a number of oceanic visitors.

What fishes are there in the bay?

A specific study to determine the kinds of fishes which occur in Biscayne Bay has never been made (cf. Smith, 1896; Evermann, 1898; Evermann and Kendall, 1900). The most complete information is presented in Voss et al. (1969a) on the juvenile and adult fishes of the Biscayne National Monument. This area encompasses the southernmost section of south Biscayne Bay and the extensive north portion of Card Sound, from the western edge of Biscayne Bay seaward to the 10-fathom curve; this area is bounded by 25° 31' N and 24° 17.5' N. Thus, a list of fishes of the monument would include species typically found on coral reefs, the coastal "green" waters, and the open ocean "blue" waters. Conversely, it would exclude species which inhabit that part of the bay north of

Rickenbacker Causeway, which includes a considerable amount of territory influenced and fed by several tributaries, and hence some estuarine species may be excluded.

A list of 496 fish species from the Biscayne National Monument area, and based on specimens in the University of Miami Fish Museum, is provided in Voss et al. (1969a), which is reproduced here as Appendix I. An early list of the fishes of Biscayne Bay was provided by Smith (1896), but it is incomplete because the collector specifically identified only the larger species. Up to 1898, Evermann and Kendall (1900) had reported that 129 papers had been written on Florida fishes, some of which dealt with descriptions of new species or range extensions in Biscayne Bay. In the intervening years between the report of Smith and that of Voss et al. (1969a), scattered papers have appeared which deal with fishes of Biscayne Bay, but none synthesizes the knowledge of the bay's fish fauna as well as that presented in Voss et al. All that can be added since then is a list of 17 additional species that have been reported in the literature (Table 1).

The fishes of Biscayne Bay belong to 95 different families. Studies on the larval fishes occurring in Biscayne Bay by de Sylva (1970, 1976) and de Sylva and Scotton (1972) show that the number of families and species known to occur in the Bay will probably increase as better knowledge on larval fish identification is gained. Although identification of species of larvae is difficult, it was shown that at least 52 different fish families occur there as larvae.

There are virtually no historical data on which species of fish occurred at the time when Smith (1896) made his observations. We might suspect that the fish fauna of the eastern part of the bay in the summer was originally similar to that reported from the Tortugas by Longley and Hildebrand (1941), but with more temperate species also occurring in Biscayne Bay during the winter. Also, the freshwater regime has changed over the years, with much less fresh water entering the bay from run-off and seepage (Kohout and Kolipinski, 1967). The rivers on the northwestern part of the bay formerly carried a far greater volume of fresh water into the bay (Romans, 1775; Smith, 1896: 171-172), and hence we may suppose that the western edge of the bay supported a much richer estuarine fish fauna than it does today. Indeed, Biscayne Bay had once been considered as a site for the commercial propagation of oysters because of the voluminous freshwater discharges into it (Smith, 1896).

It appears that Biscayne Bay was never a productive area for fishes, in comparison to the adjacent coral reefs, because of its relative scarcity of appropriate substrate and habitat. Indeed, Brice (1898) noted that "the commercial fisheries of Biscayne Bay have never been important" and that the only business was in sea turtles, sponges, and line-caught fish.

The best detailed description of early Biscayne Bay is from Gregg (1902) who, with his fishing companion and guide Captain John Gardner, made detailed observations of the sport fishes and fishing in the 1890's.

One fish species mentioned in the early literature of the bay apparently does not occur there today, and two other species are scarce. Smith (1896: 175) reported the saury (Scomberesox saurus) as being one species reported to him by W. F. McCormick, though there is no indication that this identification was ever confirmed. Since it is a temperate, pelagic species, possibly it appeared as a straggler during a cold spell, but it is unlikely that it ever occurred in any numbers. Smith (1896: 174) also mentioned that the black drum (Pogonias cromis) was "found near the oyster beds in the bay," where it was "common." The species has, to my knowledge, not been taken since 1962 during a survey of the fishes caught by anglers off Rickenbacker Causeway, and at that time it was considered as relatively rare. Smith also indicated that the red drum (Sciaenops ocellata) was "abundant at all seasons." While it is still caught by anglers in the south part of the bay, it could never be considered as "abundant." Presumably, the diminution of oyster beds on the western shores has at least partly been reponsible for the scarcity of drums in this area.

Where do the fishes occur in the bay?

There are possibly no places in the Bay where some fish species do not occur. It is especially important to know which seem to be the most important habitats for the most diverse assemblages of fishes, so that decision-makers can establish priorities in protecting and managing our natural resources. The following ecological subdivisions for juvenile and adult fishes are presented in Voss et al. (1969a) to characterize fishes of the Monument area and in the adjacent Florida Keys:

Oceanic fishes--75 species
Rock, coral, and seawall fishes--250 species
Grassbed and tidal-flat fishes--254 species
Sponge and alcyonarian fishes--35 species
Open-sand fishes--53 species
Open-water and surface inshore fishes--24 species
Littoral fishes--17 species
Mangrove fishes--57 species

Estuarine fishes--44 species

To exemplify the diversity of fishes within these broad ecological niches, these species were further divided spatially and temporally into the following categories: (a) Associated with sargassum, Physalia physalia, jellyfishes, or floating debris, (b) Occurs in area only in the young and juvenile stages, (c) Young often associated with larger fishes or sea turtles, (d) Mainly in deeper water situations, at edge of area, (e) Mainly in clearer water of the outer reefs, (f) Young common inshore around pilings and sea walls, (g) In pockets of coral rubble, (h) Burrows in sand associated with this type of area, (i) Juveniles found offshore, adults move inshore, (j) Inhabits live conch during the day, (k) Associated with sponges, isolated corals, shells, or obstructions in grassbeds, (l) Usually near the surface in these areas, (m) Present during fall and winter months only, (n) Sandy beach, clear moving water (well oxygenated), (o) Still protected water, often silty bottom, (p) Lives in sea cucumbers during the day, (q) May live in sponges.

Other studies in Biscayne Bay's waters have been done in areas too restricted or atypical to be extrapolated to the waters of Biscayne Bay as an entity (Siebenaler, 1953; Tabb, 1958; Tabb and Kenny, 1958; Roessler, 1971, et seq.; Bader and Roessler, 1971).

Clearly, the greatest species diversity of juvenile and adult fishes is found in the coral of the patch reefs and the outer reefs, around the offshore islands, then decreasing in grassbeds, open areas of Biscayne Bay, and finally in the mangroves, where the fewest numbers of species are found. Studying these habitats, Roessler (1962, 1963) found the greatest number of species of juveniles and adults over beds of thick growths of Thalassia growing in a calcareous mud, and the least number of species in a sand-mud mixture overlain with mud, with an intermediate number of species being taken in an intermediate habitat. Low (1973) intensively studied the fishes of the shoreline grassbeds, predominantly Thalassia with scattered Diplanthera. He concluded that of the 175 fishes (largely juveniles) collected by him, about 60 species were primarily inhabitants of the inshore grassbeds or at least common there, and of these perhaps 12 are dependent upon the grassbeds for a part of their life cycle. He emphasized the importance of these beds for commercially important fishes such as mullet, balao, sardines, yellowtail, muttonfish, grey snapper, and white grunts, while among the sport fishes young snappers, seatrout, and permit used the grassbeds as a nursery area, and the seatrout used the grassbeds during its adult period. Fish fauna in areas without rooted vegetation and in turbid, denuded areas appeared to be poor.

A major lack of knowledge has been our ignorance of spawning and nursery grounds. Although the studies of Roessler and Low determined that grassbeds were important habitats to juveniles and adults, the studies were limited by necessity, since they were done by financially impoverished graduate students, to small sections of the northern part of south Biscayne Bay, near Virginia Key and Key Biscayne. Whether such areas are representative of the entire bay is unknown.

An attempt to delineate spawning areas and times was made by de Sylva (1970, 1976) by towing plankton nets for postlarval fishes at 39 stations in south Biscayne Bay and Card Sound. Results (Fig. 1) show that fish larvae occur throughout the bay. These larvae range from 3 to about 20 mm, and one must infer that they were spawned, and thence grew, somewhere near where they were captured. Unfortunately, since little is known about the growth rate of most larvae under natural conditions, and because little is known about the speed and direction of wind-induced and tidal currents in south Biscayne Bay, it is difficult to state from exactly where these larvae originated. It can be said that, since these larvae usually belong to families which occur in the bay, they probably continue to grow and metamorphose into the juvenile stages in the appropriate habitats, which are often the grassbeds.

Based on preliminary analysis of the larval fish data, it can be seen that the greatest numbers of larval fishes are found in three areas: (1) around the former effluent canal of Florida Power and Light's Turkey Point electrical generating station, where the water temperature is relatively high year-round; (2) in the northeastern and northwestern part of the south bay, between Rickenbacker Causeway and Dinner Key, where there is considerable amount of sewage and other pollution; and (3) in the area of the "Safety Valve," just south of Cape Florida. In spite of the high numbers at Turkey Point, a few samples with large numbers of larvae accounted for the high average numbers. When species diversity is calculated (number of species compared to number of individuals), it is seen that actually this area was among the poorest in the bay. The Rickenbacker to Dinner Key strip shows a somewhat higher species diversity, reflecting eutrophication from sewage, though it is not extensively degraded as seen in the high dissolved oxygen values in those areas. The highest species diversity occurs in the "Safety Valve" area, which represents a mixture of Biscayne Bay species plus those carried in from offshore by winds, tidal currents, and eddies from the Florida Current (de Sylva and Scotton, 1972).

Virtually nothing is known about the spatial (or temporal) distribution of fishes in Biscayne Bay. There are vague allusions to "runs" of sport fishes by anglers, and these are reported in general terms by dockmasters and anglers, to be summarized in fishing columns. But the anglers may be purposely vague as to exactly where and how many fish were taken, with the result that only general non-quantitative information is available. The commercial fishery also yields little data, partly because only a few species can be sought by law, and partly because the fisheries are limited to certain areas within or adjacent to the bay. Thus, there is no long-term, near-adequate sampling of this area's fish populations such as occurs everywhere else in the U.S., and consequently no data are available on which to base scientific evaluations.

Through the kindness of one of our esteemed and expert angling colleagues, an approximation has been given of where some of the major sport fishes can be taken. These are based on four years of extensive and intensive angling and are, therefore, subject to possible criticism. Nevertheless, I believe that because this angler fishes in the same areas, with the same gear and the same techniques, his information is valuable, especially since it is unique (Fig. 2), to make comparisons over long time periods to detect shifts in major areas of concentrations.

When do fishes occur in the bay?

This question can be divided into: (1) seasonal, (2) day-night (diel), (3) tidal, and (4) ontogenetic occurrence. Seasonal migrations may be associated with spawning, and comprise estuarine, bay, and reef species that move offshore to spawn, such as eels, mullets, jacks, and groupers. A second group of seasonal migrants consists of temperate species that move southward in the winter, such as some sharks, croakers, and bluefish.

As mentioned earlier, since few collections have been made during the year on a scientific basis throughout the bay, the question cannot be answered authoritatively. However, two such studies can provide some information on juveniles and adults. The first is a sport fishery study conducted by Dr. Richard A. Wade, with the aid of Dr. Henry A. Feddern, under the supervision of Dr. C Richard Robins, from 1960 to 1962, with the support of the Sport Fishing Institute. In this study, done from the Bear Cut bridge and the drawbridge on Rickenbacker Causeway, it was determined that 98 species of fish were caught by anglers. A summary of this study is provided by de Sylva (in Voss et al., 1969a: 29-34).

These data have been analyzed further to depict when the important sport fishes occurred at the causeway, as reflected in anglers' catches during that period. It was not possible, however, to determine fishing effort and to compare it with sampling effort so that relative occurrence of species and their abundance may merely reflect the number of anglers fishing during a given period.

For both the Bear Cut bridge and the drawbridge, the period from October to April yields the greatest number of fishes taken by anglers (Tables 2 and 3). The Bear Cut bridge, however, is a relatively more stable environment reflecting a high-salinity regime which has a number of offshore reef species passing through. Conversely, the drawbridge fishing area is affected somewhat by polluted, brackish waters from the Miami area, and seems to attract the seasonally migrating species. Between the two areas, we can obtain a general picture of seasonal occurrence of some important species.

Evaluation of these tables is difficult because so many factors are involved. These factors include availability of fish and bait, occurrence of bait schools and their attractiveness to and satiation of predators, and environmental conditions such as wind force and direction, temperature, and air temperatures. These have been evaluated but without conclusive results.

The second study on the seasonal occurrence of bay fishes is by Low (1973). The lowest number of grassbed species occurred in the winter. This may have been due to low temperatures, high winds with resultant high turbidities, or the lack of a correlation of spawning times and juvenile nursery ground requirements during the winter, or a combination thereof. Then, too, the abundance of fishes during the early spring and summer may be associated with the most luxuriant growth of grassbeds.

Diel migrations occur among reef fishes, such as snappers and grunts, which leave the shelter of corals for the adjacent grassbeds to forage for food. No evidence for diel migration in Biscayne Bay among grassbed fishes was found by Roessler (1962, 1963), who showed that areas having extensive to moderate cover of *Thalassia* contained more fishes at night. However, this may be interpreted to mean that the fishes of the grassbed communities depended more at night for shelter in these beds than for feeding, since they already were in areas of ample food supply, in contrast to the offshore coral reefs, and hence were subject to capture more easily in spite of their ability to see and thus avoid the oncoming net.

Tides are known to influence the migrations of some fishes, either by generating currents with which they or their food swim, by causing them to drift passively with these tides, or by causing them to be captured more easily by nets as they are pushed against the meshes by the tides. No such difference in number of species caught in trawls in the bay was shown by Roessler (1962, 1963), possibly due to the relatively small tidal velocities, but also reflecting the difficulty in collecting where tidal currents are strong.

Ontogenetic migrants are those that spend their larval or juvenile life within the area, moving with growth into offshore areas, or being hatched offshore and drifting inshore to bay waters where they find a suitable habitat for food or shelter. In Biscayne Bay, the studies of Roessler (1962, 1963) and Low (1973) are notable in documenting the importance of the bay as a nursery ground for juveniles, while de Sylva (1970, 1976) attempted to show the distribution, abundance, species diversity, and relation to environmental conditions of fish larvae.

Little is known about the importance of the bay as a spawning or nursery ground, and this is by implication rather than by direct observation. Low (1973) concluded that most spawning in Biscayne Bay took place during the spring, although some occurred during summer, and that peak abundance of juveniles was in late spring and summer. Reef species spawned somewhat later and their juveniles were thus more abundant in summer and fall. Juveniles of most of the coastal and pelagic species, except for jacks and sardines, were rarely taken inshore. The seasonal volume of zooplankton shows a strong relationship to the number of larval fishes (Table 4), which may be interdependent.

Studies by de Sylva (1970, 1976) confirm the observations by Low in that the peak occurrence of larval fishes (Table 5) in Biscayne Bay was from February to May, dropping sharply thereafter, which would correspond to the peak occurrence of metamorphosed juveniles observed by Low in late spring and summer.

How do bay fishes interact with and depend on their environment?

This section must be related to papers presented by my colleagues. Yet, it is nearly impossible to relate the occurrence of fishes to their bay environment because so few studies have been done. A summary of studies performed on fishes of Biscayne Bay (Table 6) reveals that relatively few have been undertaken to establish the relation between their occurrence or abundance and their habitat. Most have been purely descriptive works dealing with feeding, development, or non-quantifiable ecological parameters. Here is the vacuum that should excite studies for future research--the how and why.

Only a few studies relate to the ecology of bay fishes. The earliest, by Robins (1957) on the easternmost shore of Biscayne Bay, focussed on the need for a more thorough study of what was there and on the lack of previous studies. Roessler (1962, 1963) showed the relationships between trawl catches and substrate, time of day, and tidal cycle (*vide supra*), while Low (1973) related the distribution, occurrence, and abundance of fishes taken in haul seines. Studies on the ecology of larval fishes by de Sylva (1970, 1976) related their distribution to temperature, salinity, dissolved oxygen, and turbidity in south Biscayne Bay. Specific studies on fishes or fisheries have not answered the questions on how fish populations in the bay respond to natural or man-made fluctuations in the environment or in fishing pressure, such as described by de Sylva and Staiger (1975).

Numerous physico-chemical and biological attributes of the bay interact with, and some are influenced by, fishes. It seems unlikely that any single variable acts alone, except for possibly temperature, and probably several factors operate synergistically to influence the metabolism of fishes. The following are the more obvious environmental factors in the bay:

a. Physical Attributes

1. Depth. The depth of Biscayne Bay is relatively shallow (Wilson, 1975), averaging about 6 feet, with maximum natural depths of 13 feet. Most fish species are found at all depths, and thus do not seem to be restricted by depth. Depth requirements of fishes here, however, are usually associated with turbidity, wind speed, light penetration, and consequent growth of grassbeds or lack of it. No quantitative information is available on depth ranges of fishes in Biscayne Bay, although because the bay is so nearly uniform it would not appear to be a controlling factor *per se*.

2. Bottom type. As mentioned earlier, Roessler (1962, 1963) and Low (1973) found that this was extremely important, with grassbeds supporting higher diversity of fish species and numbers than sand-mud or sand-grass bottoms. Voss *et al*. (1969a) listed the kinds of ecological groupings in the bay (*vide supra*), which clearly demonstrate that greater species diversity occurs over coral, rubble, or other bottoms with irregularities and shelter. Probably Biscayne Bay has never had a diverse fish fauna within the bay simply because there is so much smooth sandy area, with little shelter or hiding places.

3. Turbidity. No studies have been carried out in the bay on the relationship between water clarity and the distribution of juvenile and adult fishes. Turbidity affects the fish's ability to see a bait if one is trying to catch a fish by angling, and thus if one is seeking species which depend on vision, clear water is advantageous, whereas species dependent upon olfactory and auditory senses could be taken in turbid water. Fish species are able to detect moving nets and thus avoid capture; thus, a poor net catch in clear water might be interpreted as reflecting few

numbers, when in reality these low numbers reflect net avoidance.

Preliminary studies are underway to determine the relationship between turbidity and the number of larval fishes caught by plankton net (de Sylva, 1976). Higher catches are taken in slightly turbid waters, whereas very turbid waters yield fewer larvae, and clearest waters yield intermediate numbers. The question of net avoidance, net clogging, and turbidity as an index of eutrophication has not been resolved.

4. Salinity. Historically, the northwestern shores of the bay were more estuarine in nature (Romans, 1775), but have become more saline, whereas the southwestern part of the bay, which was formerly saline (Smith, 1896), has become more brackish (de Sylva, 1970, 1976). It can only be assumed that the characteristics of the fish fauna have changed. Additionally, the extensive freshwater intrusions that once dotted the western edge of the bay (Romans, 1775) have gradually dried out through saltwater intrusion (Kohout and Kolipinski, 1967). The southwestern edge of the bay, however, is now more subject to sudden runoff of fresh water when flood gates are periodically opened to reduce flooding on land.

The western edge of the bay is characterized during the rainy season by brackish, euryhaline species, and during the winter by species moving in from waters of higher salinity and occupying the mangrove habitat as juveniles and adults. No quantitative data are available on these relationships.

During the summer, the larval fish fauna of the south bay may be divided into three zones of salinity: the low-salinity, western fringe with its estuarine fishes, the central bay with an admixture of estuarine and coastal species, moving with the tide, and a hypersaline area on the western side of the upper keys from Angelfish Creek northward along the western approaches to Elliott Key. The fish larvae here are usually coral-reef and oceanic species. Wedges of high-salinity water periodically penetrate the bay from offshore, sometimes bringing with it larvae belonging to deep-sea fish families from offshore, blue waters (de Sylva and Scotton, 1972).

5. Temperature. Perhaps the greatest information on the bay's physical properties is available on the natural regimes of temperature in the south bay, and on the effects of heated effluents from electrical generating stations upon fishes (de Sylva, 1968; Voss *et al*., 1969b; Roessler, 1970, *et seq*.; Bader and Roessler, 1971; Nugent, 1970; Smith, 1971). In addition to field studies, Albertson (1973) conducted laboratory studies on temperature tolerances of three species of grunts to assess thermal tolerances. The natural fluctuations of temperatures in Biscayne Bay are such, however, that they do not exceed lethal limits (see Albertson, 1973) under normal conditions in most parts of the bay. Along the shallow intertidal zones of the mangrove regions, tidal ponds, and mud flats, temperatures probably exceed 34-35°C, yet the fish species living here (largely poeciliids and cyprinodontids) are eurythermal, other factors being equal. It must be noted, however, that the bay fishes should not be considered truly estuarine eurythermal species, since the bay is not an estuary, nor must its fish species tolerate the broad ranges of temperature and salinity characteristic of northern brackish bodies of water. Hence, Biscayne Bay's fishes resemble stenotopic tropical species in most of their characteristics.

The relation between temperature and catch by anglers on Rickenbacker Causeway (Tables 7 and 8) show a distinct pattern of year-round, tropical species taken at warm temperatures, contrasted with seasonal, temperate species taken during cooler waters.

6. Oxygen. Stressed waters have typically been considered to reflect reduced levels of dissolved oxygen as indicative of sewage pollution (cf. McNulty, 1970). Studies on south Biscayne Bay larval fishes and their environment indicate that dissolved oxygen is ample for fish metabolism in the open bay and, while lower in the northwestern fringes than in the open bay, is still adequate for healthy fish populations and, while lower along the western bay, is certainly not sufficiently low to be considered as indicative of an environment potentially endangering larval or adult fishes (de Sylva, 1970, 1976).

7. Currents. Currents act upon fishes by dispersing them as larvae, juveniles, or adults, by moving food to them, and by replenishing anoxic or polluted water with new water. Vertical currents may carry them into favorable areas for feeding, or unfavorable regions so that they may perish. The horizontal current regime of the bay appears to be more important than vertical water movements, if indeed they are important to Bay fishes. Inshore movements of deep-sea larval fishes from offshore areas has already been discussed (de Sylva and Scotton, 1972), and possibly upwelling of deep ocean waters may be involved here.

8. Tidal currents. These are undoubtedly important in transporting fish larvae from offshore into nursery grounds in the bay. No quantitative data are available on this aspect, nor is any information available on the flux or quantity of fishes, either as larvae or as adults carried from the bay to offshore waters. Similarly, nothing is known about the transport of food for fishes, at any stage of their life cycle, to and from the offshore area. Both larvae and adults of blue-water fishes are sometimes transported into Biscayne Bay. Fowler (1941) reported a 65-mm sailfish (Istiophorus albicans) being taken off Coconut Grove, Miami, in May, 1936, and George Miller, National Marine Fisheries Service, Miami, reports (personal communication) that several years ago he observed an adult sailfish of 6 to 7 feet long just west of Virginia Key jumping in water which was only a few feet deep. Dolphin and flyingfish of 2-4 cm are commonly dipnetted by RSMAS personnel from their laboratory dock during incoming tides and onshore winds. It is not known whether waters transporting these species are influenced by currents, tides, winds, or a combination thereof.

9. Winds. No studies are available on the relationships between wind velocities and directions and the species and numbers of fishes in the bay. Anglers are aware of some vague relationship but no one has been able to document when the best angling occurs in relation to wind. Preliminary studies based on the sport fishery study by Wade (vide supra) suggest that angling (and hence fish movements) is best during a combination of a northeast wind and a flood tide, or during a southwest wind and an ebb tide. Since both factors seem also to be influenced by moon phase, water temperature, and the occurrence of cold fronts, the question basically remains unsolved.

Hurricanes and severe cold snaps which occasionally occur in south Florida both are extreme examples of south Florida weather, and probably should not be considered as representative of a common phenomenon to which the bay fishes are exposed. Nevertheless, they do occur, yet little documentation is available on the reaction of the bay fishes, except to say that they probably do not tolerate such extremes very well (Robins, 1957).

10. Moon phase. This is a much-debated environmental factor which has little to substantiate its importance. Yet sport and commercial fishermen and scientists alike realize that there are some relationships between catches and moon phase, though there are no good data which can relate fish behavior to moon phases. Some obvious factors such as the brightness of the moon or the occasional correlation of moon phases with other factors, such as tides or winds, may be erroneously attributed to lunar cycles.

b. Chemical Attributes

1. Natural runoff substances. These may occur in runoff as vitamins, hormones, trace elements, or minerals which variously interact with, predominantly, the lower levels of the food web upon which larval, juvenile, and adult fishes are dependent. Work by Brook (1975 and in progress) may shed some light on this extremely complex enigma of the food web.

2. Nutrients. Nitrates, phosphates, and silicates are the obvious and most common naturally occurring compounds in the bay waters. How these may limit or affect fishes or the food supply of fishes or their habitats is unknown.

c. Biological Attributes

The most important biological attributes of Biscayne Bay are theoretically as sources of 1) food, 2) shelter and lack of predation, 3) suitable habitat for spawning, and 4) for nursery areas, 5) interactions with predators, prey, other non-predatory but competitive fish and invertebrate associates, and 6) interaction with other organisms such as birds, mammals, and reptiles. In spite of ongoing studies (Brook, personal communication) almost nothing is known about these interactions either qualitatively or quantitatively, and the ultimate source of energy for bay fishes is still speculative.

d. Human Attributes

The effect of man on the fish fauna of the bay has been alluded to. Although I wish to avoid repetition, the massive changes in the bay deserve note, such as the alteration of its once-pristine, clear waters (Handbury, 1896; Smith, 1896; Brice, 1898; Gregg, 1902, Moore, 1910) to the level of degradation (Voss *et al.*, 1969b; McNulty, 1970; de Sylva, 1970, 1976; Scotton, 1972; Rosendahl, 1975; Wilson, 1975; Bilhorn, 1975; Volker, 1976). These affects can be broadly summarized as being due to the introduction of sewage and industrial wastes, insecticides, herbicides, fertilizers, heavy metals, medicinal compounds, dredging, diking, and filling, canal, causeway, and bridge construction, removal or destruction of mangroves and sea grasses, and possibly overfishing, in conjunction with the above, by sport and commercial fishermen.

Regarding pollution, the question of temperature influences upon fishes or thermal pollution has been covered extensively in the literature (see de Sylva, 1968; Voss *et al.*, 1969b; Roessler, 1970, *et seq.*; Bader and Roessler, 1971; Nugent, 1970; Smith, 1971), but temperature as a controlling factor in tropical fishes is especially important to tropical marine fish species because they are already living very close to their upper lethal temperature limits (de Sylva, 1968; Voss *et al.*, 1969b; Albertson, 1973). Thus, the question of heated effluents or thermal pollution, now mitigated, was an important one since even a slight temperature elevation of a few degrees could be detrimental to bay fishes. The average annual temperature for August (the hottest month) is approximately 30°C, and the upper thermal tolerance for these fishes approximates 32°C. Consequently a Δt of 2-3°C is potentially lethal to bay fishes. Thermal effluents at both the Turkey Point plant and the nearby Cutler Power Plant of Florida Power and Light Company have had varying effects on fishes and their environment which affect the fishes' well-being (Roessler, 1970 *et seq.*; Bader and Roessler, 1971).

It is important here to note that Biscayne Bay, like other bodies of water such as Lake Michigan, Chesapeake, Delaware, and Galveston bays, and San Francisco Harbor, have all had their environmental destruction first heralded by opposing fishermen--sport and commercial--each of whom decried the efforts of the other, while in reality environmental pollution and destruction was taking the toll of the spawning, feeding, and nursery grounds. The repeated cries of one faction against the other seem to occur every decade. Today, the sport fishermen accuse the commercial seiners of destroying Biscayne Bay (de Sylva, 1975b).[1] An early quote reminds us that fishermen have always blamed other fishermen. Concerning Spanish mackerel, it was said that "at one time this fish was common in the bay, which was a favorite resort, but it is now scarce, and is said to have become so since the extensive seine fishing by Gloucester {Massachusetts} vessels began along the keys about five years ago" (Smith, 1896: 173). Our memories are short, and we blame the unknown. We do not admit that natural phenomena and cycles can result in poor fishing, yet we are reluctant to blame ourselves for destroying the fishing we seek.

This section should be concluded by a discussion of food webs of estuarine fishes, which has been recently summarized (de Sylva, 1975a). Except for a study of the adjacent Card Sound fishes by Brook (1975 and studies in progress), nektonic food webs have *not* been studied in Biscayne Bay. More important, the dynamics of these food webs in relation to *other* processes in Biscayne Bay are virtually unknown (Snedaker and Brook, this volume). It seems incredible to me that such a beautiful and bountiful body of water can exist next to a city of nearly 2 million people, whose economy and ecology depend extensively upon the bay, without it having received the study, care, and nurture of those caretakers responsible for its health and future.

DISCUSSION

The preceding review serves merely to focus on the paradox that there have been nearly 200 studies on the fishes of Biscayne Bay concerning what, several concerning where, even fewer concerning when, and virtually none concerning how. Where do we go from here?

The questions revolve about what we need to know and what information we can obtain. This is divided into:

a) *What we should have known*: (1) What species occurred in the bay 80 years ago, what was their environment, and how did it function? (2) Was the bay *ever* an important area to fishes, and if so to what species, and at what stage of their life cycle? (3) What were the early habitats in the bay? Clearly, we cannot reconstruct the past, for we have no data, and thus we must rely on the data we have now, which are pitifully small. Hearsay from sport and commercial fishermen and the few scientific data available will not serve to answer quantitative questions posed by de Sylva and Staiger (1975).

b) *What we should know*. To paraphrase the time-worn phrase of science that "we know nothing," I summarize our knowledge about the fishes of Biscayne Bay in that "we do know nothing." Therefore, we must concentrate not on what we should have known, but on what information we must obtain now. This is, in order of importance: (1) What species now occur in Biscayne Bay?; (2) What is their geographical, seasonal, diel, and ontogenetic distribution?; (3) What important, distinctive habitats can be identified in the bay?; (4) What are the seasonal distributions and migrations of these fishes?; (5) What are the relationships among these species to one another, to their prey,

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[1] This paper summarizes current knowledge on the Biscayne Bay commercial fisheries and their effects on the stocks, and also evaluates the effects of sand and shell dredging.

predators, and competitors?; (6) How are their distributions related to their physico-chemical and biological environments such as bottom type, turbidity, temperature, salinity, and dissolved oxygen?; (7) How does species diversity indicate richness of habitat?; (8) How are species diversity and species numbers related to the environment?; (9) How is species diversity related to the health, degradation, and long-term stability of the bay?; (10) How can we evaluate and predict short- and long-term changes in species composition and diversity or species loss in relation to natural and man-made environmental variations?; (11) How can we determine the relative contribution of man and natural fluctuations in populations and species diversity?; (12) How can we determine the normal metabolic activities of the bay fishes such as feeding, spawning, and migrations, and relate them to natural and man-made changes in their environment?; (13) How can we determine the dynamics of the food web and trophic relationships of the bay species?; (14) How can we determine the relative contribution of foods from the offshore waters into the bay and, thus, for bay species; and (15) How have pollution, environmental degradation, and sport and commercial fisheries affected and how might they affect the fish populations of the bay and their feeding, spawning, and nursery grounds?

The above questions can be answered only through carefully designed sampling programs which utilize a variety of sampling methods in numerous habitats over a period of time sufficient to permit an analysis of the trends that populations of bay fishes are following, so that an analysis of such trends may be made and so that concomitant environmental data can be applied to and correlated with the trends of the fishes.

Along with these studies, other processes must be studied concurrently. These include studies of the:

a) *Physical processes*: How do such variables as temperature, salinity, turbidity, winds, tides, moon phase, and combinations of these cause bay fishes to occur when and where they do?

b) *Chemical processes*: How do estuarine runoffs affect fishes and their occurrence, feeding, spawning, and migrations?

c) *Biological processes*: (1) Have there been real changes?; (2) Was this area ever *really* important biologically to fishes?; (3) What different life stages of fishes utilize the bay and, if so, why?; (4) What are the critical ecological indicators which may forecast changes in the bay and why?; (5) What are the critical habitats for potentially endangered species, e.g., snook, tarpon, and bonefish?; (6) How do fishes function in the bay system, and what is their role in the energy-transfer processes?

d) *Man-made processes*: There is a pressing need, not based upon hearsay, to determine what can be considered as control areas for fish populations and habitats, and thence to study various effects of man's activities upon these populations and habitats. Among these are: (1) shoreline alteration, (2) mangrove removal or filling, (3) dredging and/or filling, (4) grassbed removal, (5) turbidity increase, (6) diking, (7) creation of causeways, and (8) additions of various pesticides, trace metals, and heavy metals. Similarly, parts of the bay should be set aside as experimental areas to permit one to manipulate and monitor the environment in attempts to improve it for man's use, i.e., better angling, commercial fishing, underwater photography, such as might be envisioned by the establishment of artificial reefs or islands, fishing piers and bridges, or underwater fish habitats.

To summarize, it is paradoxical that so little is known about the fishes of Biscayne Bay, yet that so much fuss has been raised about the fishes and fisheries of Biscayne Bay. Little is known about the what, when, where, and how of these fishes and fisheries, but these answers must be obtained before intelligent, dispassionate, and objective answers can be given to the public. No quick answers can answer the question: What has man done to our bay's fishes?

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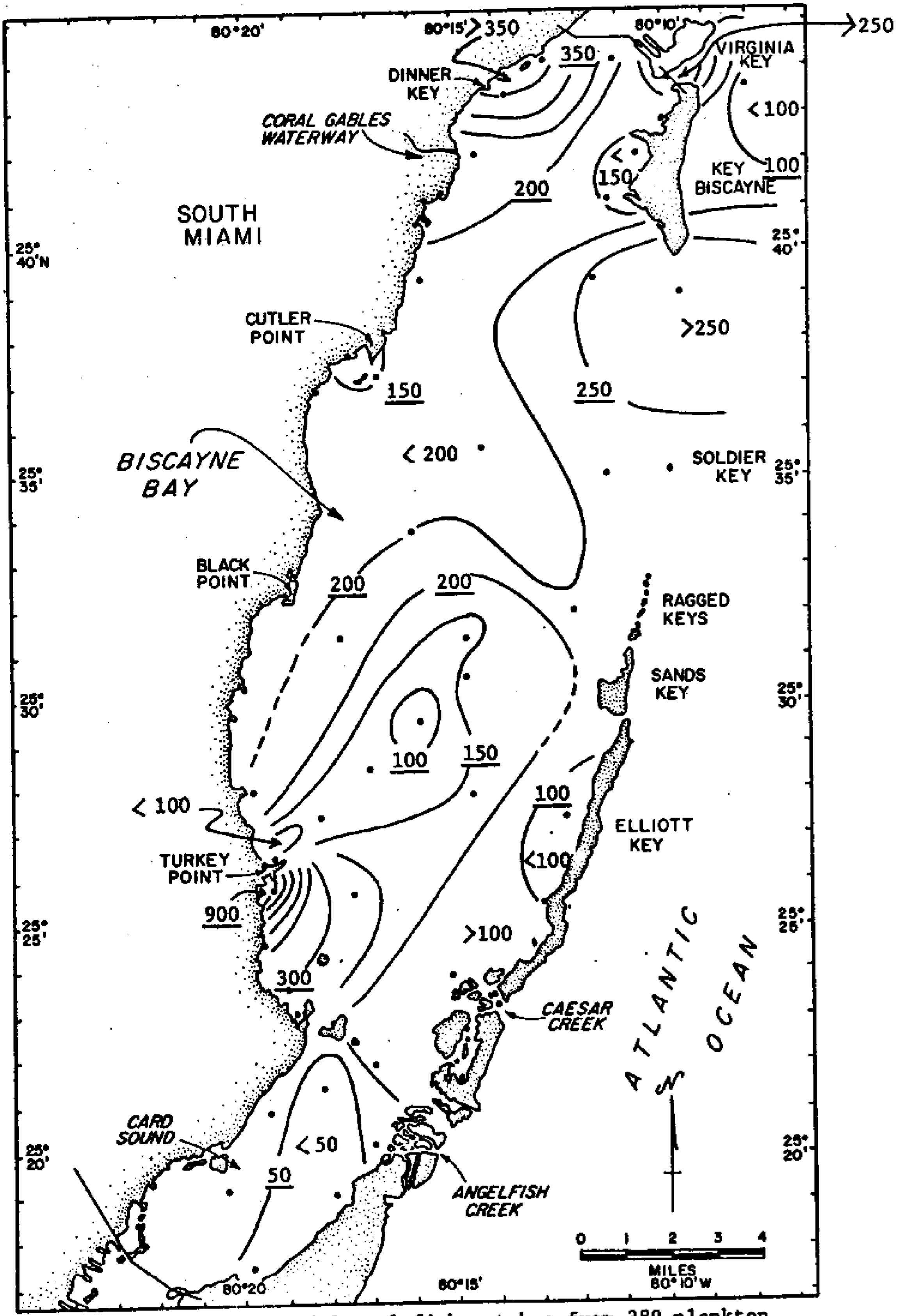

Figure 1. Mean number of larval fishes taken from 389 plankton tows using a 1-m net (15-minute tows), January - December, 1970. Isopleths are contoured every 50 units. Dots are monthly collecting stations.

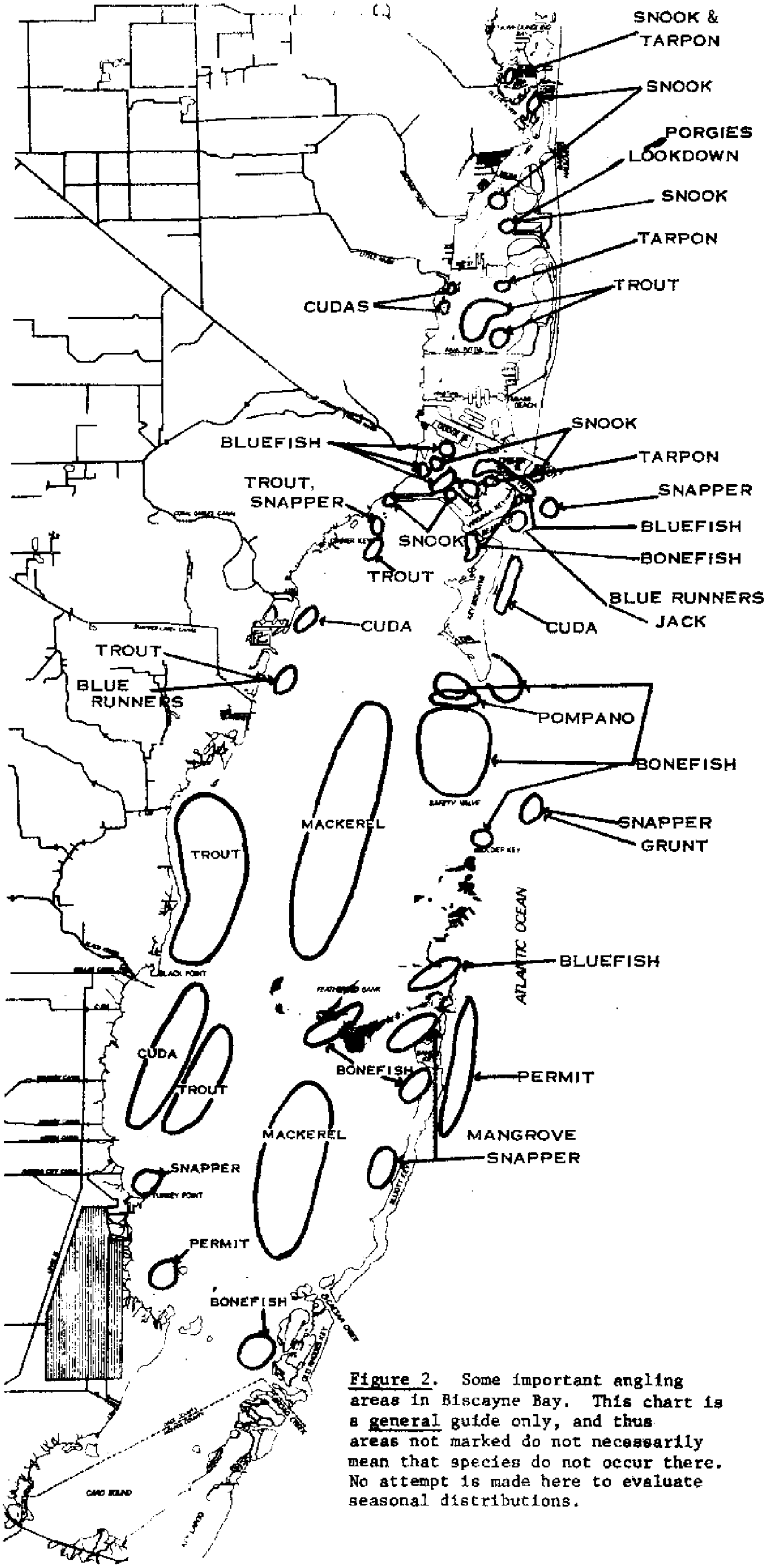

Figure 2. Some important angling areas in Biscayne Bay. This chart is a general guide only, and thus areas not marked do not necessarily mean that species do not occur there. No attempt is made here to evaluate seasonal distributions.

Table 1. Addendum to the 496 fish species of the Biscayne Bay area listed by Voss *et al.*, (1969a).

common name	scientific name	reference
rainwater killifish	*Lucania parva* (Baird)	1
dragonfish	*Stomias ?affinis* Günther	2
scaleless dragonfish	*Bathophilus* sp.	2
lightfish	*Cyclothone ?braueri* Jespersen and Tåning	2
yellowfin menhaden	*Brevoortia smithi* Hildebrand	3
gizzard shad	*Dorosoma cepedianum* (Lesueur)	3
southern hake	*Urophycis floridanus* (Bean & Dressel)	3
halfbeak	*Hyporhamphus unifasciatus* (Ranzani)	3
broad flounder	*Paralichthys squamilentus* Jordan & Gilbert	3
mushroom scorpionfish	*Scorpaena inermis* Cuvier	3
rough triggerfish	*Canthidermis maculatus* (Bloch)	3
lesser amberjack	*Seriola fasciata* (Bloch)	3
tomtate	*Haemulon aurolineatum* Cuvier	3
pinfish	*Lagodon rhomboides* (Linnaeus)	3
Gulf kingfish	*Menticirrhus littoralis* (Holbrook)	3
sand drum	*Umbrina coroides* Cuvier	3
lanternfish	*Myctophum* sp.	4

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[1] Roessler, *et al.* (1971)

[2] de Sylva and Scotton (1972)

[3] Low (1973)

[4] de Sylva (1976)

Table 2. Frequency of occurrence of the most common fishes caught by anglers at Bear Cut bridge, Rickenbacker Causeway, June, 1960 - October, 1962.

	1960							1961				1962										N
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	
1. white grunt, *Haemulon plumieri*	7	8	-	1	23	-	-	7	11	19	12	71	36	37	43	50	13	15	5	17	21	396
2. crevalle jack, *Caranx hippos*	-	1	-	-	4	-	-	4	-	6	5	151	5	1	1	-	1	1	1	1	8	190
3. bluestriped grunt, *Haemulon sciurus*	31	3	-	-	13	-	-	-	2	2	3	20	21	20	6	18	3	13	9	7	5	176
4. sailor's choice, *Haemulon parrai*	4	-	-	-	3	-	-	10	1	1	-	19	9	-	-	2	4	5	27	-	-	85
5. pigfish, *Orthopristis chrysoptera*	-	-	-	-	-	-	-	-	-	-	23	10	39	5	2	1	-	-	-	-	-	80
6. gray snapper, *Lutjanus griseus*	1	-	-	8	6	2	-	4	2	6	-	7	1	3	6	2	3	2	16	1	4	74
7. lane snapper, *Lutjanus synagris*	2	-	-	1	-	-	-	2	2	1	1	5	2	9	3	3	18	18	1	-	3	71
8. planehead filefish, *Monacanthus hispidus*	2	-	-	-	-	-	-	-	-	2	27	2	13	14	1	1	1	-	-	-	-	63
9. tomtate, *Haemulon aurolineatum*	-	-	-	-	9	-	-	2	-	2	1	3	3	4	2	25	-	1	-	-	1	53
10. Spanish mackerel, *Scomberomorus maculatus*	-	1	-	-	-	-	-	2	-	10	6	2	21	1	-	-	-	-	-	-	7	50
11. bluefish, *Pomatomus saltatrix*	-	-	-	-	2	-	-	17	2	8	-	1	1	-	-	-	-	-	-	-	6	34
12. king mackerel, *Scomberemorus cavalla*	-	-	-	-	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10	22
13. pinfish, *Lagodon rhomboides*	-	-	-	-	-	-	-	-	-	-	-	3	9	-	-	-	1	1	-	-	-	14
14. inshore lizardfish, *Synodus foetens*	-	-	-	-	1	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	4
TOTAL:	47	13	0	10	73	2	0	48	20	57	78	295	161	95	64	102	44	56	59	26	65	1315

Table 3. Frequency of occurrence of the most common fishes caught by anglers at the drawbridge, Rickenbacker Causeway, June, 1960 - October, 1962.

	1960							1961				1962										N
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	
1. Spanish mackerel	1	-	4	12	30	168	14	9	-	110	14	119	138	109	41	17	10	26	1	16	39	878
2. crevalle jack	2	4	6	5	38	5	11	7	2	24	11	9	15	2	45	7	4	7	6	25	25	260
3. king mackerel	-	-	-	-	19	103	13	-	-	4	1	17	5	2	-	2	2	-	-	-	45	213
4. pinfish	-	-	-	-	-	-	15	-	-	12	1	41	32	20	3	1	1	-	-	-	4	130
5. pigfish	-	-	-	-	-	-	3	-	-	2	29	17	17	23	6	1	-	-	-	-	-	98
6. inshore lizardfish	-	-	-	-	-	2	5	-	-	3	1	8	14	14	21	1	-	1	-	-	2	72
7. bluefish	-	4	-	2	3	4	1	3	18	8	-	-	-	1	10	-	-	3	3	1	6	67
8. planehead filefish	-	-	-	-	-	1	1	-	-	12	-	1	9	3	34	-	1	1	2	-	-	65
9. gray snapper	-	-	-	3	-	1	1	2	3	2	-	-	-	-	2	2	6	15	7	4	7	55
10. lane snapper	-	-	-	-	-	-	-	-	-	3	1	4	1	5	4	8	19	5	-	1	1	52
11. tomtate	-	-	-	-	-	-	3	-	-	-	-	1	1	1	15	2	9	-	-	-	-	32
12. white grunt	-	-	-	-	-	-	2	-	-	2	-	-	3	1	-	-	6	1	2	1	1	19
13. bluestriped grunt	-	-	-	-	-	1	4	-	-	1	-	-	-	1	-	-	1	-	4	-	-	12
14. sailor's choice	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	2
TOTAL:	3	8	10	22	90	285	73	21	25	183	58	217	235	182	181	41	59	59	25	48	130	1955

Table 4. Relation between monthly plankton volume (ml/15-minute tow of 1-m, 500-µ mesh net) and number of larval fishes (number/15-minute tow) in south Biscayne Bay, 1970.

	Jan.	Feb.	Mar.	Apr.	May	June	June/July	Aug.	Sept.	Sept./Oct.	Oct.	Nov./Dec.	Dec.
mean wet vol. of plankton, ml	226.9	296.0	192.0	240.3	248.3	66.3	72.9	37.3	171.2	114.9	225.1	172.2	172.2
mean no. of larval fishes	168.1	300.4	252.0	354.0	571.8	114.9	47.2	33.1	94.3	191.8	168.2	103.8	78.4

Table 5. Seasonal catch of larval fishes taken in a 1-m plankton net towed for 15 minutes, south Biscayne Bay, 1970.

	number of tows	sum	mean no.	σ^2	σ	$\sqrt{N}$	S.E.
Jan.	21	3,530	168.1	56,121.6	236.9	4.6	51.5
Feb.	34	10,215	300.4	140,550.0	374.9	5.8	64.6
Mar.	30	7,559	252.0	127,663.3	357.3	5.5	65.0
Apr.	34	12,036	354.0	131,623.8	362.8	5.8	62.6
May	35	20,014	571.8	1,490,596.8	1,220.9	5.9	206.9
June	35	4,022	114.9	37,403.6	193.4	5.9	32.8
June/July	35	1,651	47.2	5,565.2	74.6	5.9	12.6
Aug.	35	1,158	33.1	1,035.7	32.7	5.9	5.5
Sept.	26	2,451	94.3	12,076.6	109.9	5.1	21.5
Sept./Oct.	35	6,714	191.8	28,274.7	168.2	5.9	28.5
Oct.	13	2,187	168.2	11,659.4	108.0	3.6	30.0
Nov./Dec.	39	4,050	103.8	35,344.0	188.0	6.2	30.3
Dec.	17	1,333	78.4	15,685.3	125.2	4.1	30.5

Table 6. List of fish species on which biological research has been carried out in Biscayne Bay.

species	kind of research	reference
numerous	keys for identification of skeletons	Moffett, 1957
Spanish mackerel	biology	Klima, 1959
grunts	development	Courtenay, 1960
flounders	biology	Jutare, 1962
tarpon	development	Wade, 1962
barracuda	life history	de Sylva, 1963
mojarras	morphology	Green, 1964
clingfish	biology & morphology	Gould, 1965
anchovies	distribution	Daly, 1966
lizardfish	parasites	Overstreet, 1966
needlefishes	biology	Eidman, 1967
mullet	feeding	Odum, 1967
eel	development	Dean, 1968
tarpon	ecology of juveniles	Wade, 1968
numerous	parasites	Overstreet, 1969
shark	hearing	Banner, 1971
flounder	development	Achmad, 1973
grunts	temperature tolerance	Albertson, 1973
numerous	distribution & ecology	Low, 1973
herrings	distribution & ecology	Low, 1973
herring	reproduction	Martinez, 1973
anchovy	developmental physiology of larvae	Rebel, 1973
sheephead	developmental physiology of larvae	Rebel, 1973
herring	developmental physiology of larvae	Rebel, 1973
menhaden	developmental physiology of larvae	Rebel, 1973
pompano	ecology	Smith, 1973
snapper	ecology of feeding	Swanson, 1973
mullet	parasites	Skinner, 1974
sheephead	feeding of larvae	Stepien, 1974
pinfish	food habits & ecology	Brook, 1975
needlefish	food habits & ecology	Brook, 1975
pipefish (2 species)	food habits & ecology	Brook, 1975
killifish	food habits & ecology	Brook, 1975
mojarra (2 species)	food habits & ecology	Brook, 1975
silverside	food habits & ecology	Brook, 1975
mojarra	biology	Charles, 1975
puffers	food & feeding habits	Targett, 1975

Table 7. Frequency (in percent) of fishes caught by anglers at a given water temperature at Bear Cut bridge, Rickenbacker Causeway, June, 1960 - October, 1962.

		Temperature, °C														N
	Name	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
1.	white grunt	<1	-	12	17	16	6	7	10	5	10	10	2	3	<1	396
2.	crevalle jack	-	-	6	<1	79	5	1	<1	<1	3	3	<1	<1	<1	190
3.	bluestriped grunt	5	-	7	5	14	13	10	10	2	12	10	6	6	-	176
4.	sailor's choice	-	-	8	13	12	-	1	1	5	31	8	19	2	-	85
5.	pigfish	-	-	54	29	14	-	1	-	1	1	-	-	-	-	80
6.	gray snapper	-	-	1	3	7	8	15	4	1	35	15	10	-	1	74
7.	lane snapper	-	-	4	6	7	1	13	4	24	6	31	1	3	-	71
8.	planehead filefish	3	-	6	32	32	3	22	<2	<2	<2	-	-	-	-	63
9.	tomtate	-	-	11	10	<2	<2	6	55	6	-	10	-	-	-	53
10.	Spanish mackerel	8	-	42	4	6	30	4	-	2	-	2	-	2	-	50
11.	bluefish	-	-	<3	<3	-	22	-	-	-	73	-	-	-	-	37
12.	king mackerel	-	-	-	-	-	45	-	-	-	-	55	-	-	-	22
13.	pinfish	-	-	64	22	-	-	-	-	-	-	14	-	-	-	14
14.	inshore lizardfish	-	-	75	-	-	-	-	-	25	-	-	-	-	-	4

Table 8. Frequency (in percent) of fishes caught by anglers at a given water temperature at the drawbridge, Rickenbacker Causeway, June, 1960 - October, 1962

		Temperature, °C																	N
	Name	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
1.	Spanish mackerel	<1	4	<1	9	8	7	7	9	16	21	<1	5	<2	<2	<2	<3	<3	878
2.	crevalle jack	<1	-	<3	-	3	3	5	8	25	4	-	9	8	5	10	13	3	260
3.	king mackerel	-	<1	5	-	8	1	<2	12	12	48	-	7	<2	<1	1	<1	-	213
4.	pinfish	28	-	11	-	-	<2	15	9	32	<1	-	<2	<2	-	-	-	-	130
5.	pigfish	8	-	30	7	8	3	9	21	11	2	-	-	-	-	-	-	-	98
6.	inshore lizardfish	11	<2	6	-	1	7	47	3	19	3	-	-	-	-	-	-	<2	72
7.	bluefish	-	<2	-	-	-	-	12	7	10	4	3	4	31	9	6	6	4	67
8.	planehead filefish	-	-	-	-	<2	<2	52	15	22	<2	-	-	-	<2	-	<2	3	65
9.	gray snapper	-	-	-	-	-	-	4	5	4	4	<2	7	27	24	20	3	-	55
10.	lane snapper	-	-	-	-	-	6	11	6	10	4	4	13	4	8	<2	33	-	52
11.	tomtate	-	-	6	-	3	-	15	34	6	-	-	-	25	-	-	9	-	32
12.	white grunt	-	-	10	-	-	-	20	5	10	-	5	-	25	10	5	10	-	20
13.	bluestriped grunt	-	-	33	-	-	-	<9	<9	-	-	<9	-	42	-	-	-	-	12
14.	sailor's choice	-	-	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-	2

DISTRIBUTION AND ABUNDANCE OF MARINE MAMMALS IN SOUTH FLORIDA: PRELIMINARY RESULTS

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ABSTRACT

The preliminary results of aerial surveys to study the distribution and abundance of the bottlenose dolphin (Tursiops truncatus) and the manatee (Trichechus manatus) in south Florida are reported. Light aircraft were used to survey the waters of the Everglades National Park from September 1973 through December 1975 and the waters of Biscayne Bay and vicinity from July 1974 through June 1975. Flights were made approximately every two weeks and the same flight path was followed on each flight in both the Everglades National Park and Biscayne Bay. Forty (40) flights (100 survey hours) were completed in the Park and twenty (20) flights (40 survey hours) in Biscayne Bay. Three hundred eighty-five (385) dolphin herds totalling 1137 individuals were counted in the Park. Sighting rate was 11.37 animals per survey hour. Herd size ranged from 1 to 25 with a mean of 2.95 animals per herd. Six (6) dolphin herds totalling 50 individuals were seen during the Biscayne Bay surveys. Sighting rate was 1.25 animals per survey hour. Herd size ranged from 3 to 13 with a mean of 8 animals per herd. Previous data of this type is not available for either area. Possible reasons for the difference in dolphin abundance in the two are given. These include geographic differences, food distribution and abundance, and direct and indirect human-related factors. Little information is available on the natural history of the bottlenose dolphin in the survey areas and a research program is outlined. No manatees were seen on the Biscayne Bay survey transects. A total of 575 manatees was seen during the 100 survey hours in the Park (5.75 per hour). The number of manatees seen per flight ranged from 0 to 75 with a mean of 14.38 per flight. In the cases of both the dolphins and the manatees, some of the same individuals were probably seen on successive flights. Little information is available about the natural history of the manatee and the research program outline for the dolphin could apply to this animal as well.

INTRODUCTION

Public and scientific interest in marine mammals (whales, dolphins, porpoises, seals, sea lions, walruses, sea cows, dugongs, and sea otters) has increased in recent years resulting, in part, from the porpoise-tuna controversy in the eastern tropical Pacific (e.g Anon. 1975a) and resulting in legislation such as the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973.

A great variety of marine mammals (mostly cetaceans) are known from Florida's waters (e.g. Moore, 1953; Layne, 1965). Unfortunately, most of the species are known only from dead specimens that have washed up on the beaches. The two marine mammals most frequently observed alive in Florida's coastal waters are the bottlenose dolphin (Tursiops truncatus) and the manatee (Trichechus manatus). Both species occur in Biscayne Bay. Various literature surveys and summaries indicate that little is known about the natural history of either species (Caldwell and Caldwell, 1972; Husar, 1974 ms; Truitt, 1974; Mitchell, 1975a, b; Odell, 1975; Odell, et al., 1975). The bottlenose dolphin is the most commonly sought-after small cetacean for use in scientific research programs and for public display in oceanaria and similar establishments. Florida's waters have been and are the source of most of these animals (Odell, et al., 1975). Because the bottlenose dolphin is easily captured and maintained in captivity for extended periods of time, there have been numerous studies on its behavior and physiology under these conditions (e.g. Caldwell and Caldwell, 1972; Ridgway, 1972). Reports from long-term residents of Miami have suggested a marked decrease in the abundance of dolphins in Biscayne Bay in recent years. A series of aerial surveys was initiated in September 1973 to document the distribution and abundance of bottlenose dolphins in the coastal waters of south Florida. Other studies on dolphin biology are being carried out through the University of Florida.

The manatee is an endangered species and its current population in Florida is estimated at less than 2000 (Anon., 1975b). We can not say if this estimate is high or low, or if it indicates that the population is increasing or decreasing since there are no other data to compare it with. Current studies underway at the University of Miami and at the National Fish and Wildlife Laboratory, Gainesville, are directed towards the documentation of distribution, abundance, and other aspects of the biology of the manatee in Florida.

The purpose of this paper is to present a summary of the preliminary results of some of the marine mammal studies conducted in south Florida since 1973 and to consider what further studies must be conducted in order to understand the biology of these two species and the role that they play in the Biscayne Bay ecosystem.

METHODS

Aerial surveys of the waters of the Everglades National Park (Fig. 1) have been conducted since September 1973 and will continue at least through June 1976. Initially, flights were made 1-2 times per month as air time and space permitted. These flights were conducted as a part of other Park studies and the major purpose was not to census dolphins and manatees. A regular series of twice-monthly flights was initiated in July 1975 for the specific purpose of counting dolphins and manatees. In both series of flights the flight path was similar. An amphibious aircraft (Lake LA-4) was flown at an altitude of 1000 feet and at an airspeed of 110 miles per hour. Each flight was approximately 3 hours in duration with 2.5 hours devoted to survey. A total of forty (40) flights was completed (100 survey hours) through December 1975.

Aerial surveys of the waters of Biscayne Bay and vicinity (Figs. 1 and 2) were initiated in July 1974 under a contract from the United States Marine Mammal Commission. Flights were conducted at approximately two-week intervals, weather permitting, for one year. A Cessna 172 or 182 was flown at an altitude of 1000-1500 feet and at an airspeed of 120-130 miles per hour. Each flight lasted about 3 hours with a mean survey time of 2.0 hours per flight. The flight path shown in Fig. 2 was followed on each flight beginning at the north end of the track. Twenty (20) flights were completed (40 survey hours).

At least two observers (pilot included) were onboard for both the Everglades National Park flights and the Biscayne Bay flights. All observers wore polarizing sun glasses to remove some of the reflection from the surface of the water, thus increasing visibility. Several types of data were recorded for each dolphin or manatee herd sighted. A herd is defined as one or more animals in close proximity. All data were recorded on a portable casette taperecorder for later transcription and analysis. Data taken included herd size, herd location, behavior, geometric structure, and presence or absence of calves and their numbers. Data on weather, tidal conditions, and sea surface conditions were also collected.

RESULTS

Bottlenose Dolphins

The surveys conducted in the Everglades National Park resulted in numerous dolphin sightings (Fig. 3). During this series of flights a total of 385 dolphin herds was sighted for a total of 1137 individuals. Herd size ranged from 1-25 with a mean of 2.95. The frequency distribution of herd size is shown in Fig. 4. The number of animals sighted per flight ranged from 0-98 with a mean of 28.4. The mean number of herds sighted per flight was 9.6. The value of 11.37 animals sighted per survey hour is a measure of sighting success per unit effort. Although the final analyses have not been completed, approximately 80-90% of the sightings were made in areas other than Florida Bay (i.e. Whitewater Bay and western inland waters, Fig. 1). Well over 50% of the sightings involved animals that were feeding. The final analyses of these data will include a detailed geographic distribution of the sightings, the behavior patterns observed, and the effects of tidal and other environmental parameters on dolphin distribution and abundance, and on survey efficiency.

Dolphin sightings in Biscayne Bay were scarce in contrast to the Everglades National Park surveys. Dolphins were seen on only six (6) flights and no more than one (1) herd on any one flight. The distribution of the sightings is indicated in Fig. 2. Herd size ranged from 3-13 with a mean of 8, and accounted for fifty (50) individuals. Survey efficiency was 0.15 herds per survey hour and 1.25 animals per survey hour. The dolphins were feeding during 5 of the 6 sightings. These 5 sightings were made in the bay.

Several interested individuals reported dolphin sightings made from land and boats during 1975 (Fig. 2). A total of sixty-eight (68) sightings was reported. Sixty-one (61) of the sightings were of herds composed of 1-10 animals (mean herd size = 2.85) accounting for 174 individuals and seven (7) sightings of herds composed of 11-25 animals (mean = 17.43) accounting for 120 individuals. The two categories of herd size are distinguished because counts of larger herds, particularly by inexperienced observers, tend to be less reliable and often inflated. Although more dolphins were seen from land and boats than seen during the aerial surveys, a measure of dolphins seen per unit search effort, if available, would probably be quite similar to that of the aerial surveys.

In all of the above surveys there are undoubtedly many repeat sightings of the same individuals.

Manatees

Formal surveys for manatees in Biscayne Bay were not conducted. No manatees were seen on the dolphin-survey transects (Fig. 2). However, these animals are frequently seen along the shore line and especially in the rivers, canals, and creeks entering the Bay. As with the dolphins, manatees are frequently seen in the waters of the Everglades National Park (Fig. 5). Over 90% of the sightings were made in Whitewater Bay and the inland waters. The number of animals sighted per flight ranged from 0 to 75 with a mean of 14.38 and accounted for 575 individuals. As with the dolphins, many of the manatee sightings on successive flights are probably of the same individuals. Upon completion of the Everglades National Park series of flights, the manatee sighting data will be analyzed in a manner similar to the dolphin data.

DISCUSSION

The most obvious difference between the Everglades National Park surveys and the Biscayne Bay surveys is in the numbers of dolphins and manatees sighted. Even though more flights were made in the Park than in the Bay, a comparison of flights made during the same time period would yield similar results. Why, then, is there a difference in abundance between the two areas? Since these studies represent the only data of this nature systematically collected from these two areas, the past situation is unknown and so there is nothing with which to compare the new data. We can only make assumptions. If we assume that dolphin abundance in the Bay has decreased in recent years and that the situation in the Everglades National Park has remained unchanged, we can speculate about the reasons for the differences. A point that must be kept in mind is that the boundaries of the areas surveyed in no way define the ranges of the dolphins (or manatees) seen in these areas.

Several points can be considered in relation to the different dolphin abundances in the two areas. The geography of the areas is different. The Biscayne Bay survey area is essentially open water whereas the Park survey area, particularly Whitewater Bay, is broken up by hundreds of small mangrove islands. Put another way, there is much more 'edge' or shoreline in the Park survey area. This may or may not affect dolphin distribution and abundance directly, but it could well be related to the distribution and abundance of some of the dolphins' food items. On many occasions dolphins were seen foraging along the edges of these islands. We know little about the food habits of Tursiops (e.g. Leatherwood, 1975) and how they might vary among different geographic areas. Differences in absolute and seasonal abundance of food items may affect dolphin distribution and abundance. Still another factor is man. Biscayne Bay is heavily used by boaters, much more intensively than the Park is. The Bay is also close to a large population center and there is easy access to the water whereas the Park waters where most of the animals were seen are very isolated. Pollution of the bay and its effects on the dolphins directly or, more likely, on their food is still another possibility. There are still other possible explanations and similar arguments could be made for the apparent difference in manatee abundance.

It is quite obvious that we know very little about bottlenose dolphins and manatees and their roles in the Biscayne Bay ecosystem. Full documentation of these roles will require time, money, and the collaboration of investigators in several disciplines (e.g. fisheries and chemistry).

Plan for Research

The proximity of the Bay and its dolphin and manatee populations to civilization and to the University of Miami's School of Marine and Atmospheric Science make it relatively easy for the field biologist to observe them and to establish a highly automated data-gathering system. If one were to plan a research program to study the dolphins in the bay it would include: (1) An intensive marking program so that individuals could be positively identified. At the time of marking (freeze-branding) each animal would be measured, sexed, a tooth pulled for age determination, and a blood sample taken for reproductive and population studies. Trained observers and the interested public could report the locations and associations of marked animals. Social structure could be studied by determining which animals stayed together and how these associations varied with time. (2) Attachment of radiotransmitters to selected individuals would vastly increase the amount of data collected. Not only could the animals be followed continuously over time, but data on water temperature and time duration and depth of dives could also be collected. The animals could be followed by plane, blimp, or boat and automatic receivers could be set up at remote locations (e.g. Cape Florida, Soldier Key, Sands Key, and Caesar Creek). These stations would transmit data from radio-tagged animals directly back to the laboratory. Similar studies could be conducted using the manatee. Studies such as these would be valuable in several respects. They would (1) provide much-needed basic information about the biology of two poorly known species; (2) information about their roles in the Biscayne Bay ecosystem; and (3) information called for in the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973 that could be used in assuring the conservation and well-being of both species.

ACKNOWLEDGMENTS

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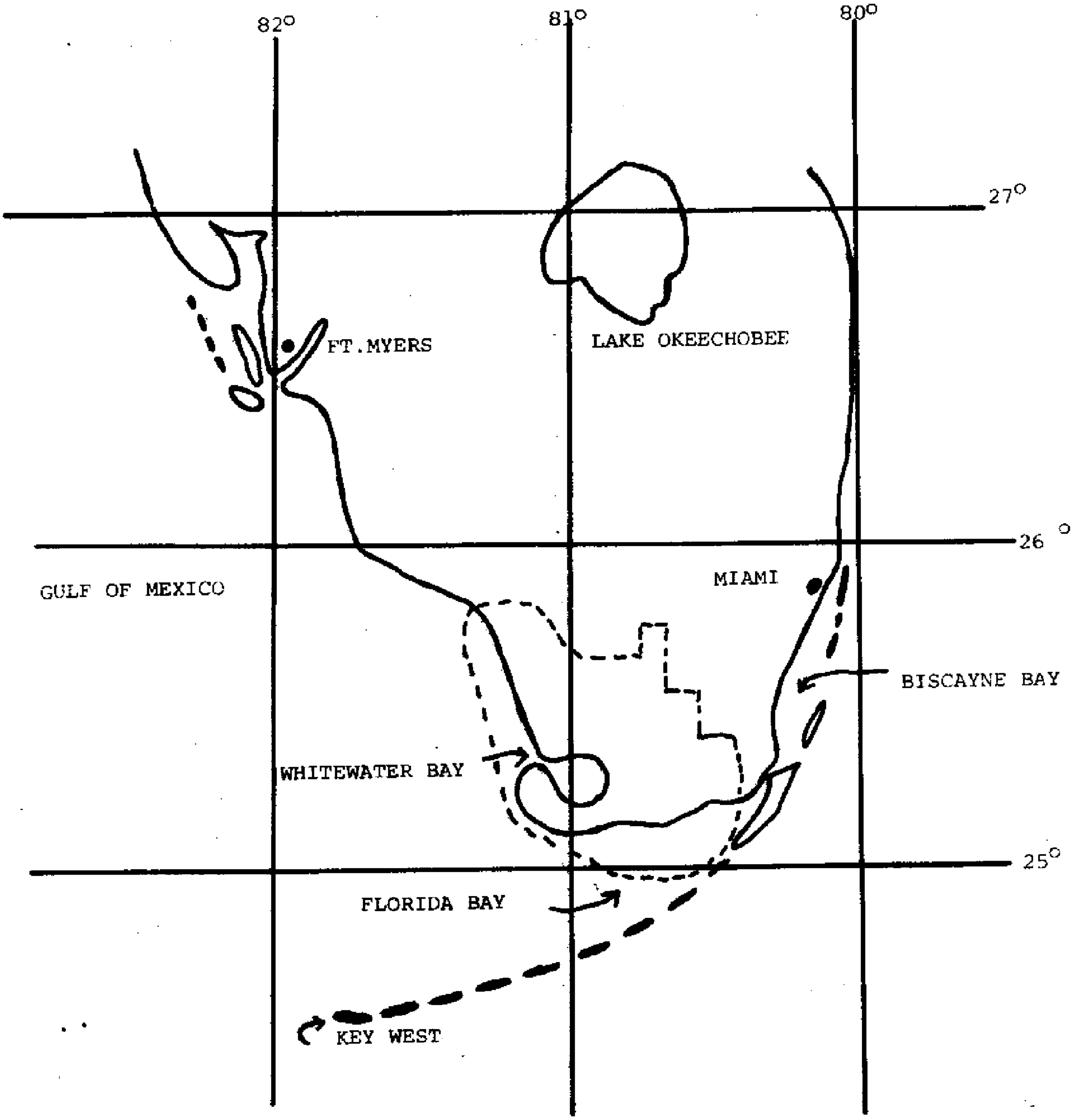

Figure 1. Outline map of South Florida. Dashed lines indicate approx. boundaries of the Everglades National Park.

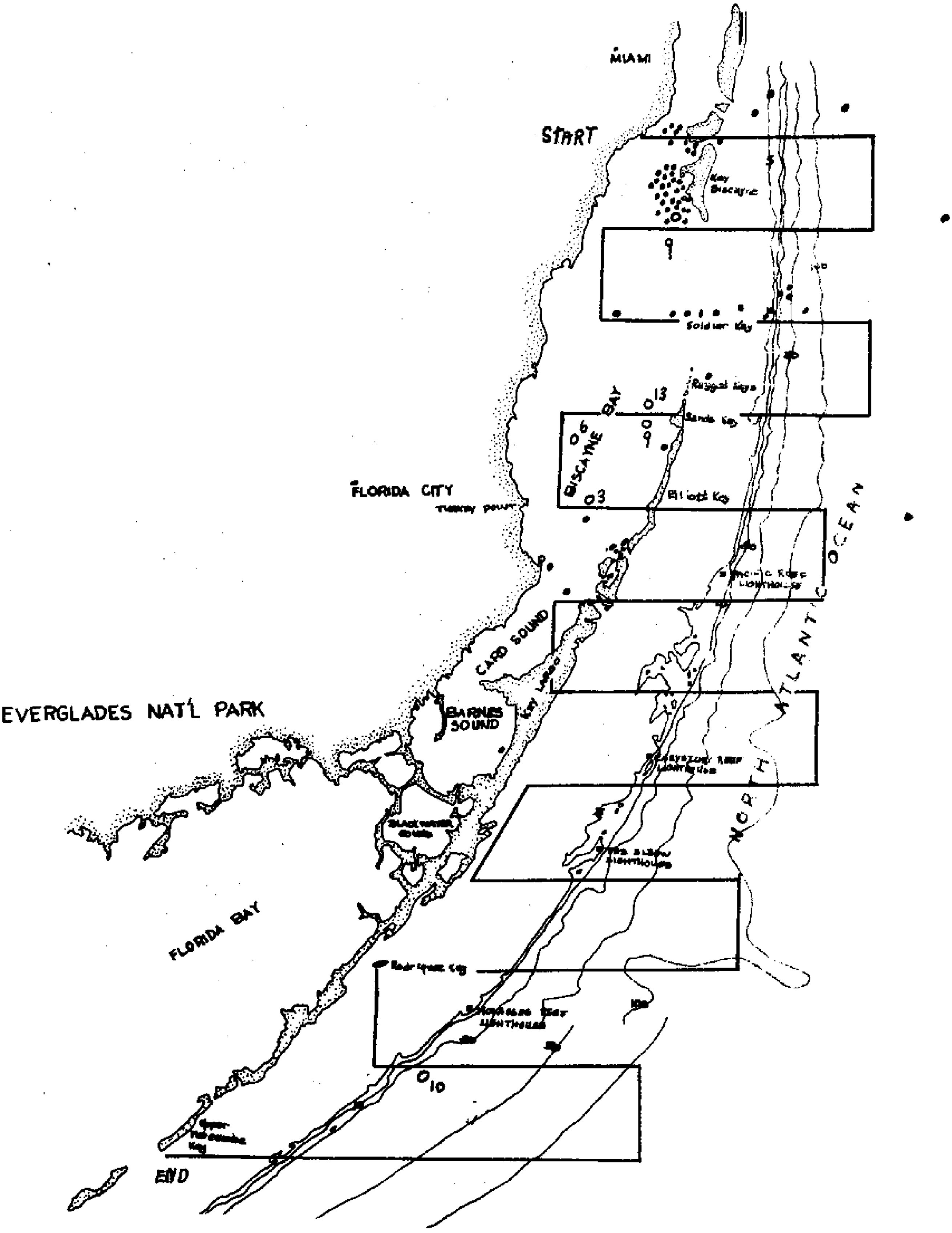

Figure 2. Map of Biscayne Bay and vicinity indicating location of survey transect, locations of aerial sightings (unfilled circles), and locations of shore and boat sightings (filled circles).

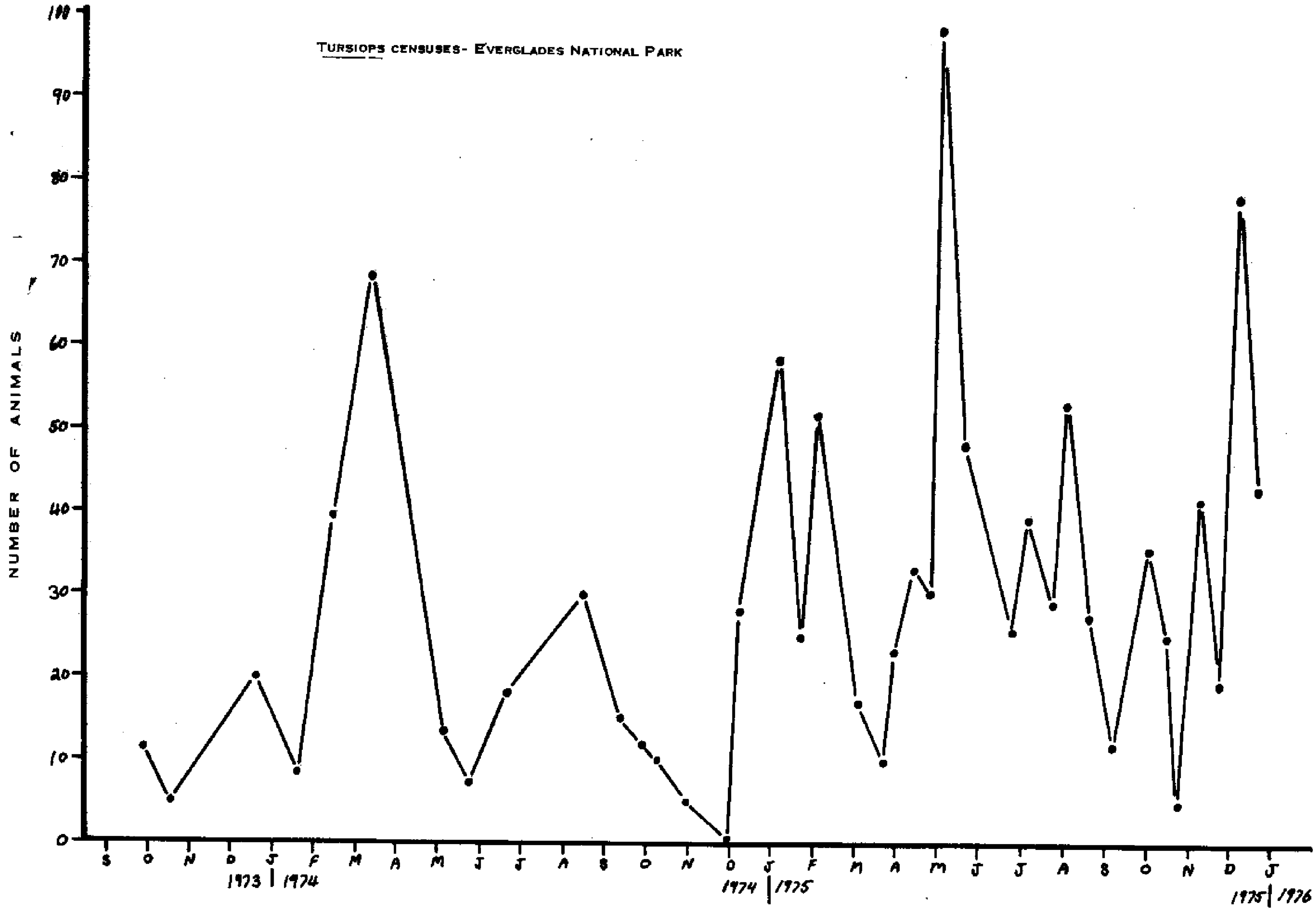

Figure 3. Counts of bottlenose dolphins in the Everglades National Park by aerial survey. September 1973 to December 1975.

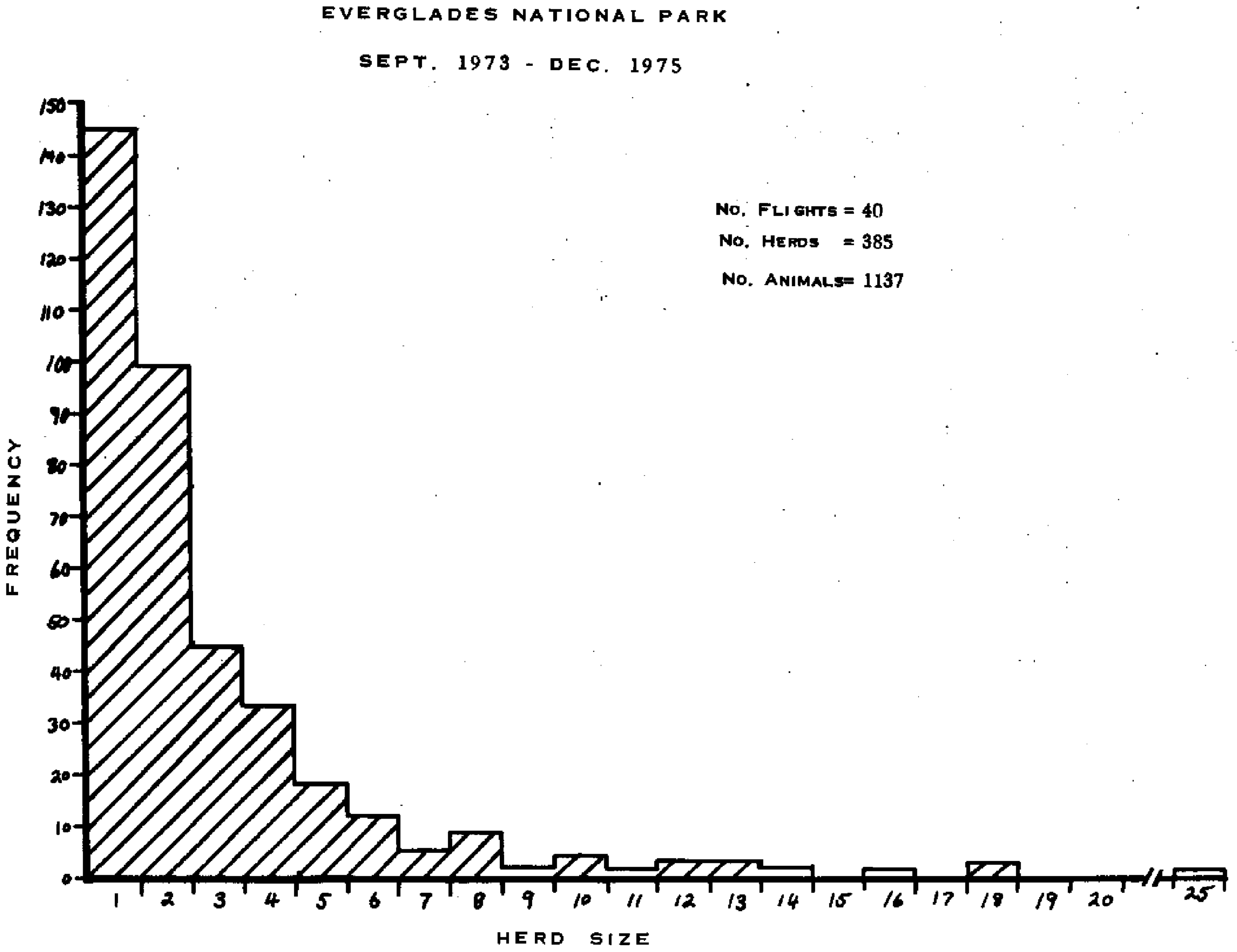

Figure 4. Frequency distribution of bottlenose dolphin herd size for animals sighted during aerial surveys in the Everglades National Park.

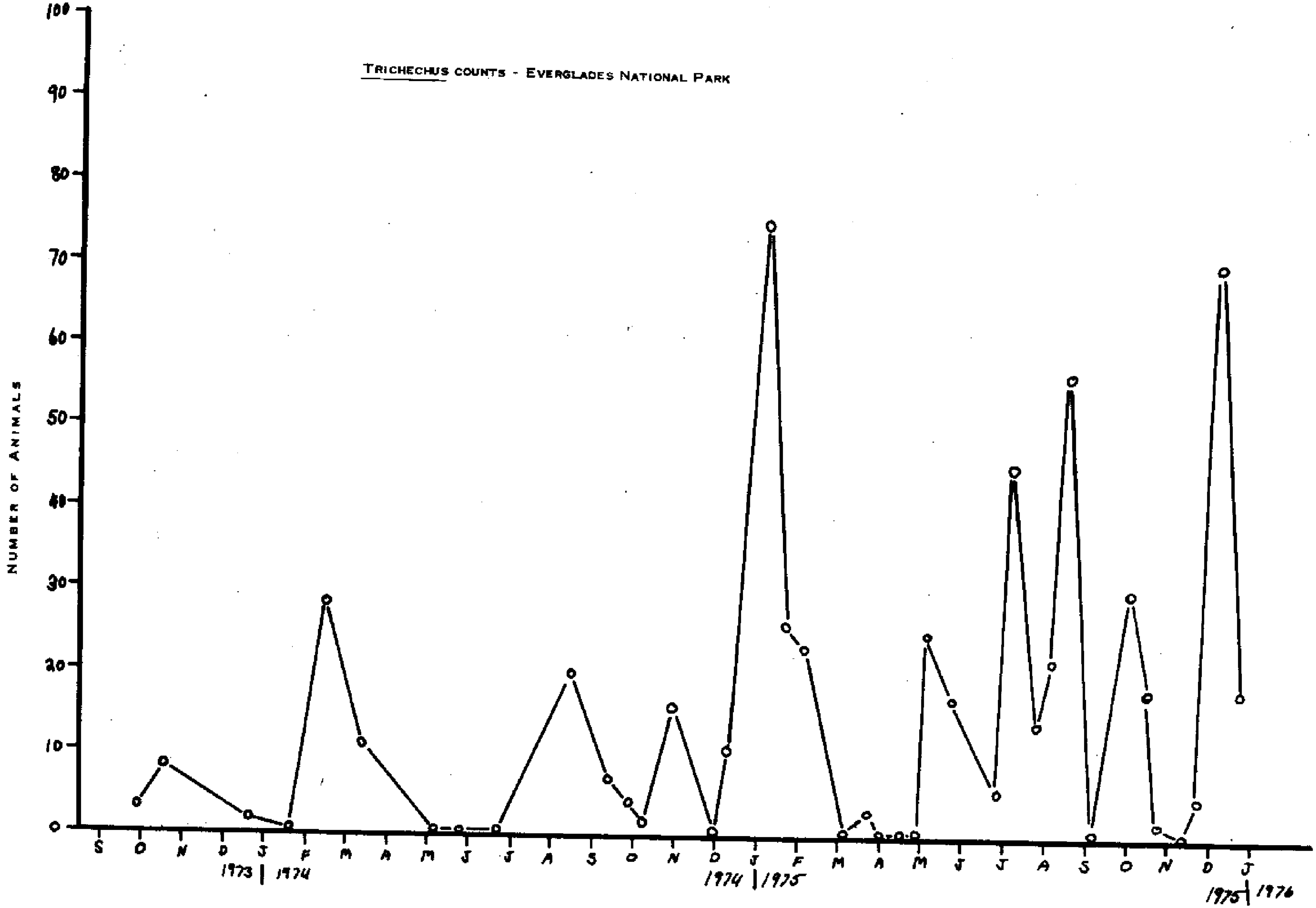

Figure 5. Counts of manatees in the Everglades National Park by aerial survey. September 1973 to December 1975.

THE AVIFAUNA OF BISCAYNE BAY

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ABSTRACT

Ecological studies of the avifaunas of subtropical estuaries such as Biscayne Bay are much needed. Broad ecological surveys are not possible until basic natural history of estuarine species is appreciated. Outline is herein presented of foraging habitats and feeding strategies of birds of Biscayne Bay. Inventory of species important from population sizes or special ecological considerations is given. References are made to completed and ongoing research with these taxa. This information is basic to future work. Recommendations for needed research are made.

INTRODUCTION

Inventory of birds of a subtropical estuary, such as Biscayne Bay, emphasizes a surprisingly diverse spectrum of species. Far more than typically aquatic birds must be considerad. Birds of the forest canopy breed in the mangroves; these too are supported by the Bay's productivity. At times the mangroves are filled with landbirds, migrants pausing to rest before or after long over-water passages. Raptores hunt over both the Bay and its fringing habitats. Colonial land birds gather to nest and/or roost at the Bay and, having foraged inland, add productivity, via their excrement, to the Bay. Many of the Bay's birds are represented there by more than one population; southern Florida wading birds, for example, are joined at the Bay in winter by members of their species from a large area of North America. Through local movements of birds and from long distance migrants, seasonal turnovers of the Bay's avian populations become complex indeed.

The ecological importance of the Bay's avifauna is obviously significant. Yet, ecological studies of this Bay, and of similar situations, are rarely directed to birds. Odum (1971), for example, "conducted no investigations of the diet of carnivorous birds", although he described them as important components of the top trophic level. One searches the texts of may seemingly widely inclusive titles of estuarine research — for example, "An ecological survey of the subtropical inshore waters adjacent to Miami" (Smith et al., 1950) — without finding mention of birds. Thus, while birds are acknowledged as important components of the subtropical estuary's fauna, surprisingly little actual information backgrounds the acknowledgement.

There are patent explanations for this lack of information. Birds are shy and volant. Their populattions are not necessarily static. Censusing an avian population is not easy. Cragg (1967:83) summarized the general situation regarding our knowledge of bird populations nicely (albeit with British ones): "except for a very few species no attempt has been made to assess population numbers ... of 200 or so breeding birds ... estimates ... have only been made for 15 species ... in only four have estimates been made in three or more years ...." Another basic lack of information arises from the lack of autecological studies of birds within subtropical estuaries or comparable habitats. With but few exceptions (e.g., Allen, 1942 and Kushlan, 1974) such studies are lacking. Significant strides have now been made in bioenergetic studies of birds (e.g., Paynter, 1974). But to study energy flows involving an avifauna, one must have estimates of the populations involved, appreciate the components of the diets of the species, and know a great deal more about factors which affect energy budgets. It can be misleading indeed to apply data of these sorts, gathered in ecological communities and in geographical areas not comfortably comparable withthe subtropical estuary to Biscayne Bay.

One fact is clear. Estuarine birds are in large part consumers at upper trophic levels. Volant, they emphasize the open nature of the estuarine ecosystem to greater degree than most animals. Probably no animals express productivity of the Bay at more remote portions of the continent (in some cases continents) than do birds.

Better knowledge of the Bay's avifauna is important. The birds constitute an enormous biomass, a biomass varying seasonally both qualitatively and quantitatively. Its place in an overview of the ecology of the Bay cannot be ignored. Changes in the avifauna will reflect themselves importantly in the entire ecosystem. Untimate consumers at apices of many of the food chains, birds' roles, if understood could serve as convenient indicators of many aspects of Bay ecology. Tabb et al. (1962: 73) showed this nicely re disappearance of certain birds from areas of changing salinity in Coot Bay. The time to gain our knowledge, however, is passing. There have been profound changes in the Bay's avifauna. These changes are ongoing. The time is uncomfortably late at which to be seeking basic information regarding a major segment of the megafauna.

Knowledge of the Bay's avifauna is critical to more than the estuarine ecologist. Biologists, wildlife managers, and conservationists remote from Florida are concerned with the species which have migrated to their areas after wintering in or passing through subtropical estuaries. Florida's conservationists, county planning boards, and lawmakers need the ecologist's information so that they may effect realistic planning for the ecosystem. Finally, and not of least importance, is the naturalist. Knowledge enhances esthetic appreciation and, as Davis (1943) aptly expressed it, the bird life is "one of the most attractive features of south Florida."

PLAN OF THIS WORK

The initial step in consideration of an avifauna is an inventory of the major taxa and at least its most significant species. For Biscayne Bay this is fairly routine. The inventory can be compiled from Howell (1932) and from Sprunt (1954 and 1963). Along with this one needs knowledge of the status of the species in southern Florida and of their population movements or migrations. The former can, in general, be found in the above references. Infra-peninsular population movements of many species are by no means well understood. Broad patterns of movement (migrations) have been summarized (A.O.U. 1957).

The next step is summarization of pertinent aspects of the natural history. What types of residents are the species at the Bay -- permanent, winter, summer, migratory, etc.,? What is known of local population movements? Have censuses been made of Bay populations? For a number of years December (Christmas) birdcensuses have been made in the northern portion of the Bay. these are published in American Birds as the "Dade County Count". Do the birds breed at the Bay?, roost at the Bay?, feed at the Bay? What are the feeding strategies? What is the general diet? Have analyses of the diet been made in Biscayne Bay or at another subtropical estuary? What pertinent research has been achieved with the species and what is the nature of ongoing research?

It is with such basic information that this contribution is largely concerned. It is information basic to future work with ornithology or general ecology. The information will clearly indicate avenues for meaningful future investigation.

Birds of Biscayne Bay

Foraging strategies

Before inventory and discusion, it will be useful to categorize the taxa in terms of usage of the ecosystem, specifically the foraging opportunities presented by the Bay and its ecologically dependent surroundings. From this the diversity of the avifauna adapted to utilize the Bay's productivity is nicely apparent. The outline can also be utilized in construction of models for a variety of studies of the avifauna .

The Bay's birds forage within:

A. Open water of the Bay. Here are found:
   1. Birds that <u>swimming submerged</u> forage for:
      a. fish (birds such as cormorants and mergansers),
      b. invertebrates (cormorants and diving ducks),
      c. plants (coots, some diving ducks),
      d. animals and plants (coots and some diving ducks).
   2. Birds that <u>plunge to the surface</u> from flight and secure prey from upper inches of surface water. These forage chiefly for:
      a. fish (pelicans, ospreys, terns, kingfishers),
   3. Birds that "skim" the surface and forage for:
      a. fish and macroplanktonic invertebrates (skimmers).
   4. Birds that either pick up food from the air or land and swim to the food. These forage chiefly for:
      a. fish (eagles, gulls and frigatebirds),
      b. dead animals and animal refuse (gulls).
   5. Birds that forage from swimming positions at the surface and reach down to feed on objects at the substrate of shallow water. These forage upon:
      a. invertebrates ("dabbling" ducks and coots),
      b. plants (dabbling" ducks and coots).

B. Shallow perimeters of the Bay and its islands. Here are found:
   1. Birds with long legs, long necks, and long mandibles. These forage for:
      a. aquatic vertebrates (herons, spoonbills, etc.),
      b. invertebrates (herons, ibises, oystercatchers).

C. Shores and exposed tidal flats. Here forage:
   1. Birds that <u>pick</u> or <u>probe</u> for:
      a. invertebrates (plovers and sandpipers),
      b. dead organisms and refuse (vultures, gulls, grackles).

D. The forest floor beneath the mangroves. Foraged in by:
   1. Birds that walk (sometimes wade) for:
      a. invertebrates (rails and night-herons).

E. The mangrove forests (usually not the forest floor). These are foraged in by:
   1. Birds that glean the bark or penetrate twigs and trunks to feed upon:
      a. insects (woodpeckers, vireos, some warblers, etc.)
      b. sap (Yellow-bellied Sapsucker).
   2. Birds that forage within the canopy for:
      a. insects (cuckoos, vireos, warblers).

3. Birds that fly up from the canopy to "flycatch" above it. These forage for:
   a. insects (kingbirds and other flycatchers).
4. Birds that forage while in flight above the canopy. These forage for:
   a. insects (swallows).

F. All of the area within the Bay ecosystem. Such foragers are:
1. Predatory birds which forage upon:
   a. assemblages of birds or other animals (falcons, hawks, and owls),
   b. eggs and young at rookeries as well as food being carried to young by adults (frigatebirds).
2. Scavangers upon:
   a. dead animals, refuse, etc. (vultures and gulls).

Inventory of taxa

The species enumerated below do not constitute a complete inventory of the Bay's avifauna. Discussed are largely those now represented by sizable populations during some period of the year. Also included are species the occurrence of which can be regarded as ecologically significant aside from abundance: rare, threatened and endangered species I include in this category — these categories were assigned by the Florida Committee on Rare and Endangered Plants and Animals (1974). General information important to an ecologist's approach is included as are comments regarding needed information.

Gaviiformes: Gaviidae
Common Loon
Gavia immer

A winter resident of Florida's coastal waters, this piscivore is present in Biscayne Bay in small numbers. Large "kills" of the birds have occurred in Florida in recent years (e.g., Stevenson, 1971: 567). Causes of many of these remain unsolved. Fresh carcasses of loons and of other aquatic birds of the Bay should be transmitted to pollution control authorities; information of significance can be obtained from them.

Podicipediformes: Podicipedidae
Pied-billed Grebe
Podilymbus podiceps

Fresh-water areas of southern Florida are habitat of a breeding population of this grebe which nests when water levels are high (they build floating nests). Large numbers migrate into southern Florida in winter and grebes then become distributed in coastal waters as well as fresh. Thus on 22 December, 1974, 41 were observed (American Birds, 1975) about the Bay's north-central portion. Throughout the entire Bay many more were undoubtedly present.

Food of the grebes, which forage while submerged, in fresh-water consists of small fishes, crayfish, and insects (Howell, 1932). Stomach analyses from birds in marine habitats of Florida are needed. To what extent do the birds move between marine and fresh-water habitats? Whether post-breeding birds of south Florida's population move into estuarine habitats is not known.

Pelecaniformes: Pelecanidae
Brown Pelican
Pelecanus occidentalis

Since 1950 the breeding range of the eastern race (P. o. carolinensis) has contracted into peninsular Florida (Schreiber and Risebrough, 1972) and the subspecies is designated "endangered." The birds now do not apparently breed in Biscayne Bay (Williams and Martin, 1970). They are common however, throughout the Bay; 285 were counted in a portion of the Bay on 21 December, 1974 (American Birds, 1975). Any number is obviously important re the total population (estimated by Schreiber et al., 1973) now remaining in the state. Every effort should be made to determine the seasonal fluctuations and composition (adults: immatures) of the Bay's population. Areas important to roosting should be determined. Status of the birds at the Arsenicker Keys, where they once may have nested, should be monitored. Dependence upon man's activities (i.e., fish refuse for feeding and man-made structures for roosting should be determined). Levels of organochlorines, apparently responsible for the population's decline should be determined from fresh carcasses which may be found.

Pelecaniformes: Phalacrocoracidae
Double-crested Cormorant
Phalacrocorax auritus

This is one of the abundant piscivorous birds of the Bay where it is common virtually everywhere. The population is large throughout the year but it appears to increase in winter when migrants of the northeastern subspecies (P. a. auritus) join the local populations (P. a. floridanus). A specimen in the University of Miami Reference Collections (UMRC 6151) found unable to fly in Biscayne Bay in April 1970 had been banded as a nestling in June 1969 at Port Clyde, Maine. A December count of birds in the north-central portion of the bay totaled 779 birds (American Birds 1975); several times this number were undoubtedly present in the entire bay at this time.

Cormorants forage while submerged. Owre (1967) listed Opsanus beta, Bagre marina, Myrichthys acuminatus, and Sparisoma sp. from cormorants taken near Biscayne Bay; Scattergood (1950) listed Scomber scombrus and Mugil cephalus from stomachs of cormorants taken near Pensacola. These lists imply that the cormorants pursue some fish and forage at the bottom for others. The numbers of the birds in Biscayne Bay, if the diet here were known, could be used as indicators of the fish populations present.

Cormorants nest in the mangroves of West Arsenicker Key. Pierce (1962) described a rookery (he did not specify nesting) at Black Point in 1885 and another at the Arsenickers.

The hundreds of cormorants perched upon pilings and other dock-side structures are attractive sights. Along with the pelicans they are an important part of the picturesque fauna of the bay.

Pelecaniformes: Fregatidae
Magnificent Frigatebird
Fregata magnificens

In 1885 Pierce (1962) observed frigatebirds in north Biscayne Bay and found them roosting near the Arsenicker Keys. These portions of the bay are still frequented by the birds, particularly in spring and summer. At these times herons and ibises are nesting at the Arsenickers. I counted more than 100 frigatebirds about this rookery in early summer 1975. The frigatebirds, which roost in mangroves of the coastal fringe and nearby islets, are attracted by opportunities to rob adult herons of food they are carrying to their young; eggs and small nestlings may be taken as well. Frigatebirds also seize flying-fish and pick up other marine organisms from the water's surface (Bent 1922).

Their long, forked tails, seven-foot wing-spans, and peerless aerial maneouverings place these birds among the most picturesque of any avifauna and the bird-watching tourist in southern Florida has such pan-tropical birds high on the list of species to see.

Regarded as a "threatened" species, much needs to be learned about birds of the local population. Careful inventory should be made of the bay's birds.

Ciconiiformes: Ardeidae
Herons and Egrets

Ten species (there are two color morphs of two of these) are of importance about the bay:

Great Blue Heron (Ardea herodias) The white morph or color phase of this species is known as the "Great White Heron" and was until recently accorded specific distinction as Ardea occidentalis (See A.O.U. 1973).

Green Heron (Butorides virescens)

Little Blue Heron (Florida caerulea)

Cattle Egret (Bubulcus ibis)

Reddish Egret (Dichromanassa rufescens) Reddish and white morphs or color phases are found.

Great Egret (Casmerodius albus)

Snowy Egret (Egretta thula)

Louisiana Heron (Hydranassa tricolor)

Black-crowned Night Heron (Nycticorax nycticorax)

Yellow-crowned Night Heron (Nyctanassa violacea)

Only two of these are essentially non-piscivorous. The Cattle Egret, which has colonized Florida since 1950, is probably the most abundant ardeid in the world. It now breeds in large numbers at West Arsenicker Key (several thousand nests in 1975) and on mangrove islets in Greynolds Park (these mangroves are a part of the bay ecosystem). Largely insectivorous, the egrets fly inland to fields and open areas to feed. This species has reversed the usual pattern of ciconiiforms removing estuarine productivity through distributing excreta away from the bay. Browder (1973) analysed stomachs of more than 100 Cattle Egrets from southern Florida.

Yellow-crowned Night Herons, a species of "special concern", are at the bay essentially birds of the mangroves where they feed to a large extent upon crustaceans and molluscs. They probably nest solitarily in the bay's mangroves; they join the mixed species assemblage of ardeids nesting at the Arsenicker Keys.

Black-crowned Night Herons are less abundant about the bay than the preceeding species and, at least inland, their diet includes fish to a considerable extent (Howell 1932). They may breed sparingly about the bay.

The remaining herons are largely piscivorous and occur at the bay in varying abundance. Robertson and Kushlan (1974: 427) summarized the seasonal movements of the species in southern Florida. Migrations from outside the state and intra-peninsular population shifts are noteworthy. The species employ different strategies in foraging (Kushlan 1976) and the spectrum of prey taken is great. Foraging is virtually throughout the bay ecosystem: shallow shorelines, within as well as bayward of the mangroves; along canals penetrating the bay's perimeters; along tidal creeks; at the shorelines of causeways; and about the extensive tidal flats. Important feeding areas exist in the landward swamps which receive fresh-water runoff from the interior (see Wanless 1974: 191). Where the coastal mangrove swamp gives way to dwarf red mangrove swamp and/or fresh-water swamp, ciconiiforms gather to feed. Robertson identified the bight between Old Rhodes and Totten Key as an important feeding area of some ciconiiforms.

Although Heald et al. (1974: 184,185) commented on the volume of mangrove productivity wading birds consume, there are no actual figures for such that I am aware of and in making their estimates a non-ardeid, the Wood Stork (Mycteria americana) was used as a base-line. Data used for this bird were gathered at inland fresh-water situations.

At this time we are not certain of the main feeding areas of the ardeids from the Greynolds Park breeding rookery of Little Blue Herons, Snowy Egrets, Cattle Egrets, and others (J. King pers. comm.). Nor do we know the main feeding areas of the Arsenicker Key breeding birds. Flights of these birds should be tracked to and from their rookeries. Special consideration or "immunity" from development should be accorded prime feeding areas.

Two herons merit special comment. The Reddish Egret and the white morph ("Great White Heron") of the Great Blue Heron are "threatened" and "rare" respectively. The most northerly breeding locality on the Atlantic Coast of the latter is at the Arsenickers (Robertson 1964). The species increases in abundance southward along the Florida Keys. The former probably breeds at the Arsenickers (adults flushed from the breeding colony in summer 1975) and probably (Robertson 1964) at Islandia. Rich Paul (pers. comm.), under auspices of the National Audubon Society, is currently studying the species in Florida and elsewhere. Important information can usually be gained from study of species at the periphery of their ranges which in these cases are, in part, in Biscayne Bay.

Ciconiiformes: Ciconiidae
Wood Stork
Mycteria americana

The Wood Stork an "endangered" species, enters the bay at times. The ecology of the species has been investigated by Kahl (1964) and others are conducting ongoing studies of this stork which nests in mangrove areas elsewhere in southern Florida and at inland points. In recent years only small numbers of the birds have fed seasonally in the bay.

Ciconiiformes: Threskiornithidae
White Ibis
Eudocimus albus

There are coastal breeding colonies of this species and some birds from the much larger inland breeding colonies apparently move to the coast after breeding (Kushlan 1974). West Arsenicker Key, by my counts, contained well more than 1,000 ibises in the spring of 1975, most of them nesting. On certain days outflights of ibises from the rookery proceeded north along the west side of the bay to at least Fender and Black Points before being lost to view. Thus the bay appears to afford this breeding colony foraging areas. The birds also breed at Greynolds Park; it is not clear where these forage.

Kushlan (loc. cit.) found that at coastal areas quite different food was taken than at inland habitats. His estimates of the energy requirements of the birds provide information pertinent to birds of south Florida estuaries. Major feeding areas of breeding birds of the bay and of those entering the bay at other times of the year need to be determined. Population censuses within the bay are needed.

Ciconiiformes: Threskiornithidae
Roseate Spoonbill
Ajaia ajaja

This "threatened" species occurs with some regularity about the bay. There are apparently no recent records of nesting anywhere within the bay's perimeters. Allen's (1942) extensive study of the species provides information important to any considerations of the ecology of mangrove swamps. Ongoing study of the birds in Florida Bay is being conducted by J. Ogden of the National Audubon Society.

Anseriformes: Anatidae
Ducks

Species of waterfowl visiting the bay seasonally, chiefly in winter, are too numerous to enumerate. These are largely migrants from northern states and Canada, although the Mottled Duck, Anas fulvigula, which breeds in largely fresh water of southern Florida, enters the bay at times. Numbers of ducks in the bay today are much reduced, as are duck populations throughout the continent. Pertinent to reductions of species wintering in Biscayne Bay are, presumably, those factors enumerated by Lindall (1973) as threatening fish resources of southern Florida: reduction of fresh-water runoff into the estuaries, pollution, pesticides, thermal addition, and dredging and filling activities. Human traffic in and about the bay must also be a deterrent.

That the Lesser Scaup (Aythya affinis) was formerly "the most abundant species of duck in winter and spring" is indicated by Howell's (1932: 149) quoted account from 1910 of flocks in the upper end of Biscayne Bay "sometimes two or three miles long" numbering "tens of thousands." In 1973 and 1974 censuses in roughly the same area recorded, respectively, 182 and 12 individuals (American Birds 1974, 1975). Lesser Scaups consume plant and animal food in about equal quantity (Kortright 1942). They dive when foraging, securing food while beneath the surface.

The Red-breasted Merganser (Mergus serrator), a piscivore foraging while submerged, is seldom hunted. It frequents shallow bays and estuaries of Florida in winter. Probably never abundant as the Lesser Scaup was, the birds are a noticable part of the bay's avifauna. In December 1974, 160 were tallied within a portion of the north-central part of the bay (American Birds 1975).

Falconiformes: Cathartidae
Turkey Vulture
Cathartes aura

Concentrations of these vultures about the bay have increased as the city has grown. In 1973 a December census of birds within a circle 15 miles in diameter, including both urban areas and the bay, tallied 1,200 Turkey Vultures (American Birds 1974). This is probably only a portion of the total present at that time. The concentrations are largely seasonal. Numbers increase in fall and winter, presumably from birds migrating to the city from north of the state and possibly from intra-peninsular populations. The vultures forage at garbage dumps, sewage disposal areas, and incinerators. They also search the bay's shorelines where they glean refuse, animal wastes, etc. Along with gulls and some additional scavengers, these birds are subsidized by man and their concentrations have grown in correlation with man's activities. They are a conspicuous sight about the bay, roosting on the ground or in trees wherever suitable areas are found; until Burlingame Island, at the mouth of the Miami River, was "improved" hundreds of the birds roosted there. Their actual importance, in terms of the bay's productivity, seems largely incidental.

Falconiformes: Accipitridae
Bald Eagle
Haliaetus leucocephalus

To considerable extent piscivorous, the Bald Eagle is an apex of the organochlorine, heavy metal residue-concentrating food chain of aquatic animals (Krantz et al. 1970). This, along with habitat change and illegal shooting, has resulted in substantial reductions of the eagle's populations in eastern United States (Braun et al. 1975). Numbers still breed in peninsular Florida and Florida Bay. An eyrie existed in Biscayne Bay near Bear Cut in 1959-1960 (W.B. Robertson, Jr., pers. comm.), another south of Tahiti Beach in the fifties and early sixties, and in 1974-1975 breeding was attempted near Cutler. Eagles continue to frequent the bay. These are, presumably, birds from nearby areas in Florida; some may be migrants from elsewhere. The unhappy status of our national emblem was well described by Zimmerman (1976). Every effort should be undertaken to protect the bay's eagles from molestation and to insure suitable habitat for foraging, roosting, and possible future nesting.

Falconiformes: Pandionidae
Osprey
Pandion haliaetus

A fish-eating raptor, the Osprey has also been severly reduced in numbers over much of the United

States and is now "endangered". The population in southern Florida, however, has remained relatively stable (Henny and Ogden 1970). Ospreys still nest at points within Islandia (Robertson 1964) and elsewhere about the bay. The population apparently increases in winter as migrants arrive.

As with the eagles, every effort is needed to preserve suitable habitat for the birds. Protected zones should be maintained about nests, nesting success should be determined and populations of the birds about the bay should be carefully monitored.

Falconiformes: Accipitridae, Falconidae
Hawks and falcons

Mangrove forests attract a variety of hawks and falcons. Attention is well directed to some of these.

The Red-shouldered Hawk (_Buteo lineatus_), a permanent resident, is ubiquitous in southern Florida. More characteristic of inland habitats, it nevertheless ranges into the mangroves where it forages, roosts, and may nest. In the mangroves it preys upon a variety of reptiles, mammals, birds, etc. which are part of the ecosystem's food web.

The Short-tailed Hawk (_Buteo brachyurus_), an extremely rare bird in Florida, hunts and sometimes nests in mangrove forests. It preys largely upon small birds, foraging along forest edges (Ogden 1974: 97). In southern Florida the species becomes more numerous in winter, its population apparently contracting southward in the peninsula (Ogden _op. cit._). I have seen individuals in mangroves at the southern end of the bay and Robertson (1964) suggested that it might nest in Islandia.

Merlins (_Falco columbarius_) migrate through southern Florida and some winter here. Individuals frequent the mangroves where they hunt small birds and insects. In spring, merlins perch atop mangroves where they intercept small birds in migration making their way in from the ocean towards landfall.

Gruiformes: Rallidae
Clapper Rail
Rallus longirostris

This rail is restricted to salt marshes or marine swamp-forests. Three subspecies have been described from Florida's coastline. _R. l. scotti_ is distributed from Pensacola along the southern tip of the peninsula (excepting the Florida Keys) and northward through Biscayne Bay (Howell 1932). The loud, harsh calls of this secretive bird are frequently the only evidence of its presence within the mangrove forests. Arthropods and molluscs are among the food items it takes from about the mangrove roots. Little is known about its niche within this habitat. Because of the ongoing destruction and alteration of mangrove habitats, there is concern for the population.

Gruiformes: Rallidae
American Coot
Fulica americana

Coots, largely winter residents in southern Florida, congregate in fresh, brackish, or sheltered marine waters. They often become abundant locally and flocks exceeding 1,000 are not unusual. During the December 1974 census about portions of the northern one-half of the bay, 1,401 were counted (American Birds 1975). Omnivorous, coots forage along shorelines while afoot, dabble for food while swimming at the surface, and dive to procure food and will move distances while submerged. A variety of plants and animals is consumed. Large concentrations of the birds effect considerable impact on an aquatic ecosystem. Information, which could be easily gained, since the birds are tractable in captivity, as to their bioenergetics in a subtropical estuary is apparently lacking.

Charadriiformes: Charadriidae
Plovers

Short-legged, running birds, plovers range the tidal flats and beaches of the bay. With relatively short, stout bills, they pick up food from the substrate, securing a great variety of littoral invertebrates.

Common within the bay are: the Semipalmaled Plover (_Charadrius semipalmatus_) found on mud flats and along shorelines as a migrant and wintering bird; Wilson's Plover (_Charadrius wilsonia_), is present at all seasons and breeds sparingly; its nest is a "scrape' in the sand above high tide lines; the Black-bellied Plover (_Pluvialis squatarola_), a conspicuous bird along shorelines and tidal flats, migrates to breed on the arctic tundra.

Charadriiformes: Scolopacidae
Sandpipers, yellowlegs,
turnstones, sanderlings, etc.

More than 20 species of this much diversified family of littoral-inhabiting birds may be looked for within the bay. These range in total length from about 140 mm in the smallest species to more than 500 mm in the largest. Bills of the smallest are about 16 mm in length, of the largest as much as 180 mm. The species can, therefore, reach into varying depths of water and substrate, many of them probing for food. The birds exhibit a variety of feeding techniques (Baker and Baker 1973) which further define their species-specific niches. The scolopacids, along with other charadriiform taxa, exploit a wide littoral environment (see, e.g. Hall 1960). Enumeration of some of the species at the bay will emphasize this.

Willets Catoptrophorus semipalmatus inhabit coastwise marshes and protected shallow water. They winter in some numbers within the bay; some breed in coastal areas elsewhere in southern Florida on certain keys in Florida Bay. Medium-sized (about 380 mm in length and with bills 50 mm long) willets wade while feeding and take a variety of crabs (Uca, Sesarme), other arthropods, molluscs, small fish, etc.

Ruddy Turnstones (Arenaria interpres) are abundant, except in summer, along the bay's intertidal areas. Flocks of the birds, moving along the shorelines, glean marine invertebrates and their eggs and larvae, from beneath stones, shells, seaweed, etc., which the birds overturn with their bills.

The Sanderling (Crocethia alba), its nesting in the arctic completed, migrates southward over littoral areas of the world. Compact flocks hurry along the beaches and exposed flats of Biscayne Bay gleaning invertebrates exposed by receding waves.

Dowitchers (Limnodromus spp.) winter in southern Florida. Their long bills (bills about 75 mm, bodies about 285 mm in total length) enable them to probe deeply for a variety of invertebrates.

Charadriiformes: Laridae: Larinae
Gulls

The Laughing Gull (Larus atricilla) breeds locally and occurs in large numbers in Biscayne Bay in winter. In portions of the upper one-half of the bay, 6,384 were tallied on 21 December 1974 (American Birds 1975). In winter the Ring-billed Gull (Larus delawarensis) migrates south into Florida and its numbers in the bay become considerable (from the same count as above, 4,972). Small numbers of Herring Gulls (Larus argentatus) and Bonaparte's Gulls (Larus philadelphia) also winter about the bay.

It is chiefly the Laughing and Ring-billed gulls that form the very large wintering assemblages of gulls in and about Biscayne Bay. In January 1973 I estimated that no fewer than 70,000 gulls were present. These roost at night on mud flats and spoil islands (where they are immune from approach by terrestrial predators). The birds feed throughout the bay as well as its urban surroundings. The sizes of the flocks of these birds at their inflighting and outflighting over the bay while en route to and from their roosts cause no little comment. The gull "traffic" over the area, especially at Miami International Airport and in its vicinity and the presence of the birds at the airport where they come to scavenge and rest and sun in the open areas of the field, create serious problems for aircraft operation.

Wintering gull populations can be controlled to some extent by elimination or alteration of spoil islands and other man-made areas where the birds roost. Relocating garbage and refuse dumps where the birds gather to feed or employing different methods of disposal of this refuse will also be effective. These are the primary attractions for the birds.

It is obvious that the bay's productivity is not the important factor attracting this large segment of its associated fauna. Scavengers, the gulls have discovered superabundant food supplies. Their adaptations to aquatic environments, in particular their roosting requirements, and the proximity of food, albeit of non-aquatic origin, have concentrated their population at the bay. The guano deposited at the bay by this extremely large number of roosting birds must be considerable indeed. As with the Cattle Egrets, the usual process of birds distributing their excreta inland, the bay thus loosing a part of its productivity, has been reversed here.

Charadriiformes: Laridae: Sterninae
Terns

Terns, primarily piscivorous and plunging to the surface for prey, are represented at the bay by at least 7 species (some of them in categories of concern), that appear, at least seasonally, in numbers. Two are considered here.

The Least Tern (Sterna albifrons) migrates from South America and breeds within littoral areas along coastlines and riverine systems of the United States. Colonial in nesting, the birds seek open areas of high beach for their scrapes. Increasingly in south Florida freshly bull-dozed sandy areas, land fills, spoil islands, etc. present the only habitat for nesting. At one time the birds nested abundantly along the dredged up right-of-way of Biscayne and other causeways and on the increasing areas of land fills. Growing human populations have seriously interferred with Least Tern colonies. The species is now considered "threatened".

Unusual nesting sites of these terns were first reported about 15 years ago. At the present time "roof-nesting" is well-established and numbers of locations of such within the urban surroundings of Biscayne Bay are known (Fisk 1975). These birds continue to forage in bay habitats. There has been, thus, the unusual situation of a species maintaining its dependence upon the bay's productivity for food, but shifting its nesting habitat away from the marine littoral.

The Royal Tern (Thalasseus maximus), now a species of "special concern", no longer breeds in Florida (Kushlan and Robertson 1974); it remains, however, common about the marine littoral and is variously abundant in Biscayne Bay throughout the year. Foraging carries many well beyond the bay to the ocean littoral. Many roost on spoil islands, flats, and exposed areas within the bay. Those birds which return to the bay from the ocean are, through their excrement, enriching the bay from the ocean itself. They are, of course, not the only species to do so. A great many of the fish-eating and invertebrate-devouring species forage to some extent along or offshore the coast and seek protected sites within the bay for roosting.

Charadriiformes: Rynchopidae
Skimmers

The Black Skimmer (Rynchops nigra), a species of "special concern", exploits the bay's productivity in winter when its numbers may reach several hundred, possibly 1,000 or more. It forages from flight with its lower mandible partly immersed, the bill snapping shut on contact with fish and invertebrate prey. Largely crepuscular and nocturnal, the skimmers roost by day on spoil islands, tidal flats, and other open spaces.

Cuckoos, nighthawks,
kingfishers, and woodpeckers

These species, of diverse taxa, exploit the mangroves or their immediate vicinity.

The Mangrove Cuckoo (CUCULIFORMES: CUCULIDAE: Coccyzus minor) is as certain other birds to be discussed, a species evidently in current colonization of southern Florida. Its range is still largely that of the mangrove forest (to an increasing extent inland of this) where it is present all year. Its diet, as with most cuckoos, probably emphasizes caterpillars. Close study of its diet would be of interest with respect to the mangrove food chains involving insects.

The Common Nighthawk (Chordeiles minor) winters in South America, returning to breed in this continent. Crepuscular and nocturnal, the birds forage awing. During the nesting season much foraging is accomplished about the mangroves where flying insects, which are abundant at this time of year, are taken.

The Belted Kingfisher (CORACIIFORMES: ALCEDINIDAE: Megaceryle alcyon), solitary when not breeding, defends stretches of tree and shrub-bordered marine and fresh-water habitats. From its perches, or from hovering flight nearby, the birds plunge to the surface for fish.

Two of the several species of south Florida's woodpeckers utilize the mangrove forests. The Red-bellied Woodpecker (PICIFORMES: PICIDAE: Centurus carolinus) is widespread in Florida. About Biscayne Bay it is commonly seen in the mangroves both of the coastlines and on nearby islets. It forages, in part at least, for tree-frequenting invertebrates found on bark and within the wood of trunks and twigs. At least two species of termites, Prorhinotermes simplex and Kalotermes jouteli, occur commonly in the mangroves (Banks and Snyder 1920) and are no doubt among food sought by these woodpeckers. The Yellow-bellied Sapsucker (Sphyrapicus varius) is a winter resident in southern Florida. The birds drill rows of small holes in the bark of twigs and trunks and visit these sap "wells" regularly to drink the accumulated sap. While sapsuckers are most frequent in upland situations, that they also forage in mangroves is indicated by the numerous trees which bear "scars" of the bird's activities. This is an unusual ramification of the mangrove food chain.

Passeriformes
Passerine birds

To most people these are the familiar birds of the landscape, the songbirds of city parks and yards. Where urban areas extend to the bay, these birds become bayside dwellers and are, to an extent, subject to certain influences of the bay. The Passeriformes to be emphasized in this discussion are those which under natural conditions are obvious parts of the food web of the bay. They are, with a few exceptions, conveniently discussed as groups and in very general manner.

The migrants which in spring and fall pass along the peninsula often rest and feed in extraordinarily large numbers in the mangroves and other coastwise vegetation. Anyone in spring who has witnessed the flocks of warblers (PARULIDAE) flying landward from the open sea appreciates the importance of coastal forests in affording both shelter and food to migrating birds. Such birds inhabit, at different seasons, different land masses and continents of the hemisphere. A portion of the bay's productivity, then, supports population movements of insectivorous birds, as well as those dependent upon fish and aquatic invertebrates, to and from Florida. In addition to warblers, vireos (VIREONIDAE), tanagers (THRAUPIDAE), finches (FRINGILLIDAE), and species of additional families may enter or depart southern Florida via the mangroves. Swallows (HIRUNDINIDAE) fly Florida's peninsular route to and from South America in large numbers. They forage awing across the air space above the bay and the mangrove forests, feeding while passing, upon flying insects.

Certain passerines are resident seasonally within the mangroves fringing the bay. Small numbers of some parulid warblers may winter here. Other passerines breed within the forests fringing the bay. The Red-winged Blackbird (ICTERIDAE: Agelaius phoeniceus), flocks of which forage about the mangroves as well as inland of them in winter, breeds in considerable numbers in marshes and dwarf red mangrove areas adjacent to the bay-fringing trees. Breeding is apparently geared to the spring-summer "blooms" of insect life about the coastal mangrove areas. A subspecies of the Prairie Warbler (Dendroica discolor paludicola) is one of the characteristic birds of mangrove areas of southern Florida, its song being heard wherever there are extensive stands of mangroves about Biscayne Bay.

Some passerines, all of which in Florida are more or less restricted to the mangroves, are regarded as relatively recent colonizers of southern Florida from West Indian areas. These are of more than ordinary interest to the ornithologist. Because their habitat is a restricted one that is being rapidly modified, the birds are of concern. The Gray Kingbird (TYRANNIDAE: Tyrannus dominicensis), a summer resident, is as the following species probably a recent colonizer (Robertson and Kushlan 1974: 443). The species is extending its range inland, particularly into ecologically "disturbed" areas. It feeds largely upon flying insects it detects and flies for from perches about the coastal mangroves. The Black-whiskered Vireo (Vireo altiloquus) is moving northward coastwise in Florida. A summer resident, it too is found nesting in mangroves. Little is known of the invertebrates it forages for within the canopy. The West Indian subspecies of the Yellow Warbler (Dendroica petechia gundlachi) was first observed more than 30 years ago (Greene 1946: 255) in mangroves of the lower Florida Keys. Its northward spread has brought it to the mangroves of the Arsenicker Keys and the mainland of Card Sound where I encountered singing birds in spring 1975. A canopy-feeder of small invertebrates, it can be expected to breed in mangrove areas northward along Biscayne Bay.

SUGGESTIONS FOR RESEARCH WITH THE BISCAYNE BAY AVIFAUNA

Suggestions fall into a number of easily outlined categories: First, a year-long monthly census by overflight of the bay with respect to a.) the megavifauna and b.) the locations of feeding, roosting, and breeding concentrations of these megavifauna should be undertaken.

Second, a study should be implemented to locate the feeding areas of the Ciconiiformes from the breeding rookeries at Greynolds Park and the Arsenicker Keys.

Third, a year long census of the Charadriiformes (Charadrii) should be undertaken on a monthly basis. This can be carried out by visiting concentrations of these populations by foot, car and/or boat. While it would be impossible to achieve a complete census of these birds, enough could be sampled to allow meaningful estimates of the total populations.

Fourth, a judicious sampling on a monthly basis should be undertaken of populations of certain abundant species of the bay. If ten samples per month were taken of species such as cormorants, coots, and a medium-sized heron, the following analysis should be made: a.) stomach contents; b.) pesticide levels; c.) subspecies they represent if there are more than one subspecies of this bird in the bay; d.) breeding condition and fat deposit. The specimens should then be wet preserved and deposited in a recognized institutional collection for future reference.

Fifth, life history work should be undertaken with one or more of the passerine species that breed in the mangroves.

Sixth, bioenergetic studies of one or more of the estuarine species should be undertaken. Double-crested Cormorants are easily kept in laboratory conditions (DeLaRonde et al. 1972) and certain base-line data have already been gathered for these birds (Dunn 1975). Coots would, presumably, be appropriate birds for such study. Additional species which might be selected should represent taxa with widely different feeding strategies and diet.

DISCUSSION

Little has been presented here with respect to Biscayne Bay's avifauna as it must have been before Dade County's urban communities grew up about it. Obviously, drastic changes in the water and general flora and fauna of the bay, destruction of much of the fringing mangrove forests, and drainage of the peninsula's interior wetlands - from which populations of aquatic birds moved back and forth to coastal waters - have resulted in enormous changes in the bay's bird populations. The numbers of endangered, threatened, and rare species of birds cited in the preceding inventory attest to these changes. The ecologist can address himself to the changes by gaining information adequate to 1) acquiring knowledge basic to understanding the requirements of rare as well as more abundant species, and 2) being in a position to recommend planning which may encourage a response by the species.

It is patent that many of the endangered and threatened species are primarily piscivores (Brown Pelican, Bald Eagle, Osprey). At the same time other piscivores of the bay (Double-crested Cormorant, Red-breasted Merganser, etc.) have not declined drastically. Careful monitoring of these populations and study of the species' diets will be worthwhile.

It is noteworthy that not all the birds at the bay are decreasing in population. Populations of some wintering gulls have probably increased significantly. At least one species now present, the Cattle Egret, was not a part of the avifauna of even thirty years ago. These bring a new dimension to the avifauna one, as would be expected, intimately associated with human activity. It will be of interest to estimate what addition to the bay's productivity excrement of the large populations of the species may have brought about.

We can now certainly foresee a threshold in management of some of the bay's bird populations. Areas where species held to undesirable congregate to roost and feed can be altered. Conditions required for successful breeding - such as with the threatened Least Tern - can, if we so determine, be created and protected.

High on the list of priorities is action re: the shrinking mangrove fringes of the bay. These (as for that matter the whole bay) lie virtually within the metropolitan area and, conveniently reached, can be a laboratory of meaningful research for the many biologists of nearby institutions.

From an ornithologist's point of view, we face, in a sense, a dilemma circular in nature. We lack a tremendous amount of basic ecological information about Biscayne Bay's birds. Much of this information we can never gain unless the ongoing degredation of the bay is somehow deaccelerated. But until we have our basic information it is hard to make recommendations regarding planning for the bay. Preventing as little alteration of the bay as possible, will, for the moment, buy some time in which to get on with our ecological studies.

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ECOLOGY AND THE FOOD WEB OF BISCAYNE BAY

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ABSTRACT

A review of the knowledge concerning the ecology and food-web relationships in Biscayne Bay reveals that relatively few studies describe the interactions between organisms and their environment.

Biscayne Bay is highly productive, with 43.8% of the bay bottom being covered with nutrient-contributing seagrasses. Other forms of primary production, as well as the detrital input from the fringing mangroves, also contribute to a broad base for higher level consumers such as game fishes, as well as valuable commercial crustacean species, including stone crab (Menippe mercenaria) and pink shrimp (Penaeus spp.).

Using the available reservoir of scientific information, it may be possible to analyze the Biscayne Bay ecosystem, with some additonal work needed in various specified areas of study, provided the investigators emphasize quantitative results within a given period of time.

INTRODUCTION

This paper evaluates the knowledge of the ecology and food-web relationships of Biscayne Bay to permit subsequent synthesis and integration and to identify the gaps that must be filled. Like many natural areas adjacent to scientific institutions, Biscayne Bay has received considerable study by many marine scientists from a variety of allied fields of interest resulting in numerous professional publications. In fact much of our knowledge of marine organisms from the southeastern, subtropical U.S. has been generated by the scientists at the Rosenstiel School of Marine and Atmospheric Science. Its professional reputation is well known. Times do change, however, and public goals have swiftly evolved toward a redressment of sundry environmental ills which have accompanied an expanding economy and improving standard of living. In this process, many scientists in our community, Dade County, have applied their knowledge and unique skills toward resolving environmental dilemmas, and their contributions are acknowledged. Now, however, the individual scientist can no longer provide useful answers to questions relating to the management and utilization of a natural resource as large and ecologically complex as is Biscayne Bay. A research plan is needed which, like all plans, must be based on working knowledge of what is known as a base for directed research, and the setting of priorities in that endeavor. The inventory of knowledge presented here on the ecology and food-web relationships of Biscayne Bay is directed toward that purpose. In evaluating this inventory, it is not the purpose nor is it feasible to prepare a complete synthesis and review of the very large and detailed data and information base. This must follow. This inventory of knowledge points to the data and information available and calls attention to the missing links which must be closed for its maximum utilization. It is a plan for Dade County citizens to initiate and Dade County scientists to implement.

Biscayne Bay is a single ecosystem in the sense that each of the defined parts is coupled to, and dependent upon, all other parts. This coupling occurs through the perpetual circulation of waters, the movements of marine organisms, and the waste products from Dade County which find their way to the water's edge, thence travelling toward the Gulf Stream. Through flows of detrital materials from the intertidal marshlands and through the varied interactions of man, the bay is also closely coupled to the terrestrial landscape (Snedaker and Fell, 1975).

To understand the trophic structure of Biscayne Bay it is necessary to know how much organic matter is available for use by marine consumers, not in isolated parts of the bay, but in the whole bay itself. This means that measurements of the gross primary production and the quantity of detrital import must be available for use. Presently, too few studies provide an accurate estimate, but available data strongly suggest that Biscayne Bay is a highly productive lagoonal ecosystem.

The energy in the organic matter products of photosynthesis results from a variety of plant producers. Within the bay, there are the submerged macroalgae and the seagrasses of the benthic communities, the free-floating phytoplankton of the water, and many kinds of photosynthetic smaller organisms such as bacteria. From Government Cut to the Card Sound Bridge the seagrass beds comprise some 65,700 acres (26,600 ha) or some 43.8% of the bay bottom (Roessler et al., in press). Substrate occupied by producers in lesser abundance, and devoid of any producers except benthic microalgae due to hard bottoms, mud, and relatively swift tidal currents, occupy the remaining 56.2%. While the community productivity of the algal beds is not known, the productivity of the seagrasses demonstrates the significant role that the benthic communities serve in providing energy for marine consumers. A mean value for <u>Thalassia</u> (turtle grass) of 1.4gC/m^2/day (from Thorhaug and Stearns, in press, and Zieman, 1970), multiplied by the corresponding acreage, results in an aggregate annual production of 13,970 metric tons per year.

Biscayne Bay behaves as a steady-state system in that the total inputs of organic matter do not differ significantly from its output through consumption by consumers at all levels. From the seagrasses alone, some 14,000 metric tons of organic matter are available for secondary production to fisheries. Assuming 10% is converted into fish protein, then these beds may account for an annual yield of 1,400 metric tons of finfish, shellfish, and crustaceans. However, the seagrasses are a fraction of Biscayne Bay, and the other areas also contribute to this estimate.

An estimate for the microalgal productivity of the sediments (1gC/m^2/day) by Bunt et al. (1972) is only slightly less than that of the seagrasses. Clearly, the total photosynthetic capacity of all these components of the community is a crucial base for the marine food webs of the bay. Concentrations of chlorophyll are patchy, but based on the pigment to carbon assimilation of Bunt et al. (op. cit.) productivity from this source is then 0.22gC/m^2/day. The epiphytes of <u>Thalassia</u> were estimated by Jones (1968) to have a productivity of 20% of the seagrass which is equivalent to an additional 0.28gC/m^2/day. These figures show the broad primary productivity base of the food web of Biscayne Bay.

These measures and estimates of primary production and secondary production must not be confused with measures of the net yield of fisheries that might be available for sport or commercial harvesting. Just as a mature climax forest has a high productivity, the energy assimilated in photosynthesis maintains the structure of the forest, diversity of plant and animal species, and its complex functioning; little remains to be called a yield. However, a "yield" to man does occur in aesthetics and panorama and the subtle ways in which that system purifies our water and air and buffers man against his own environmental mistakes. Biscayne Bay, quite possibly, is such an ecosystem, providing many services contributing to our physical and aesthetic senses of well-being without being noted for a large net yield of marine life. Measures of gross primary productivity tell us how much unseen work is being done by Biscayne Bay irrespective of its yield of sport or commercial fisheries.

FOOD WEB OF BISCAYNE BAY

The energy available in the organic products of photosynthesis may follow any of several different pathways, leading ultimately to use by a multitude of different kinds of organisms and its subsequent dissipation in respiratory metabolism. For instance, some organic production of Biscayne Bay may be exported to the Gulf Stream and used by "blue-water" animals. Another fraction may enter directly into decomposer chains powering the activities of those tiny organisms which regenerate the mineral nutrients needed by the primary producers, and in doing so perform many kinds of biochemical work for the ecosystem which are only now being documented. Still another fraction may be utilized by herbivorous marine organisms which are themselves a food resource for the various carnivores and omnivores. One of the most pertinent questions that one could ask about any ecosystem, and one that is supremely important for Biscayne Bay, is how does this system allocate its gross primary production among the many kinds of users? How does one system select for one spectrum of species and another, almost similar system, reveal a different spectrum of species? The following evaluation of knowledge reveals that a base exists for answering these questions, but much work remains to be done in developing a framework for integrating what is known and what additional information is needed.

It was stated earlier that to prepare a synthesis from the work and inventory already described was not feasible. However, before searching out those areas of information which require intensive study to move from a descriptive to a quantitative data base, some definitions are necessary. For example, if the reference to "food web" means studies of the interaction, both qualitative and quantitative, among the trophic levels of the Biscayne Bay ecosystem, then research efforts with this problem as an objective have not been numerous. This is not a criticism of this university whose marine facility was opened in 1943, but is symptomatic of two general problems in ecological studies. First, the holistic, or total ecosystem, approach to ecosystem analysis of any marine area, except the open ocean, is a recent concept, requiring an integrated approach of all disciplines. The second is a natural corollary: the money required to finance such an approach is far greater than that for biological investigations of individual organisms or of assemblages of organisms which may be a part of that system.

The literature on Biscayne Bay contains detailed and ecological studies of numerous animals and plants of the bay, with Dr. Hilary B. Moore and his students having examined 44 animal and 5 plant species (Tabb and Iversen, 1971). With certain important exceptions, most invertebrate and vertebrate species found in the bay have been identified. The notable exceptions are the polychaetes and the peracaridean crustaceans (amphipods, isopods, tanaids, mysids, and cumaceans) which have been shown to be important links between trophic levels (Fenchel, 1970; Heald, 1969; Odum, 1970; Brook, 1975).

Many general ecological surveys of the area show the diversity of animal and plant species. Smith et al. (1950) conducted a survey of the inshore waters adjacent to Miami. Voss and Voss (1955) studied the Soldier Key area. South Biscayne Bay in the vicinity of Turkey Point was examined by Iversen (1969). Voss et al. (1969) reported on the ecology of the proposed Biscayne National Monument. The ecology and distribution of postlarval fishes in southern Biscayne Bay were studied by de Sylva (1970).

Another group of studies was stimulated by the effects of pollution. McNulty (1955, et seq.) wrote on the impact of sewage pollution on the bottom communities of northern Biscayne Bay. However, the largest body of information was probably generated by the possible effects of thermal pollution in south Biscayne Bay resulting from the location of a power plant with conventional and nuclear capacity at Turkey Point (Bader, 1969; Bader and Roessler, 1971, 1972; Bader and Tabb, 1970). These studies were funded by the Atomic Energy Commission and the Florida Power and Light Company. Most recently, Roessler and Beardsley (1974) discussed the environment and problems of the bay and provided a review of the most recent studies.

If this literature is examined for studies at the community level, which is a necessary base for synthesis, then it is obvious that only a limited number of studies have been made. Mills' (1969) definition states that a community is a group of organisms occurring in a particular environment, presumably interacting with each other and the environment, and separable from other groups by means of ecological survey. McNulty et al. (1962a, b) discussed the benthic community in relation to other benthic organisms and the sediments. Moore et al. (1968) examined the biomass of certain invertebrates in the flats near the Miami Seaquarium on Virginia Key. O'Gower and Wacasey (1967) studied the animal communities associated with *Thalassia*, *Diplanthera* (shoalweed), and sand beds and correlated them with water movements. If this work had been concentrated in one area of the bay, a foundation for further integrative work would now be available. However, for Biscayne Bay, there is no equivalent to the studies of Heald (1969) and Odum (1970) which examined the flow of energy in the North River system of the Everglades National Park. While this work was not entirely quantitative, the pathway by which primary production in the form of vascular plant detritus moved through the food web of that system was described. The abundance and biomass of the benthic and cryptic fauna of a seagrass bed in Card Sound, which is sometimes included in the Biscayne Bay ecosystem, and its relationship to higher trophic-level consumers, was described by Brook (1975). However, it was believed that the findings should not be extrapolated to Biscayne Bay.

The bottom types of south Biscayne Bay and Card Sound were shown by Roessler et al. (in press). These areas were delineated by their most obvious visible characteristics. The previous survey work has described the biota likely to be found in a given area, but with few exceptions the quantitative data were not compiled. If data did exist for various areas, it would be highly questionable if they could be extrapolated to cover the entire bottom type. For example, suction-dredge samples were gathered on the same day in three widely separated sites in Biscayne Bay, each dominated by dense growth of turtle grass. Near Bear Cut, animal numbers found in two $0.25m^2$ samples averaged $10,728/m^2$. Near West Point, Key Biscayne, 2.4 km south, the average was $4,316/m^2$. However, on Featherbed Bank (8 km from Bear Cut), in an area of equal blade density, this figure was $290/m^2$ (Brook, unpublished data). In other words, differences of two orders of magnitude in animal abundance were shown in areas which had a similar classification. This is an example of the risk in either extrapolations or generalizations.

This review, with names and dates changed, could probably be applied to estuarine and lagoonal areas throughout the world where a university research facility is located. This problem in Canada was described quite recently by Hargrave and Levings (1975), who pointed out the lack of integrative studies in areas containing valuable fisheries, when such studies were clearly in the national interest and could be nationally supported.

We recognize that the small number of integrated studies is probably a function of the funding available and that, in the past, only goal-oriented research could promote the large grants necessary for a whole ecosystem analysis. From the broad data-base already accumulated and the experience and knowledge presented at this meeting, we feel that a constructive effort has been taken toward the analysis of the Biscayne Bay ecosystem.

The opening portion of this meeting was concerned with the abiotic parameters of Biscayne Bay. We have discussed herein the biotic components--the producers, consumers, and decomposers. Since we are concerned with the total system, this represents a logical start. Earlier we described Biscayne Bay as a single system, but prior to an attempt to analyze its operation, it might be helpful if, for analytical purposes, this multidisciplinary group would examine if it should be treated as a unit, or a group of interacting systems, or as several independent systems only interacting on an intermittent basis.

It is incumbent upon this group to show the areas where data are current and readily available for incorporation into synthesis of the system under discussion. If data on the physical parameters such as circulation, basins, sediments, winds, and mixing are known, then this segment requires little additional work. If the chemical oceanographers can supply information on this segment of the system, then there is further reduction in the time required for data-gathering. Finally, from our fellow biologists, all that is required is to summarize the areas where data exist and to formulate a program for obtaining the data still missing.

For example, if there is a section of the bay, except for the immediate vicinity of Virginia Key, where a large body of information has been accumulated, then we might concentrate our efforts in filling in the gaps in our knowledge in that area. While we have information on the contribution of the various producers to primary productivity, there are no data on the productivity of all kinds of producers in a given area at a given time, or the contribution of each producer over an annual cycle in a given location. It has been postulated that seagrass productivity moves into the food web via the detrital pathway (Darnell, 1959; Odum and de la Cruz, 1967; Odum, 1970; Heald, 1969 and many others). The same case is made for the mangrove production (Odum and Heald, 1972). Yet, we do not know how much of this material actually moves into higher trophic levels, either directly or indirectly. Another problem which requires resolution is the impact of imported materials or, its opposite, the transport of production out of the community. These examples only illustrate some questions in a single sphere of research. New data are necessary for almost all biotic components of the system. The essential material to be gathered prior to synthesis fall into two general classifications: data must be quantitative and time-dependent. We need estimates of some measure of potential energy in each compartment, in the form of kilocalories, biomass, carbon, or other selection, and the rates by which this material moves through the system during a given time. This unifying measure is termed the "state variable," and we favor the use of carbon in future studies.

We must obviate a long-term sampling program. Therefore, laboratory and literature values will be used wherever possible to determine the rates of interaction between the compartments. We believe that modelling of a system, based on biological insights and representative data, can be useful in determining the effects of perturbations on that system. Obviously, a model need not be a miniature replica of the system, only that it behaves similarly. For example, by means of the model it may be possible to assess the impact of the loss of mangrove shoreline and its attendant input of detritus, or the effect of additional channels and increased boat traffic which might increase turbidity.

Charles Darwin said that..."the problem was not that of finding the correct answer, but rather, of finding the correct question." Herein lies the value of the holistic approach based on the natural principles which govern the structure and functioning of our ecosystems. The phrase holistic approach is frequently misused to mean that everything is studied in its most infinite and precise detail, and from the resulting mass of data a knowledge of the ecosystem is obtained. This is both prohibitively expensive and ignores the importance of asking the correct question. Questions such as what is the best use of this system, or how can this system be best managed, or, even, how does this system contribute to the local economy, often are not answered by documenting the parts, pieces, and minutiae of a system. Instead, they are answered by structuring a total ecosystem research project which is based on the question to be answered even if it means that we scientists with our disciplinary specialties are only able to make a correspondingly small contribution to the solution. The authors recognize that much research and study must still be done, but also emphasize the importance of communicating the correct question(s) to those who must do the work. The background work has already been done, and now it is time to put it together within the context of the needs of Dade County and its citizens.

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Man's Interaction

A GEOGRAPHICAL HISTORY OF THE BISCAYNE BAY AREA

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ABSTRACT

Biscayne Bay's geographical history is relatively short, and both natural and cultural environments are undergoing change. The Bay's natural history can be said to start ca. 1100 B.C., with its human history possibly beginning at about the same time. Small settlements along its shores began ca. 300 A.D., and nonagricultural peoples utilized available resources until ca. 1763 A.D. Little environmental impact occurred, but the balance between population and food supply was precarious. After an uninhabited but exploitative 40-year period, pioneer agricultural colonization of the Bayshores began and continued through the 1800's marked by Seminole and Civil Wars, military operations, and substantial natural coastal changes. There were also increasing human modifications of the natural environment.

The founding of Miami in 1896, and an expanding national economy, led to a still continuing intense urbanization of the northern Bay area. Major modifications of the natural environment have resulted, including widespread elimination of the biotic cover and considerable dredge and fill in the upper Bay. Much research remains to be done on the historical natural and cultural relationships in the Bay area, and to determine precisely the relative influences of natural and cultural processes on the Bay area as a whole.

INTRODUCTION

So far as this author is aware, no integrated natural and cultural history of the Biscayne Bay area has ever been attempted, although individuals have provided useful works on selected aspects of its natural history (Wanless, 1969), and of the human history of some of the communities surrounding the Bay (Muir, 1953; Redford, 1970; Parks, 1971). Nor have there been - again so far as the author is aware - any in depth studies examining the overall natural-cultural relationships emphasizing the Bay region as a whole geographic entity. A small step, however, has recently been taken in this direction by Wilson (1975), and no doubt this symposium will add much to what we know.

Since the present author has, for the past two years, focused his research on the northern Biscayne Bay area from the points of view of historical and coastal urban geography, it seems appropriate at this time to present a very brief summary of what he has found up to this point. The scope of the topic is vast and so this presentation is of necessity a most sketchy tentative - an essay, if you will - of the Biscayne Bay area's geographical (that is, natural and cultural) history.

DISCUSSION

Probably the best chronological starting point for a summary of the geographic history of the Biscayne Bay area is the approximate date at which it first began to assume its present geographic configuration and attributes - that is, when its geomorphic and marine relationships generally in evidence today were initially established. To determine such a date, even roughly, is more difficult than it sounds, for the outlines of the Bay itself have been evolving under natural conditions during the past several thousand years.

Wanless (1969: 39) has indicated that marine waters first entered the deepest parts of the Biscayne Bay Basin, i.e., some 7 m below present sea level, about 5400 B.P. However, he was using the original Scholl and Stuiver (1967) south Florida submergence curve, which has since been revised somewhat (Scholl et al., 1969: 563), pointing to an earlier date for this initial marine penetration. Later, around 4200 B.P., basal lagoon mud was formed, when sea level was about 3.0 m below its present stand (Wanless, 1969: 47). Somewhat later, i.e., about 3500 B.P., or 4100 years ago, the world's post-glacial sea level rise slowed to about 3.5 cm/100 years (Scholl et al., 1969). At this time, sea level was about -1.6 m and, while the sedimentary island barrier complex of north-eastern Biscayne Bay (i.e., from Baker's Haulover to Key Biscayne) had not yet been formed, the processes leading to its emergence had begun (Wanless, 1969: 45, 53,55).

Wanless does not offer a date for the attainment of the island barrier complex's present dimensions, but he does suggest one for its initial formation: about 3000 years ago (Wanless, 1969: 55). This date corresponds to roughly 1100 B.C., and can perhaps be used to start the history of the Biscayne Bay area as it is generally recongized today. Furthermore, Wanless suggests that barrier island erosion has taken place in the past 1000 years, or roughly since 950-1000 A.D.

Biscayne Bay, in its present general form, is thus a very recent creation, particularly its northern barrier complex. Moreover, this complex, at least, has been undergoing fairly frequent ecological changes due to natural environmental conditions ever since its formation. Wanless (1969: 59) felt that Bear Cut and Norris Cut were opened some time in the past 1000 years or so. Recent historical research has shown that, while Bear Cut was in existence prior to 1743 A.D., and possibly as early as the 16th century, Norris Cut was not formed until some time between 1829 and 1838 A.D. (Chardon, 1976). In addition, before the creation of Norris Cut, another inlet existed further north during at least the 18th century and possibly earlier. This inlet, known to the people of the times as Boca Ratones, was closed due to sedimentation by 1822 (Chardon, 1976a), thereby forming present Indian Creek.

The evidence, both scientific and historical, therefore conclusively indicates that several substantial modifications have occurred in the Bay area, due to natural causes, during Biscayne Bay's relatively short existence. These modifications continued to take place in the 150 years immediately preceding major human settlement of its shores. More precise determination of these modifications is needed, and a further area of research lies in those coastal changes which also appear to have occurred on the Biscayne Bay mainland (Chardon, 1975).

Given the brief geologic duration of the Bay's existence and its dynamic environmental conditions, it is difficult indeed to provide with any certainty a specific date for initial human occupance of its shores, or for its first resource utilization by humankind (and to what extent), or for the early effects of humans on the natural environment. During the past 30 years, much has been discovered about prehistoric Indians around the Bay, but the available archeological materials have suggested relatively few answers to the large number of questions concerning early man's use of, and effects on, the Bay. However, new sites are continuously be uncovered, though often they are in very bad shape due to modern construction and other factors (Laxson, 1968, 1959). Sites discovered earlier were also largely destroyed before they could be scientifically examined, such as happened in the case of the largest mound on Biscayne Bay, most of which was leveled in 1895 to make room for the Royal Palm Hotel, at the mouth of the Miami River (Sewell, 1933).

Somewhat similar treatment was accorded the only other known major burial mound on the Bay - at Surfside, on the barrier complex (Willey, 1949).

Nevertheless, going on what we have, latest findings indicate a human settlement in existence some 15 miles north of the Bay, dated as early as 1100 B.C. (Mowers and Williams, 1972; Bullen, 1974), and it may be that human activities affecting the Bay began at about the same time. This early human occupance date, interestingly enough, occurs at roughly the time Wanless (1969) postulates for the initial formation of the northern Bay island barrier complex. However, it also appears that those human settlements actually on or very near the Bayshores were not established until around 300-400 A.D. (Bullen, 1974); but it may be that these dates will be pushed back with further research.

Over 140 prehistoric sites have been discovered in Dade County alone, but less than a dozen of these are located on or very near the Bay. Most of these last are actually a little distance from the Bay itself, such as those at Arch Creek, Little River, Surfside, and Uleta River (Figure 1). On the other hand, the two largest ones, which developed especially in later years, are located almost on the Bay. One was Tequesta, in present downtown Miami, on the north bank of the Miami River about where the present Dupont Plaza Hotel stands. The other can be considered in much the same light, for it was located on Indian Creek, between 91st and 93rd Streets and on Bay Drive, in present Surfside. Most of the prehistoric settlements on or near the Bay indicate occupance from about 500 A.D. almost to Spanish times, and one or two settlements continued up to the 18th century.

The people who inhabited these sites were nonagricultural, and lived by hunting, fishing, and gathering of both land and marine products. Those Indians who settled very near the Bay adapted to their immediate environment by depending more and more on shellfish and other marine resources for their livelihood. Settlements were at first very small, consisting at most of 100 people (Willey, 1949), but with time the numbers of people and their adaptations to the estuarine environment increased. By the time the Spaniards arrived in the 16th century, there was at least one substantial village - Tequesta, probably including several hundred inhabitants - and possibly up to four others on Biscayne Bay (Swanton, 1922: 333). The utilization of marine resources must have advanced considerably, for one Spanish source mentions that the Tequesta Indians hunted the sea cow and went whaling (Lopez de Velasco, 1571-74).

The paucity and type of archeological remains, and the lack of written documents, make the normally difficult problem of estimating prehistoric populations virtually unresolvable at present. The first European documents relating to human settlement on the Bay do not occur until well into the 16th century, by which time the introduction of Old World diseases and Spanish labor deportations to the Greater Antilles (which may well have affected south Florida) could easily have reduced to small fraction any large populations which might have existed along the Bay.

Nonetheless, the available evidence indicates that the population in the Bay area in prehistoric times was never large. As of the 1560's and 1570's, there was, according to Spanish sources (Fontaneda, 1575; Lopez de Velasco, 1571-74), only one Indian village (Tequesta) undeniably known to have been located on Biscayne Bay itself, or very near its shores. Though the Spaniards established a short lived mission there, garrisoned by about 30 soldiers (McNicoll, 1941), no estimate of the number of inhabitants has yet been found; but the village could not have contained more than a few hundred people.

It would seem that the relationships of these primitive peoples with the Bay area's natural environment were intimate. But lest it be assumed, as is so often the case, that the Biscayne Bay Indians of the 16th century were living an idyllic life of plenty, it should be mentioned that the balance between population and resources was precarious. The first Spanish missionary wrote in 1568 (McNicoll, 1941: 15) that there were severe food shortages of several months' duration, implying that even under normal conditions there was barely enough to go around. A slight increase in population in the 1500's was apparently sufficient to cause quite a strain on local food resources. In fact, by 1743, the local populace was seminomadic, and the settlement at Tequesta was then only inhabited during the summer months; in winter, everyone went to the Keys (Chardon, 1975). Whether this seminomadism prevailed in prehistoric times, or whether it was an adaptation to limited resources after Spanish times, is not yet possible to determine, but it did exist in the 1700's, until the Indiand abandoned the Biscayne Bay area in the 1760's.

The environmental impact of prehistoric peoples up to about 1600 A.D. is also difficult to evaluate at this time, but, aside from some possible biotic changes, it could not have been great. Surprising though it may be, there seems to have been virtually no contact between the Biscayne Bay Indians and the agricultural peoples in the West Indies until just prior to the arrival of the Spaniards (Bullen, 1974; Sturtevant, 1960), nor much interchange with agricultural Indians in the northern parts of Florida. The Tequesta Indians remained nonagricultural, their livelihood based on hunting, fishing, and gathering. Such an economy would have had relatively little effect on the ecology of Biscayne Bay, though the possible use of fire to drive game may have led to substantial modification of the vegetal cover. Even this is a moot point, however, for studies have suggested that lightning could have been responsible for the development of fire resistant tree cover, indicated by the dominance of pine and palmetto over much of the landscape (Hofstetter, 1974), though in part the prehuman vegetation was of the climax type (i.e., hammock). Further research on this topic is needed.

In short, the first people to use Biscayne Bay may have come to the Bay around 1100 B.C., at about the time of initial development of the island barrier complex. Settlement along the Bay seems to have been continuous from about 300-400 A.D., and continued, in this phase, to 1763. The settlements were small, with one center eventually emerging as dominant - Tequesta, at the mouth of the Miami River. The impact on the Bay area, up to about 1600, was slight, but the population lived in precarious balance with its local food and other resources. Agriculture was unknown among these Indians.

From about 1550 to 1760 A.D., Europeans had made contact, but little change seems to have taken place in the human occupance of the Bay area. The Indian population continued to be based at Tequesta, maintaining its seminomadic, nonagricultural, sea-oriented existence. The population appears to have increased somewhat by the early 1700's, but, when the Spaniards tried to found a second, even briefer mission at Tequesta in 1743, it was clear that the Indians were already being substantially reduced (Chardon, 1975). By 1763, the last remaining Indians on Biscayne Bay had disappeared, and the Bay remained unpopulated, in spite of several European attempts to colonize its shores, for the next 40 years, more or less, until the first Bahamian, American, and possibly Cuban settlers began to arrive in the early 1800's (Chardon, 1975; Parks, 1975).

It is difficult to assess just what changes were made in the natural environment from 1550 to 1800, and especially the last 40 years, during which there was no settlement, but there seems to be no doubt that some modifications were taking place. First, although no mention has yet been found on this subject, the Spaniards usually introduced plants and animals whereever they established missions, and often even where they didn't settle at all. To what extent they did so, either in the 1500's or later, in this area inhabited by nonagricultural Indians, it is not now possible to say, but there may have been quite a few plants, and possibly some animals, introduced.

Second, by the mid-1700's, frequent contact was being maintained between Cuban fishermen and Indians along southwest Florida and the Keys, and this may have resulted in considerable alteration of biotic environments, both marine and terrestrial. Third, in the 1700's some bands of Seminoles were beginning to make hunting forays into the Biscayne Bay area in search of game for markets further north (Covington, 1968). Fourth, the Biscayne Bay area was being frequented, especially during the 40-year period of nonsettlement, by Bahamian seamen, who came to hunt, fish, catch turtles (and possibly pen them), and, significantly for our purposes here, to cut timber. None of these activities (or the wrecks which seem to have occurred here during this and other times) led to the creation of permanent European or other settlements on the shores of Biscayne Bay (Chardon, 1975), and from 1763 to 1800 there were no settlements at all. In spite of this, the effect on the natural environment was certainly greater than at any previous time.

We are fortunate to have maps of the northern Biscayne Bay area for this time period. In the 1760's, the British Surveyor-General, William Gerard DeBrahm, surveyed northern Biscayne Bay, and summarized his findings on several maps drawn in 1770. These are adapted and presented here as Figure 2. Although some areas are much more accurately portrayed than are others, the map provides at least a partial baseline for further geographic and historical analysis. A full discussion of the background of the map is provided in Chardon (1975, 1975a), and one application of its features is presented elsewhere (Teas, et al., in this volume).

White settlement - and that of the Seminole Indians - in the Bay area began in earnest in the early 1800's. It is believed that some timber was cut from the mainland north of the Miami River (Historical Records Survey, 1940), and several homesteads were established along the shore to the south of the Miami River by white settlers (Parks, 1975). Pioneer settlement in the Bay area, and Seminole use of its resources for hunting and some small agriculture, prevailed throughout most of the 1800's, but the various activities of each group were marred by a number of conflicts between them. With the transfer of Florida to the United States in 1821, white settlement appears to have increased somewhat immediately thereafter, but difficulties with the Seminoles led to not infrequent abandonment of the pioneer homesteads. In turn, several military bases were established in the Biscayne Bay area, e.g. at Fort Dallas and on Key Biscayne, with the latter island also the scene of the construction of a lighthouse in the 1820's (Parks, 1975). Resumes of the human history during this period are found in Parks (1975, 1971).

The unsettled human conditions during the 19th century had an uncertain effect on the Bay's natural environment, but some changes undoubtedly were effected, as alternative agricultural and military operations would suggest. The early pioneers introduced large numbers of plants, including trees, and modified the vegetation to a considerable extent by their activities, which included the establishment of coontie mills. The building of the several Fort Dallases and the consequences of the military operations accompanying the Second and Third Seminole Wars also altered the landscape. The environmental effects of all these human events still remain to be determined, either qualitatively or quantitatively, but they certainly were increasingly significant. They appear to have been greatest on Key Biscayne, and on the mainland around the mouth of the Miami River and south along the coast.

It should be mentioned again that the early 1800's, at the very least, saw a number of natural environmental changes take place, notably in the island barrier complex, when Boca Ratones closed due to sedimentation and, later, Norris Cut was formed, probably at the time of the hurricane of 1835 (Chardon, 1976a).

The tempo and permanence of white settlement along the northern Bay increased in the latter part of the 1800's, and especially after 1870. So, correspondingly, did the impact on the natural environment. By 1876, about 100 permanent residents lived along the Bay, principally along the Miami River and in the Coconut Grove area (Parks, 1975). Thereafter, settlement expanded north and south, especially in the 1880's and early 1890's. On the barrier complex, other activities had begun: a House of Refuge was built in the 1870's, and an attempt was made to plant thousands of coconut palms, though the effort seems to have left little environmental impact (Redford, 1970). Pineapple farms were started on the Upper Keys; but much of the vegetation cover had apparently already been radically changed long before. Even the Bay itself did not escape alteration, for small scale dredging of channels was undertaken in the extreme northern parts of the Bay (U.S. Coast and Geodetic Survey, 1887). On the part of some local residents, at least, strenuous efforts were being made to attract people to the Biscayne Bay region, most notably by Julia Tuttle; she eventually, in 1895, succeeded in getting Henry Flagler to extend his railroad down to Miami, and with that event began the period of urban development and massive alteration of the natural environment in at least the northern part of the Biscayne Bay region.

The story of the beginnings of Miami, and of the subsequent growth of population and environmental change, is one which is complicated. It is relatively well known, having taken place in the past 80 years, but to summarize it adequately in a few pages is impossible. Sources are here extensive, however; the more popular ones include Munroe and Gilpin (1930), Sewell (1933), Muir (1953), and Smiley (1973). The story of Miami Beach is successfully and delightfully covered by Redford (1970), and the earlier years also by Lummus (1944). A brief but undocumented account of Key Biscayne is presented by Woodman (1972). There are many others, of varying focus and value; for example, this author has summarized cartographically some of the coastal changes (Chardon, 1976b), and Parks (1971) provides a history of Coconut Grove.

In brief, Miami and its neighboring communities have grown phenomenally, and the impact on the environment in the northern Biscayne Bay area, at least, has been equally phenomenal. The founding of Miami in 1896 saw several thousand people living there, and from then on the sometimes turbulent growth of the urban areas has continued to the point where there are now over a million permanent residents. Fueled by an expanding national population and economy, and especially by increasing affluence, communications, trade, and advertising, the small communities of the 1890's were soon overwhelmed by the expansion of the metropolis.

The effects on the natural environment of Biscayne Bay were immediate and pervasive. The tiny channels in the northern Bay were abandoned - temporarily, as it later turned out. But the Florida East Coast Railroad, with an eye towards stimulating trade and tourism, in 1896 started to dredge a basin north of the Miami River (and in the River itself), and to cut a channel to the sea by way of Cape Florida. With expanding trade still in mind, Government Cut was created in 1905 through the small, natural southern peninsular tip of Miami Beach - a project whose dredgings at the same time built Fisher Island, which previously had been a very shallow bank.

Mangroves were cleared, and the areas filled in and bulkheaded at the previous vegetation "coastline". Other artificial islands had begun to appear by 1919 in the middle of northern Biscayne Bay, created by dredging surrounding bottomlands. Baker's Haulover Cut was dug in 1923-24. By 1926, plans had been drawn up to extend the "Venetian Isles" all the way up the middle of the upper Bay; these plans were never realized, but their relics still remain in the Bay. Several causeways were constructed across the Bay, and more communities were created on slightly raised mangrove islands north of Miami Beach. Key Biscayne, already modified by both natural and human events in the 19th century, was the scene of agricultural, then partial urban, development. The southern tip, threatened by rapid erosion, was also bulkheaded and filled in to a considerable extent.

A partial indication of the extent to which dredge and fill have altered the northern Biscayne Bay area since the founding of Miami is provided by Figure 3. This preliminary map was constructed by comparing the shorelines of the U.S. Coast and Geodetic Survey Chart No. 165 of 1887 (the latest pre-1896 chart) and those on U.S.N.O.S. Nautical Chart 11467 (1974). Minor adjustments were made to compensate for projection differences and slight discrepancies in cartographic measurement (Chardon, 1976b).

Even so, this generalized map should be viewed as a preliminary one only; it needs to be field checked and should be used with caution. It indicates only those areas of open bay which, so far as the author knows, have been dredged, and which have been filled and raised above mean high water, since 1887. Also included are those areas, notably along the Atlantic coast, which have accreted by sedimentation (e.g. the beach just north of Government Cut). Dredged bay bottomlands are indicated in general fashion; these for the most part are close to the filled areas. The map does not show many Bay depth changes, such as may have resulted from some of the dredging operations. Finally, the dredged portions of the Intracoastal Waterway and some channels are shown, but many other channels and waterways cannot be shown due to the scale of this map.

Also, since both the 1887 and the 1974 charts locate vegetation lines as coastlines (i.e., bayward boundaries of mangrove swamps as limits of mean high water), Figure 3 does not show the extensive areas of mangrove and other intertidal zones which have been cleared and filled. These areas lie primarily on the bay side of the island barrier complex, from Baker's Haulover Cut to the southern tip of Key Biscayne; unless they were under open water in 1887, they are not shown here. The author is presently compiling a map which will include filled mangrove and other intertidal areas, but much more field research is needed before this map can be completed satisfactorily (Chardon, 1976b).

Nevertheless, Figure 3 is useful in providing an areal presentation of the dredge and fill aspects, along with seaside changes due to sedimentation and erosion (also partly the result of human activities) in the northern Biscayne Bay area. Approximately 20% of the 1887 area of open water in the Bay north of Bear Cut has been filled, and roughly another 20% dredged, as a result of the urbanization of the region (Chardon, 1976b).

Thus, about 40% of the Bay north of Bear Cut has been altered by dredge or fill since 1887. And along the Atlantic side of the island barrier complex, from the northern tip of Biscayne Bay to the southern end of Key Biscayne, almost half (44%) of the shore length has undergone some accretion or erosion since 1887; not all of it is due to the construction of the breakwater extending into the ocean from Government Cut, but much of it is (Chardon, 1976b).

On the mainland, coastal changes have not been as significant, but nevertheless are very evident. Downtown Miami grew, and Bayfront Park was created. Other modifications of one type or another took place almost everywhere along the coast, where urban land uses were decided upon. These continue to this day: witness the high-rises between Brickell Avenue and the Bay, where Silver Bluff has now virtually disappeared (with a small exception) as a purely coastal feature of the land- or seascape.

Alteration of the landscape itself has, of course, been almost total within the urbanized area. The original hammock vegetation cover is now almost entirely replaced by all types of urban land use, including parks; the same has happened to much of the other vegetal cover. One somewhat inadvertent change has come as the result of the introduction of the "Australian Pine" (<u>Casuaria</u>) in the early 1900's; it now is rapidly replacing other types of vegetation over much of the remaining open spaces.

A further comment may be added with regard to water resources and quality; these have changed dramatically, from the first blasting of the Falls of the Miami River, to increased runoff as a result of extensive paving, to the depletion and degradation of ground water supplies.

All, or most, of the effects mentioned - plus many, many others - have accompanied the rapid urban growth in the northern Biscayne Bay area. A large number of these effects, to some degree at least, have been and are being scientifically (e.g. McCulty, 1970) and otherwise examined by persons representing every discipline, or none at all. But if these environmental effects appear as problems to come, it should be remembered that the elimination or reduction of other problems, apparent to those living in other times, are in part responsible. It should also be remembered that over a million people now enjoy Biscayne Bay, where only a hundred or so were able to do so prior to urbanization. And it should further be remembered that the Biscayne Bay region is not environmentally static; coastal changes have been taking place for hundreds, even thousands, of years.

This last statement is a situation not at all unusual or uncommon in similar coastal locales (Price, 1968), and suggests that tendencies toward further shoreline alterations - and associated ecological changes - will continue in the Biscayne Bay area for the foreseeable future. Another implication is that not all of the 20th century changes in the Bay area's natural environment are solely the result of the human activities which have culminated in the intense urbanization and dredge and fill of its upper reaches.

A broad and major area of research thus appears to lie in trying to establish the relative influences of natural and cultural processes on the Bay area as a whole. In other words to what extent has human interaction affected the Bay area's overall natural environment? And, in turn, how do natural factors affect the cultural environment which has emerged? These questions are not easy to answer, as this paper has shown, even though much research has been and is being undertaken on a number of aspects of this central and fundamental problem. Though the complexities of the many natural and cultural systems involved present formidable obstacles to both measurement and analysis, it would appear that only with a good deal of understanding of the overall natural <u>and</u> human processes as they interrelate in the Bay area, can effective resource use planning be carried out and decisions successfully implemented.

It may be that rather vast and comprehensive modeling and systems analytical techniques will eventually permit a quantitative and perhaps accurate method of attacking the problem, but in the meantime one approach is to view the Bay area in historical perspective, and this I have tried to present. Clearly, the scope of the topic is great, as are present limitations of data, research, time, and the author himself. So this presentation has been, as stated at the outset, a most sketchy tentative. If I have stressed the earlier phases of this history, it is because they are less well known and yet, I feel, quite significant for an overall perspective. They are also considerably less complicated than the far more extensive and rapid changes which have occurred with the advent of 20th century urbanization.

A final note may be added. A historical perspective increases geographical awareness, since the meaning of a place or landscape is in a way a function of the events of its past, and of how those events are woven into a story of evolution and perhaps even destiny. With a comprehensive history, the Biscayne Bay area becomes more meaningful to those who visit or live there. Indeed, one might go so far as to say that the quality of the Bay area's environment cannot help but be enhanced by historical interpretations of its human and natural character. This paper, it is hoped, is a contribution towards that enhancement.

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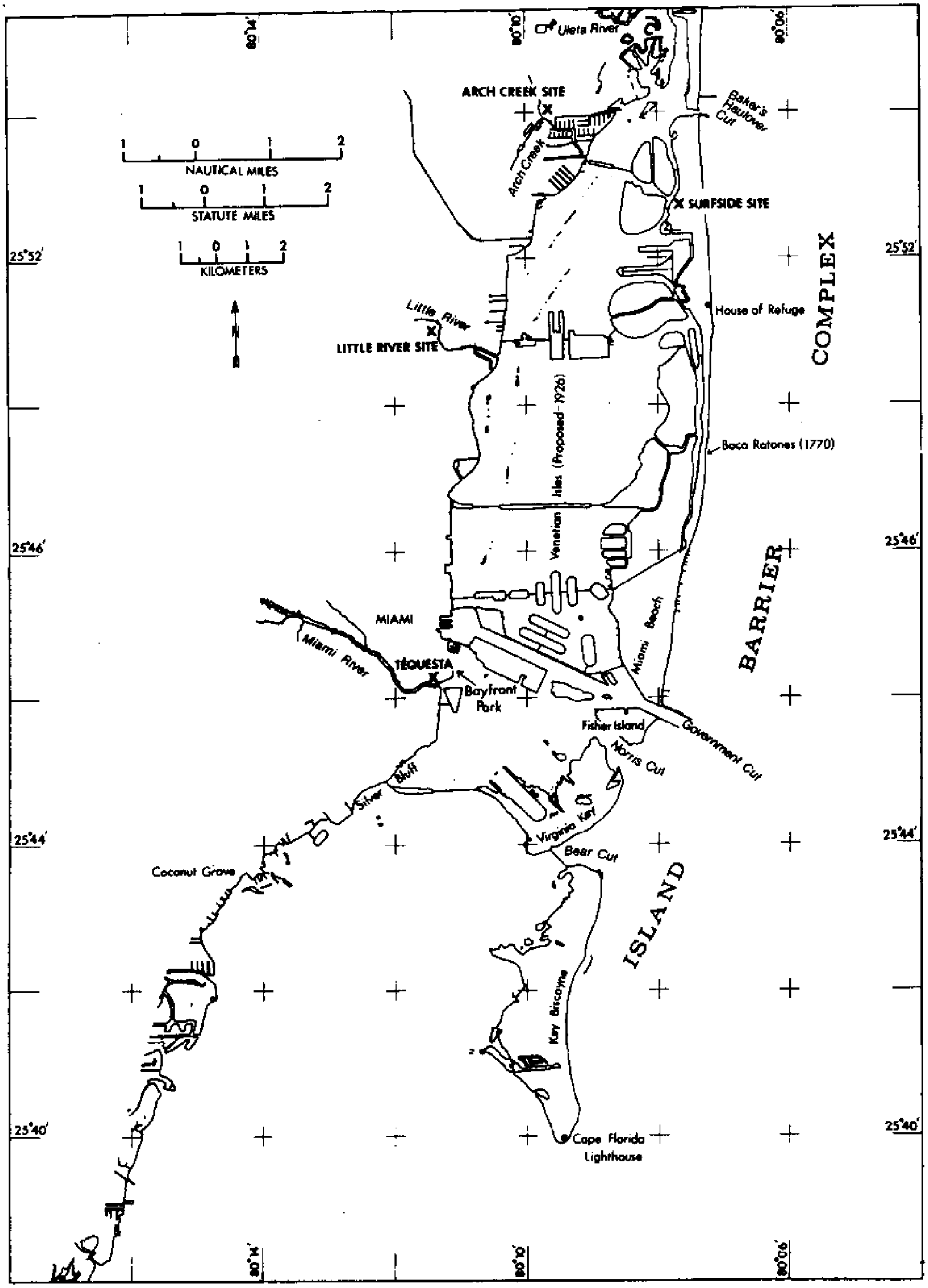

Figure 1. Archaeological sites near northern Biscayne Bay.

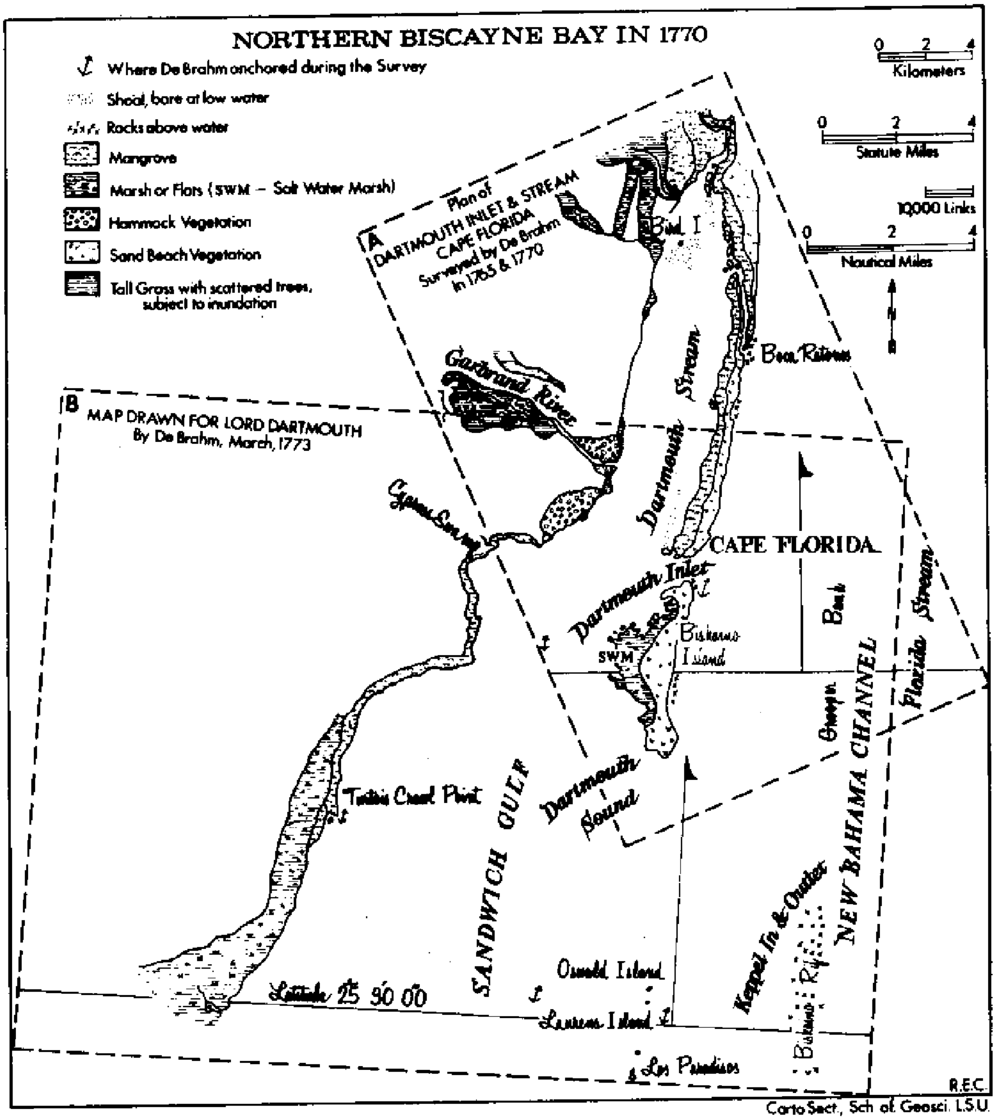

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Figure 2. Sources: Inset A from Library of Congress copy of map in British Museum, King's MS 211, fol. 83 (11), and another orininal in the Houghton Library, Harvard University. Inset B from Dartmouth Ms. D(W)1778/II/654, Stafford County Record Office, Stafford England. Reproduced with permission.

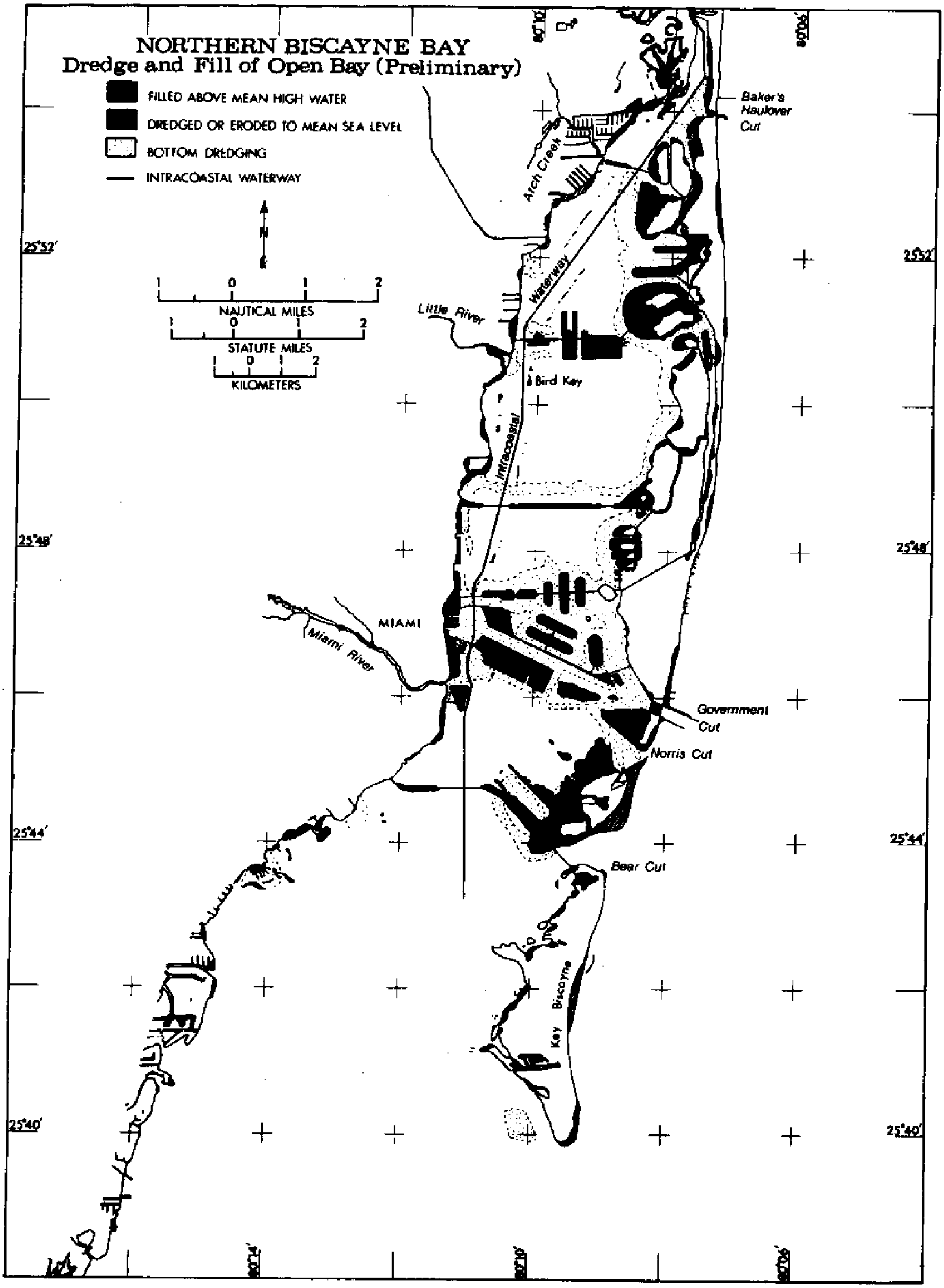
NORTHERN BISCAYNE BAY
Dredge and Fill of Open Bay (Preliminary)
FILLED ABOVE MEAN HIGH WATER
DREDGED OR ERODED TO MEAN SEA LEVEL
BOTTOM DREDGING
INTRACOASTAL WATERWAY
N
1 0 1 2
NAUTICAL MILES
1 0 1 2
STATUTE MILES
1 0 1 2
KILOMETERS
Baker's Haulover Cut
Arch Creek
Waterway
Little River
Bird Key
Intracoastal
MIAMI
Miami River
Government Cut
Norris Cut
Bear Cut
Key Biscayne
25°52'
25°48'
25°44'
25°40'
80°14'
80°10'
80°06'

Figure 3

RECREATIONAL BOATING IN BISCAYNE BAY

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ABSTRACT

One way of establishing research priorities concerning Biscayne Bay is according to existing or potential conflicting uses of the bay's resources. This paper reviews some of the major conflicts among recreational boaters and between recreational boating and other uses of the bay. The activities associated with recreational boating are highly dependent on the abundance and quality of the bay's natural resources as well as the availability of facilities such as marinas. The objectives of the ongoing boating assessment program are to establish the magnitude, type, and locations of recreational boating and the relative dependence of recreational boating on specific natural resources and marina facilities.

INTRODUCTION

Biscayne Bay offers unique opportunities for marine recreation, particularly activities associated with recreational boating. There are few other examples of a large, year-round protected bay that provide such a diversity of natural resources so close to a major metropolitan area. While it is known that many residents and tourists take advantage of the bay, there is no detailed information on how recreational boaters utilize natural resources and facilities or even the magnitude of recreational boating.

Since there is no substantial literature on marine recreation to review, this paper discusses the ongoing cooperative research by the University of Miami Sea Grant Program, Dade County, U.S. National Park Service, National Marine Fisheries Service, Marine Council of Greater Miami, and others, to examine various components of marine recreational boating.

METHODS

An assessment of recreational boating in Dade County is presently being conducted (7/1/75-8/30/76). An inventory of wet-berthed boats was accomplished by visual site counts. Ongoing destination studies combine site interviews at wet berths and launching ramps with mail questionnaires and the monitoring of offshore boating activity. The destination studies collect data on types and sizes of boats, when boaters use their boats (months of the year, day of the week, time of the day), departure sites, offshore destinations, types of recreational activities (cruising, water-contact sports, fishing, diving), and expenditures on recreational boating. Where living natural resources are utilized (line fishing, spearfishing, collecting), additional information is collected on fishing methods, fishing effort, species sought, species caught, and length/weight measurements of recreationally important fishes. It is anticipated that a more detailed study of recreational fishing (boat and stationary) will continue after 8/30/76.

DISCUSSION

It is worth noting that if all the human uses (including intensities of usages) were compatible then there would be no necessity for this symposium. The symposium and the need for applied research arise from unavoidable conflicts between users and uses of the bay's resources. With this perspective, the ideal pattern of factual information for decision-making would be to assist decision-makers in more clearly understanding conflicting uses. This is the only way to recognize the opportunity cost of a particular use which is the cost of one or more activities in terms of what activities must be foregone. Therefore, to the extent it is possible, the discussion of recreational boating is formulated in terms of competing or conflicting uses. These may be conflicts among recreational boaters or between recreational boaters and other users of the bay's resources.

Interpreting conflicting uses is not easy because there are three types of conflicts with each having its own set of unique characteristics. As a frame of reference, recreational boating will be discussed in terms of these three types of conflicts.

1. User Conflicts Through Geographical Exclusivity

Conflicts because two or more activities cannot physically co-exist at the same place at the same time is the most recognizable type of conflict. Recreational boating must compete with other activities for shoreline to provide water access points. This is reflected in the high cost of marinas. In the cases of public funding, these expensive waterfront facilities must also fiscally compete with other programs in government budgets.

There are approximately 36,000 Florida-registered boats in Dade County. In addition, as of December 1975, there were 951 documented yachts and 103 out-of-state boats berthed in Dade County that are not recorded in the Florida registrations. Therefore, the total recreational boating fleet in Dade County is approximately 37,000 boats (Figure 1).

A wet-berth inventory completed in December 1975 recorded 5,688 boats berthed in Dade County waters (Table 1). There are (depending on the measurement criteria) 3,000-3,300 organized (marina-type) wet berths. They are distributed among 3 City of Miami marinas (622), 5 Dade County marinas (460), 12 yacht clubs (497), and 37 private commercial facilities (1,700). Almost an equal number of boats is berthed in private wet slips (primarily behind homes).

It is noteworthy that the proportionately larger number of boats is moored in south bay. This is particularly the case with sail boats because south of Rickenbacker Causeway offers the best sailing area. There are so few wet-berthed sail boats in north bay (primarily Dumfoundling Bay) because there is no protected sailing area and the passage to south bay is too long for day-sailing. The fixed span, Haulover Bridge (32 feet) prevents exit to the ocean for larger sailboats.

There are definite trends towards boaters launching or mooring their boats closer to their primary offshore destinations. This trend is at least partially influenced by increasing fuel prices. Most living resources and physical characteristics which attract recreational boating are in the south bay, which places relatively more demand on marinas south of Rickenbacker Causeway.

There are presently two-year waiting lists for wet berths at county and city marinas. In some cases private yacht clubs have equally long waiting lists, but there is more variability in the waiting time among private clubs and commercial marinas than in public facilities.

Launching ramps and auto/trailer parking facilities reflect geographic exclusivity that has a time dimension. At launching ramps congestion is the primary basis of conflict among recreational boaters. A basic theorem of recreational planning is that recreators have established patterns of use with respect to time (time of the day, day of the week, season of the year). There are definite patterns of use at county launching ramps. First, over 80 percent of all recreational boating is done on weekends and holidays. To compound further the congestion problem, there are definite departure and return peaks at particular times of the day (Figure 2).

The fact that there are peaks of congestion means that recreational facilities must be designed and staffed to accommodate the busiest times (e.g., mid-day on a Sunday in July). This does not necessarily imply that facilities should be able to accommodate all occasions (e.g., Fourth of July weekend), but facilities must be designed towards peaking capabilities. Therefore, average attendance figures (yearly, seasonal, daily) may be very misleading in terms of evaluating the ability of facilities to accommodate users that have definite patterns of use.

Presently there do not appear to be serious congestion problems at popular offshore destination sites even though there are definite geographical and time (Figure 3) patterns of use. However, offshore congestion could conceivably become a problem with the continued growth in the number of recreational boats. Questions about "maximum utilization rates" and "carrying capacities" with respect to geographical conflicts could become important issues for certain recreational boating activities and areas of the bay. The ongoing destination studies will provide detailed information on activities at offshore destinations.

2. User Conflicts Through Exploiting the Same Resource

Conflicts from users exploiting the same marine resource arise primarily in fishing. This is more than a minor category of conflicts. The most recent nationwide boating survey (U.S. Coast Guard, 1974) reported that 72.8 percent of boating households used their boats most frequently for fishing. Preliminary estimates from the ongoing destination studies at county marinas indicate that at least 50 percent of all boating is associated with some type of fishing.

Recreational fishermen may be competing among themselves or with commercial fishermen for the same common property fish stocks. The most significant recreational-commercial conflict in Biscayne Bay (including the coral reefs) is over spiny lobster (Panulirus argus). Lobster landings by Dade's commercial lobster fishery have increased considerably since 1965 (Table 2).

The increase in landings at Dade County ports is a result of Cuban-Americans fishing in the Bahamas. The 1974 Bahamian Fisheries (Amendment) Act prohibited foreign lobster fishing in the Bahamas. At the opening of the 1975 season (8/1/75), Dade County fishermen could not catch lobsters on the east side of the Florida Current. Dade County's intensively fished waters (commercially and recreationally) cannot support the 1975 fleet that had previously fished in the Bahamas. The Dade County commercial lobster fishery is unquestionably already overcapitalized as reflected by the number of traps and the brevity of the active fishing season (August-November). At the opening of the 1975 season 3,311 buoyed traps were counted within the National Monument's offshore reef area (228 sq km), indicating an average trap density of 6.7 traps per hectare (U.S. National Park Service, 1975). At an estimated opening season catch rate of 0.5 pounds (whole weight) per trap day (3-day soak time) this would result in a total monthly catch of approximately 49,665 pounds.

It has long been recognized that a considerable number of people recreationally dive for spiny lobster. The high retail market price for lobster coupled with the relatively low monetary costs of diving on shallow nearshore reefs and in protected waters have encouraged the recreational fishery.

Most recreational diving is done during the first two months of the season (August-September). The reported catch per diver during the 1975 two-day preseason opening (Sunday and Monday, July 20-21) was low (Table 3), reflecting the difficulty of catching lobster by hand (Austin and Waugh, 1976).

While the catch per diver is low, it is suspected that the total amount of recreational diving for spiny lobster is substantial. During the two-day preseason opening it is estimated that 1,289 pleasure craft with 4,138 active divers captured 10,712 legal-size (approximately 1 pound) lobsters in Dade County.

Unfortunately these types of isolated observations are not sufficient to make seasonal catch and effort estimates, but they are sufficient to indicate that the necessary elements are present for growing conflicts of use between commercial trap fishermen and recreational divers. As with most user comparisons, much more is known about commercial than recreational activities.

Other conflicts where there is no (or little) information is between commercial netting and recreational fishing or between spearfishing and line fishing. The preliminary results of the destination studies indicate that these will be important issues.

3. User Conflicts Through the Interdependences of Natural Resources

The final category of user conflicts involving recreational boating arises from the most pervasive and frequently the most subtle connections between users because natural resources are ecologically interrelated. For example, land developers may compete with recreational boaters through competition for shoreline that might be utilized for marinas. At the same time, development bulkheads may conflict with recreational fishermen by altering the nursery grounds of popular sport fishes. Ecological considerations also link users that may be geographically removed from the bay (e.g., using the bay as a sink for street run-off or sewage overflow).

A somewhat ironic example of natural resource interdependence through the food web is the present controversy over commercial bait fishing in the bay. The commercial harvest of baitfishes (primarily by net) may influence the abundance of predatory fish that are the species sought by recreational fishermen who purchase the bait.

Environmental Quality and Marine Recreation

The most important aspect of the three types of user conflicts is their pervasiveness. In some fashion they connect almost all the users of the bay. For most policy considerations these links are a matter of degree, not of kind. Among all the uses of the bay, the activities associated with recreational boating place the most stringent demands on the abundance and qualities of the bay's natural resources. It is not coincidental that some of the reported reductions in abundance and quality of specific resources (e.g., fish, turbidity) have occurred over a time span when very little was known about marine recreation. It is the writer's suspicion that if the activities associated with recreational boating (various types of fishing, water-contact sports, cruising, etc.) would have been monitored over the past 15 years, that trends in recreational activities (types, locations, and intensities) would have indicated trends in the natural resources that support these activities. Furthermore, the importance of these natural resources in terms of supporting economically important recreational activities would have been firmly established. I believe this would have influenced public policy in the direction of more protection and enhancement of the natural resources that support marine recreation while simultaneously expanding the facilities (particularly marinas) that service marine recreators.

A General Data Base on User and Scientific Information for Conflict Resolution

The first step in developing information to resolve conflicts is to establish and maintain a general data base on existing uses of the bay (types, locations, intensities). In some cases such as land-use, this may be done by a simple inventory. In the case of recreational boating, it is requiring a relatively extensive sampling procedure. General user information is important for three reasons. First, natural resources can be evaluated and assigned priorities in terms of their importance to users. Second, users and activities can act as a barometer that records changes in the status of important natural resources. Finally, user information provides the subjects and rationales for applied scientific research on important natural resources. The user and scientific data base required for making informed decisions is undoubtedly extensive. However, costly research can be kept to a minimum by always orienting applied research towards the objective of resolving user conflicts.

The 1975-76 Dade County/Sea Grant recreational boating assessment program is designed to provide general user information in terms of the amounts of boating, types of boating, utilization of natural resources (destination studies), and the utilization of facilities (primarily marinas). A more difficult problem is projecting the future demand for recreational boating because the demand is expected to be highly dependent on the availability of specific natural resources and facilities. For example, it is suspected that the sale and utilization of larger pleasure craft (26-65 ft) in Dade County have been significantly constrained by the shortages of wet berths. The Canadians have attempted to address the functional relationships between the demand and supply of recreational facilities near urban centers (Acar, 1973). This is a difficult task but it must be done for long-term considerations of "maximum utilization" or "carrying capacities" of the bay with respect to alternative uses.

The ongoing boating assessment program indicates that there are two major categories of issues involving conflicts that concern recreational boaters. The first relates to the shortage of bay access points for recreational boaters. This primarily refers to the development including funding, siting, and design of marinas along the South Dade shoreline.

The second issue is an umbrella category encompassing all the conflicts surrounding the status and utilization of recreationally important fishes. The majority of recreational fishermen interpret this as conflicts between recreational and commercial fishermen (e.g., lobster, bait fishes, mackerel) or between recreational fishing and shoreline land uses (e.g., bulkheads or effluents).

These issues provide immediate and demanding challenges for researchers and decision-makers. In the case of recreational boating, the ongoing destination studies will determine the areas of conflict. The next steps are to do the necessary detailed research and then make some very difficult decisions.

ACKNOWLEDGMENTS

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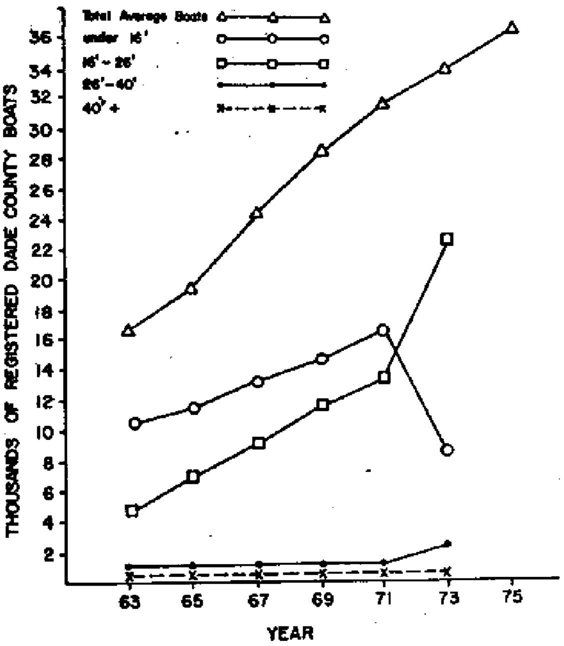

Figure 1. Number of registered Dade County boats by size (Courtesy of Florida Department of Natural Resources).

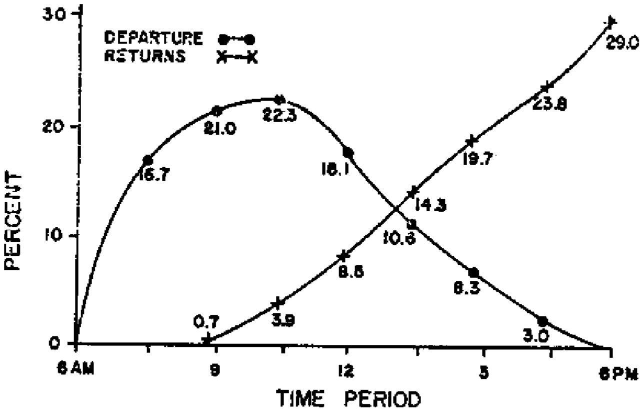

Figure 2. Incremental recreational boating departures and returns in percentages at County marina sites.

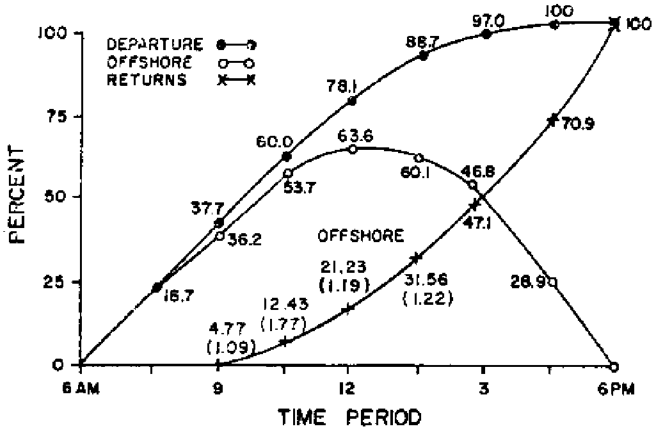

Figure 3. Cumulative recreational boating departures, returns, and offshore activity in percentages at County marina sites.

Table 1. DISTRIBUTION OF WET-BERTHED BOATS BY TYPE, SIZE, AREA, AND REGISTRATION

	Power	Sail	No Power	0-26 ft	26-40 ft	40-65 ft	65+ ft	Florida Registration Pleasure Craft	Out of State Registration	Documented	Organized Dockage	Private Slips
NORTH BAY (north of Haulover)	388	24	53	145	306	70	15	367	12	33	227	309
MIDDLE BAY (Haulover to Rickenbacker)	629	207	24	273	425	168	29	649	25	162	436	465
MIAMI BEACH (including adjacent islands)	404	78	116	173	283	137	11	361	9	112	93	511
MIAMI RIVER (including tributaries)	757	164	98	323	660	254	60	716	9	196	600	697
SOUTH BAY (south of Rickenbacker)	1030	1227	7	817	1246	283	4	1801	48	408	1614	736
TOTAL (Dade County)	3208	1907	298	1731	2920	912	119	3894	103	911	2970	2718

Table 2. SPINY LOBSTER COMMERCIAL LANDINGS THOUSANDS OF POUNDS WHOLE WEIGHT [1]

YEAR	DADE COUNTY	MONROE COUNTY	TOTAL	PERCENT FROM FOREIGN (BAHAMIAN) WATERS
1965	1329	4385	5714	17
1970	3018	6852	9871	32
1971	3418	4788	8206	43
1972	6267	5149	11416	58
1973	5622	5550	11172	49

[1] Courtesy of National Marine Fisheries Service, Southeast Fisheries Center

Table 3. LOBSTER CATCHES BY RECREATIONAL DIVERS, DADE AND MONROE COUNTIES JULY 20-21, 1975

		No. of divers per boat	Catch	Catch per Diver	% of All Boats Lobster Fishing	% of Boats from Dade County	% of Boats from Monroe County	% of Boats from Other Counties or States
Dade County	$\bar{x}$	3.21	8.31	2.52	44	97	0	03
	$S_{\bar{x}}$	1.33	9.63	2.72				
	n	244	244	244				
Monroe County	$\bar{x}$	3.07	6.13	1.96	60	22	50	28
	$S_{\bar{x}}$	.24	1.80	.49				
	n	32	32	32				

BISCAYNE BAY: URBAN GROWTH AND CHANGE

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ABSTRACT

This paper reviews the urban growth process in the immediate area to Biscayne Bay, defined by the walking distance from the bayfront.

The area has been maintaining approximately the same percentage of the total Dade County population, but it is considered by the authors that this situation will be drastically changed due to the growth constraints in other parts of the County.

The Bay does not attract a substantial number of recreational oriented trips from Dade County residents, a clear indication that the Bay should be made more accessible and that recreational oriented land uses should be increased in the study area. If policies aimed at this purpose are considered, they should be properly evaluated from the point of view of the environmental impact.

Land use patterns around the Bay are the result of the poorly guided urban growth process. Recently, the local government has improved substantially the land control process, but the redevelopment of the Bay area remains the most important challenge to our community.

INTRODUCTION

The purpose of this paper is to review urban growth in the area adjacent to Biscayne Bay in order to identify the interaction between the Bay and the community. In terms of major urban planning issues, the findings will be presented in the second part of this symposium, as the basis for the definition of a metropolitan urban policy for Biscayne Bay area.

The area of influence of the Bay could be defined according to an almost unlimited number of parameters, but this paper uses as a criteria for defining influence a combination of walking distance--around a half mile--and/or the existence of a main physical or visual barrier, such as a major road or facility and a drastic change in the use of the land.

The boundaries of the study area are Sunny Isles Causeway on the north, Biscayne Boulevard, U.S. 1, S.W. 27th Avenue, Main Highway and Old Cutler Road to the west, and Monroe County line on the south. On Miami Beach the eastern boundary is AIA and Alton Road.

POPULATION

The process of settlement around the Bay was rapid up to 1950. At that time the present distribution pattern was established, and for the last 23 years the process has primarily been the filling-in of open land with a very few isolated cases of redevelopment.

The most important characteristic of the process of urbanization is that the percentage of the total population of Dade County living within walking distance of the Bay has declined during the last 23 years. In 1950, 12.8% of the population of Dade County lived in the area. Ten years later, 1960, the figure dropped to 10.5% and in 1970 the same area represented 9.8% of the population. The estimates for 1973, the latest official figures, indicate a further reduction to 9.5% of the total projected population.

In terms of absolute numbers, population had grown from 63,482 in 1950 to 98,214 in 1960. During the next decade the population increased to 124,842. The estimates for 1973 are 130,350 in the census tracts along the bayfront (see Table I).

As indicated above, suburban areas of the city were growing at a faster rate than areas near the Bay. A main constraint to development and redevelopment along the bayfront was the small land parcel pattern which precluded large scale projects without a slow and costly process of assembling land.

On the other hand, the population almost doubled in 23 years, which indicates that a substantial amount of land was used in rather low-intensity development.

The energy crisis, the friction of urban space, and the constraints introduced by land regulations are changing the conditions in Dade County. It is expected that in the next five to ten years there will be a clear emphasis on redevelopment and the Bay may become one of the most attractive areas in Dade County.

The land around the Bay has most of the urban services and facilities required for medium and high-intensity uses; however, these conditions should be balanced by the environmental constraints and guidelines identified in this symposium.

TRANSPORTATION

The opening of the Bay to automobile traffic was a major development in the 1910's. The completion of the Venetian Causeway was a decisive factor in the early success of Miami Beach. The traffic increased and the land development market required a higher level of accessibility. Within a few years the number of causeways increased up to the present total of eight.

In terms of street patterns, the main problem in the Bay area is the North-South traffic. Inland, Biscayne Boulevard carries a heavy load and the parallel I-95 can not handle peak hour traffic. The corridor is saturated with facilities and the only hope is the construction of the rapid transit system.

A similar situation occurs in Miami Beach. To give an idea of the magnitude of volumes, it is important to notice that Collins Avenue is carrying the same average daily traffic as that of Oakland Branch of the San Francisco Rapid Transit, in terms of the number of persons moving within the corridor.

In 1950, the County ordered a consultant to prepare a "concept plan" for linking Miami Beach with Elliot Key. In 1962, the need for additional North-South facilities led Dade County to propose the Biscayne Bay Expressway, an elevated highway through the middle of the Bay from North Miami Beach to Downtown Miami.

Fortunately, from an environmental standpoint, none of these proposals advanced from the very preliminary stages. Still, the most pressing problem, from the point of view of the users of the Bay, is the lack of physical accessibility to the waterfront areas, and the opportunity of experiencing the unique qualities of the Bay.

The fact that the Bay is not easily accessible is reflected by the relatively low level of recreational trips attracted to the bayfront areas. Table II shows a comparison of work and social recreational trips.

In 1975, work was the predominant purpose of trips to the study area, for a total of 719,438 person trips, representing 8.5% of total Dade County trips. Social recreational trips during the same year were just 519,866 person trips. Traffic projections for 1985 and year 2000 accentuate this gap. It is estimated that by year 2000 work trips will be 1,028,212 persons, and social recreation trips just 642,569 persons. Most of these higher work trip generations are due to the large amount of office development along bayfront areas.

The proposed Mass Rapid Transit could increase the accessibility to the Bay, making it a more widely appreciated amenity for the residents of the area.

INVENTORY AND ANALYSIS OF THE BAYFRONT AREA

Prior to the beginning of this century several small villages including Coconut Grove, Lemon City, Fort Dallas and Ulita were in existence. At the turn of the century, expansion of the railroad from Palm Beach to Miami in 1896 was a main force in providing accessibility to northern markets and bringing tourists and new population. At the beginning of the century, most of the 5,000 or so permanent residents of Dade County lived near the Bay and the Miami River.

The process of urban growth was slowly moving north of the Port of Miami and west of the Flagler Railroad during the first two decades of the century. The real estate boom of the 1920's accelerated the process and generated two irreversible trends; the construction of causeways across the Bay and dredge-and-fill operations that allowed the development of low lands. Thus, the form and characteristics of the Bay were changed drastically. From 1920 to 1925 the population of Dade County area increased from 30,000 to 177,000.

For purposes of this report, Bayfront areas have been divided in three areas; including the North Bay area, Miami Beach and South Bay area. The South Bay area and the North Bay area are divided in the vicinity of Venetian Causeway.

The North Bay Area

The North Bay area, North of the Venetian Causeway, was developed as a suburban entity of the City of Miami. Subdivision after subdivision was added to the City, converting agricultural land to residential uses.

One large project in this area deserves special mention; the City of Miami Shores.

Developed by two corporations, the Shoreland Corporation and a subsidiary, the Miami Shores Corporation, the City had originally 26,000 acres and the development plan was based on the extension of Biscayne Boulevard from Miami, the construction of the first street with underground electric lines and a very imaginative link to Biscayne Bay.

The original plans included an artificial island of 500 acres to be created on the Bay, linked to Miami Shores by a causeway slightly over one half mile long; impressive waterfalls and canals with gondolas, a combination of yacht and country club and the most common leisure facilities such as a golf course, hotels, and theaters. Miami Shores was affected by the crash of the real estate market at the end of the 1920's and unfortunately most of the eclectic although imaginative proposals were not implemented. Today a small city of approximately 10,000 residents is a well-maintained residential area, but without the original grandeur suggested in the 1920's plan.

The most visible approach to the urban use of the Bay was the creation of artificial islands, rapidly subdivided for residential uses with the most utilitarian and narrow approach: to maximize the number of waterfront lots, without any concern for the public access to the water. The "inner" areas of these islands do not relate at all to the Bay, lacking even visual access.

The latest of the grandiose schemes in the North Bay area was Interama, which after many years of intensive effort to develop a solid financial base, collapsed a few years ago.

After the failure, part of the land was transferred to Florida International University for the development of a second campus. The City of North Miami is planning a large park in the area, purchased with funds from a city bond issue.

Although established neighborhoods such as Miami Shores, Bay Point and others have no immediate redevelopment potential, other areas of lesser quality or unity of character suggest that a considerable amount of redevelopment could occur in the relatively near future.

Miami Beach and Islands in the Bay

The area south of Haulover Beach has been developed for single-family residential use with the exception of Mount Sinai Hospital and some commercial and multi-residential development. Intensive condominium development dominates the area north of MacArthur Causeway.

The Port of Miami is one of the major combined tourist and cargo ports in the U.S. Visual sensitivity to the Bay was recognized in the development of this Port.

Virginia Key and the majority of land on Key Biscayne have been retained in recreational uses. This combined area represents the major recreational complex in Dade County. Unfortunately, high week-end traffic volumes on Rickenbacker Causeway make the use of these areas difficult for many residents and tourists. The residential area on the bay side of Key Biscayne is developed as single-family residences. The possibility of short-range redevelopment to different uses does not exist.

The South Bay Area

For purposes of this report, the South Bay area begins in the vicinity of the Venetian Causeway.

The Omni and Plaza Venetia projects located at Biscayne Boulevard near the entrance to Venetian Causeway are now under construction and represent one of the largest urban development projects to be initiated in Dade County. Unfortunately, visual and physical penetration to the Bay may be dimished when this project is completed. Immediately north of this project are a number of older single-family homes and multi-family units. As result of the Omni project a major precedent has been established for more intensive development of this area. Visual and physical penetration by the public to the Bay should become a planning policy for the entire area.

South of MacArthur Causeway is the Bayfront Park area. The northern end of the Park is now under construction as result of funds from a recently passed bond issue. This site is also under major consideration for the new County Art Museum. The Bayfront Park complex provides a major linkage between downtown Miami and the Bay. Integrated with Bayfront Park is the Miamarina complex, a combined restaurant and marina, which incorporates imaginative design in a bayfront area.

A major development potential exists on the property now used for open auto parking at the southern end of Bayfront Park and to the north of the Dupont Plaza Hotel. The area is planned for office and commercial uses.

South of the Miami River is an area known as the Brickell area, which terminates at the Rickenbacker Causeway. A transition from single-family to office, hotel and condominium uses began in the early sixties. Today prestigious office uses and the Four Ambassadors Hotels dominate the skyline in the northern part of the Brickell area. Unfortunately, visual and physical access to the Bay has been diminished at the pedestrian level. Future development should incorporate more sensitivity to public bayfront access.

As a result of the Brickell Area Study prepared by the City of Miami Planning Department, zoning ordinances and review board was established which offers bonus provisions for developers who give visual and physical access to the Bay.

South of the Rickenbacker Causeway is a high income area of single-family homes. Redevelopment of this area seems unlikely due to its homogeneous character. No major rezoning requests have been initiated in this area, with the exception of property that fronts on South Miami Avenue. Bay access to the public is provided by the Alice Wainwright Park. Immediately South of this area is the Viscaya home and gardens. This complex once owned by the Deering family and now owned by Dade County is one of the major assets of the community. South of Viscaya is the Mercy Hospital complex. A considerable amount of acreage associated with this hospital indicates a real potential for further development. Unfortunately this complex already has severely blocked the view of the Bay.

Fair Isle is an undeveloped island which has undergone extensive zoning battles. Although development does not seem imminent in the near future, a long range development potential does exist. The intensive development of Fair Isle could result in the rezoning of adjacent bayfront properties to intensive uses. The Coconut Grove Study prepared by the City of Miami Planning Department indicates Fair Isle for multi-family development.

Kennedy Park is the next major open space on the Bay. The Park was recently completed with funds resulting from approved bond issues. Several yacht clubs south of Kennedy Park give private access to Biscayne Bay. The Dinner Key area includes the City Hall of the City of Miami and government offices. The City Hall structure was originally the sea plane terminal for Pan American Airways.

The Coconut Grove Bayfront Park terminates the major open space uses in Coconut Grove although some access is provided at the Barnacle, an historical landmark. West of the Barnacle is an area that fronts on Main Highway in downtown Coconut Grove which is presently being considered for rezoning to permit residential development.

South Coconut Grove is one of the early areas of development in Miami. Old prestigious homes with several new additions such as the Dupont Estate front on the Bay. This is a well established area, begun before the turn of the century, and redevelopment is unlikely in the forseeable future.

South of Coconut Grove and in the City of Coral Gables are several high-intensity multi-family structures. These units face on the waterway near the waterway's entrance to Biscayne Bay and were the result of court ordered zoning.

South of the Coral Gables Waterway is the ill-fated Cocoplum project. Original plans for this project indicated a mixture of housing types around a golf course facility. Zoning was not approved for the project and the developer decided to use the existing single-family zoning to build individual homes. At that time the State intervened, principally the Trustees of the Internal Improvement Fund, the Department of Pollution Control and the Coastal Coordinating Council, and prohibited the development of any single-family homes in low land areas which is a good part of the site. Today, several single-family homes are under construction on the high ground areas. Tahiti Beach, which was on this site and open to the public, was closed as a result of construction for the Cocoplum project.

Gables Estates, south of the Cocoplum tract, is a very high income single-family neighborhood. Although densities are low, visual and physical access to the Bay is virtually lost for the public.

Matheson Hammock, a major recreational area for Dade County, is one of the best examples in South Florida of integrating a public open space facility with the natural quality of the area. A marina, bike trails, picnic areas and other bayfront passive and active uses are available.

Of recent origin and of major importance in the South Bay area is the Saga Development. A mixture of residential types are proposed, with some already completed. A buffer area between the Bay and the Saga project was retained. This resulted from recommendations included in the South Bay Area Study prepared by the Dade County Planning Department.

The South Bay area, unlike the majority of the North Bay area and the Beach, still has large undeveloped land areas that have the option of being planned on sound environmental principles. The Turkey Point power plant is the only major developed land use south of the Saga project area. The concept of a natural buffer between development and the Bay should be utilized as a development policy in the future. In fact, the recommendations toward very limited development in the South Bay area should be a paramount planning policy. The Dade County Planning Department has designated all undeveloped bayfront property as an area of environmental sensitivity on the Year 2000 Plan.

CONCLUSION

Biscayne Bay urban area needs a planning process that could coordinate the agencies and organizations with vested interest in the Bay, those with power and resources to influence decisions. Participants in this process could be the County, municipalities, and universities and interested community organizations and citizens.

The future of Biscayne Bay is and should be a main concern for local government and the Dade County residents, working within the framework of state and federal legislation.

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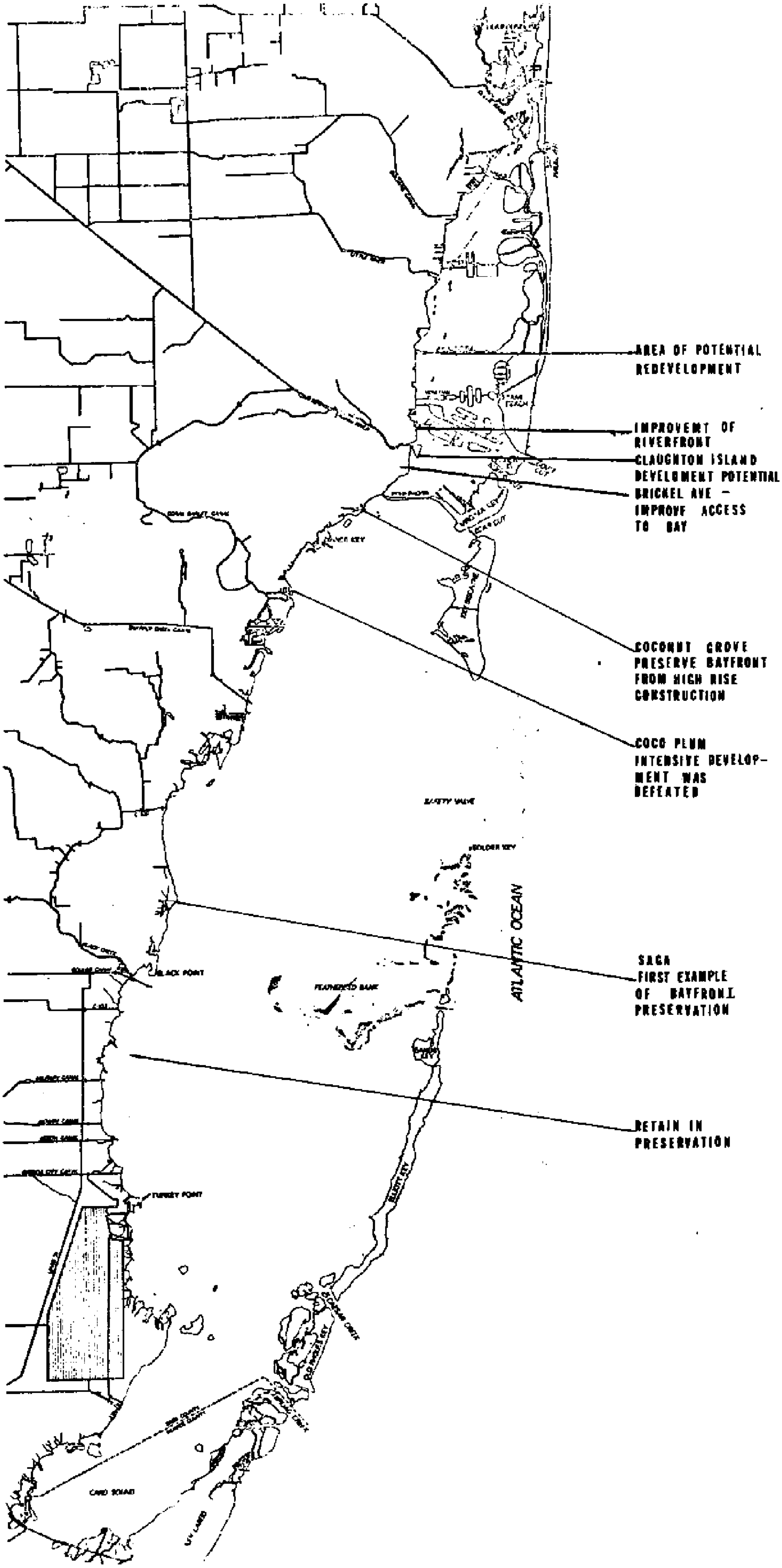
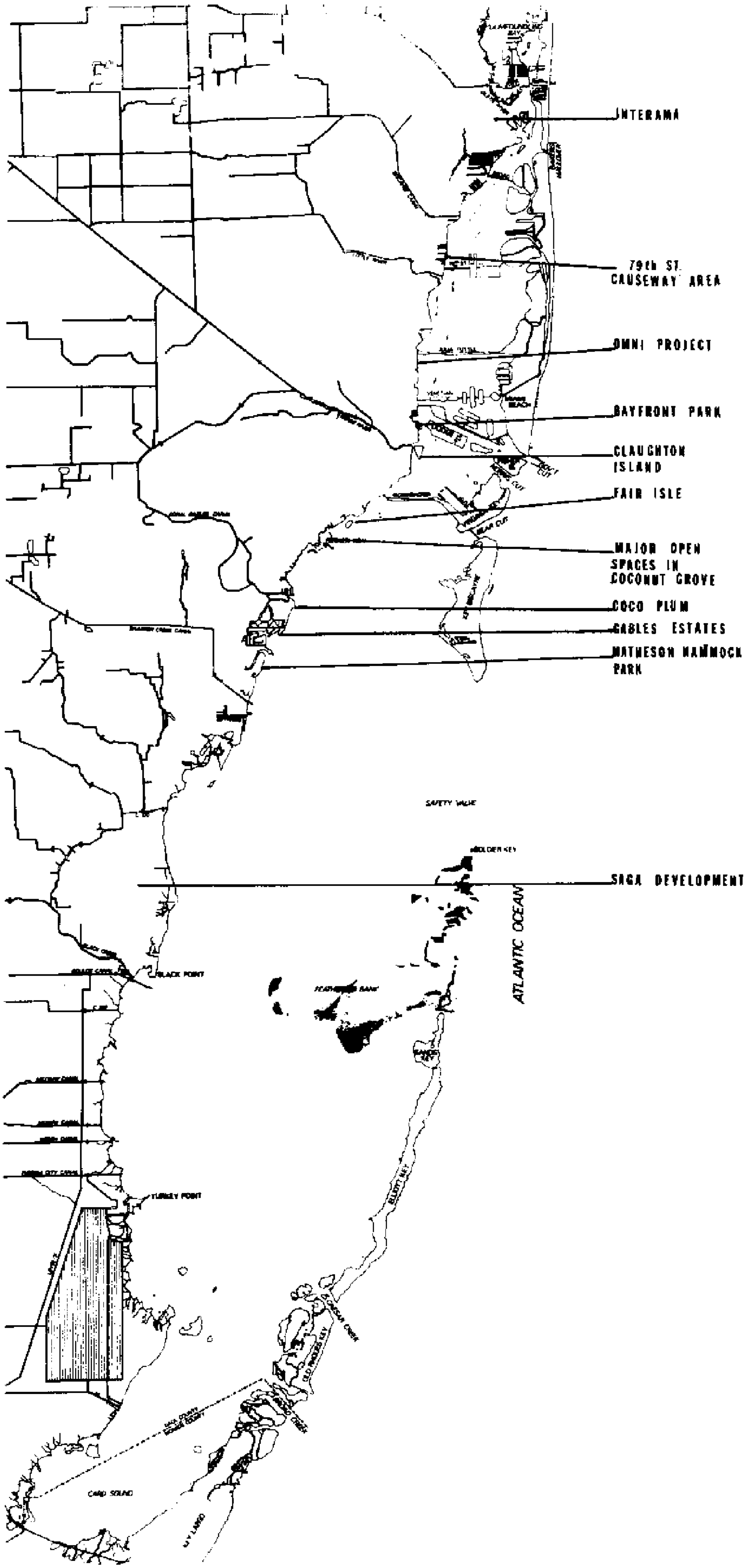


PLANNING ISSUES ON THE BAYFRONT



MAJOR BAYFRONT DEVELOPMENT

TABLE I

POPULATION

By Sub-Areas for Years 1950, 1960, 1970 and 1973

	1950	1960	1970	1973*
North Bay Area	28,843	38,157	45,503	48,780
South Bay Area	13,825	18,947	25,169	26,590
Miami Beach Area	20,814	41,110	54,170	54,980
Total Bay Area	63,482	98,214	124,842	130,350
Total Population of Dade County	495,084	935,047	1,267,792	1,365,550
Bay Population as % of Dade County	12.8%	10.5%	9.8%	9.5%

*Estimate, Dade County Planning Department.

SOURCE: U.S. Census of Population, 1950, 1960, 1970 and 1973, Metropolitan Dade County Planning Department.

TABLE II

TRAFFIC GENERATION

By Sub-Areas, by Purpose for Years 1975, 1985 and 2000

	1975		1985		2000	
	Social Recreation	Work	Social Recreation	Work	Social Recreation	Work
North Bay Area	11,782	16,091	11,885	18,069	12,242	19,733
South Bay Area	10,942	20,880	12,556	33,019	13,547	40,298
Miami Beach Area	16,188	24,511	17,348	27,182	23,244	26,546
Total Bay Area	38,912	61,482	41,789	78,270	49,033	86,577
Total Dade County	519,866	719,438	585.401	888,315	642,569	1,028,212
% of Total	7.5%	8.5%	7.1%	8.8%	7.6%	8.4%

SOURCE: Preliminary Data, MUATS Department of Traffic and Transportation, Dade County, 1976.

Man's Impact

THE IMPACT OF WORKS OF MAN ON THE PHYSICAL REGIME OF BISCAYNE BAY

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ABSTRACT

In 1896 when the City of Miami was founded Biscayne Bay existed in a natural condition much as it had over past centuries. Development began shortly after with the construction of Government Cut, an artificial inlet, and the Miami Ship Channel. The peak of development occurred between 1919 and 1926 with the construction of two causeways and another artificial inlet, Baker's Haulover. By this time the circulation of the Bay was completely altered from its original condition and, in fact, water quality was vastly improved. After a hiatus in development from 1926 to 1946, activities began again on a large scale with the construction of three causeways and a large land fill for the Port of Miami. Although man's impact on North Biscayne Bay has been extremely severe on the biological community, the changes caused by construction of inlets have resulted in a much greater exchange of water between the Bay and the ocean. This benefit has been partially offset by construction of causeways which has decreased and constricted the circulation within the Bay. In 1974 the State Legislature passed a strict law regulating development of the Bay. Future activities will therefore be limited and subjected to careful scientific scrutiny.

INTRODUCTION

In 1896 when the city of Miami was founded, Biscayne Bay existed essentially in a completely natural state. In spite of the fact that the bay may have been affected by human activities since 1100 B.C. as reported by Chardon (in this volume) the import of such a small primitive population on tidal circulation was negligible as compared to what happened in the subsequent 80 years of dynamic growth.

Since changes of major significance have been limited to the northern part of the Bay, the area considered in this presentation will extend generally from Dumfoundling Bay on the north to a line drawn west of the southern tip of Key Biscayne. This discussion will be limited to the effects of those works of man that have actually changed the geometry and thus the hydrodynamic characteristics of the Bay. Discussions of other factors such as the introduction of nutrient and sewage effluent will be covered elsewhere in this volume. Fig. 1 shows a major portion of the area described as it now exists, including all of the development projects discussed.

DISCUSSION

Physical Factors

Biscayne Bay is a shallow estuary separated from the Atlantic Ocean by a chain of spits and islands formed by accretion of the prevailing littoral transport of sand from the north. Interchange of bay and ocean waters is driven by the ocean tide through a series of inlets between the islands and around the south end of Key Biscayne. The ocean tide is semidiurnal, having a mean range of 2.5 feet and a spring range of 3.0 feet (National Ocean Survey, 1974). Swanson (1974) indicates that the mean sea level at Miami Beach has been rising since 1924 at a rate of .012 feet per year (approximately one foot in 80 years). Analysis by Marmer (1951) of earlier records at Baltimore, Md. and New York, N.Y., indicates that this trend has existed along the Atlantic Coast of the U.S. at least since 1893 but at a slightly lower rate.

In understanding the effects of the works of man on an estuary such as Biscayne Bay it is important to understand the effect of the tidal prism on the circulation in the estuary and the exchange of waters with the ocean. The tidal prism is the amount of tidal flow entering and leaving the estuary with each tide. It can be approximated by multiplying the mean surface area of the estuary by the mean tidal range within the estuary.

Since the oceanic water is generally of better quality than that of the estuary, a large tidal prism as compared to the volume of the estuary is desirable from the point of view of water quality. If the surface area or tidal range is increased the tidal prism will increase and decreases in these parameters will cause decreases in the tidal prism. Increases in surface area may be caused by dredging canals or lagoons, decreases are caused by land fill, either in the form of islands or by marginal fills of inundated marsh land. Since the tidal range within the estuary is reduced from that of the ocean by frictional resistance, opening of channels within the estuary or the enlargement of inlets connecting it to the ocean will tend to increase the tidal range.

The portion of Biscayne Bay lying north of Cape Florida presently has a surface area of about 2 billion square feet and a mean tidal range of about 2 feet, giving a tidal prism of about 4 billion cubic feet per tide. By way of comparison, the Miami River which is the principal source of fresh water has an average flow of 701 cubic feet per second which corresponds to .016 billion cubic feet per tide or 1:250th that of the exchange with the Ocean. This shows the great significance of the tidal prism as the driving force of the circulation of Biscayne Bay.

In addition to its effect on circulation, changes in the tidal prism have a considerable effect on the littoral processes along the ocean beaches by way of the inlet. Any inlet interrupts the flow of sand along the beach causing sand to go out to sea and sand to go into the estuary. The more flow through the inlet, the more effective it is as a barrier. Since the net littoral drift in southeast Florida is from north to south, an inlet will tend to cause accretion to its north and starvation of beaches to its south. Inasmuch as the volume of the tidal prism must be carried in and out through the inlets on each tide, its volume will effect the transport of sand, intensifying or alleviating erosion as it increases or decreases.

Biscayne Bay in 1896

In 1896 Biscayne Bay was not much different than it had been for the last few centuries. Its northern portion was extremely shallow with the northernmost inlet being Norris Cut, 13 nautical miles to the south of Dumfoundling Bay. This was then as it is now a shallow inlet with relatively little tidal flow. Approximately one mile further south was Bear Cut which had a substantial cross-section and contributed considerably to the tidal exchange with the Bay. By far the largest portion of the exchange with the Ocean came across the swash channels south of Cape Florida and flowed northward. Although no data on tidal ranges are available, the tidal range in Dumfoundling Bay must have been very small while the range at Cape Florida was very nearly that of the open ocean. This would have given a tidal prism of about half its present value and would have produced a situation of brackish, stagnant water at the north end of Biscayne Bay and in Dumfoundling Bay. Charts of the area by the U.S. Coast and Geodetic Survey (1887) show large marsh areas all along the shores of the bay. With the predominance of tidal flow coming from south of Cape Florida, the littoral transport of sand to that point would have had little interference.

The Opening of Government Cut

On 13 June 1902, Congress authorized the U.S. Army Corps of Engineers to provide a channel 18 feet deep through the peninsula approximately one half mile north of Norris Cut. This project was completed in 1905 and has been widened and deepened ever since. Initially the dredged material was placed on a spoil bank to the north of the channel to form what is now known as the MacArthur Causeway. Only two openings were provided in this spoil bank, one along the shore of Miami Beach, and one along the mainland shore. Both of these openings are the same width today as they were constructed at that time. However, the openings were shallow and restricted the tidal flow. Depths on the Miami Beach side as shown by the U.S. Coast and Geodetic Survey (1919) were only two feet. The westerly opening was only slightly less restricted. It is interesting to realize that at that time Miami Beach was little more than sand dunes and mangrove swamps. The construction of Government Cut and the Miami Ship Channel with its attendant spoil bank must have greatly reduced the tidal prism of the area north of the spoil bank by restricting the flow and thus reducing the tidal prism. Although we have no data to confirm this, the water in the northern area must have been very stagnant as a result of the channel dredging, with significant circulation only along the west side of the bay. With few changes this situation existed until 1919.

As a result of the tidal flow through the Cut, the beaches along Fisher Island, Virginia Key and Key Biscayne began a cycle of erosion which has intensified ever since as navigational improvements were made to the channel and the inlet.

The Development of Miami as a Resort Area (1919-1928)

The contrast between charts showing the Biscayne Bay area in 1919 and 1921 (USC & GS 1919 and 1921) presages the spectacular growth that occurred during the next ten years. In 1919 the situation remained basically as it was on completion of Government Cut and the Miami Ship Channel. The chart shows Star Island, just north of the causeway as existing or under construction, and a wooden bridge is shown crossing shallow water in the present location of the Venetian Causeway.

The 1921 chart shows that extensive dredging and filling has occurred, particularly in the Miami Beach area south of the Venetian Causeway. This dredging resulted in the opening of a major channel along the west shore of Miami Beach known as Meloy Channel from the northern portion of the Bay to Government Cut. A major improvement in the circulation of this part of the Bay must have resulted, but it may have been masked by an increase in sewage pollution due to the rapidly increasing population. At this time we also see islands constructed along the causeway.

Whatever the situation in 1921, the most spectacular improvement in the waters of the northern part of the Bay occurred when Baker's Haulover, 8 miles north of Government Cut was opened as a tidal inlet in 1924. This inlet would have completely changed the environment of the area by increasing the tidal range and providing large quantities of oceanic water in each tide to the upper bay area.

Although this inlet improved the water quality in the Bay, it has had disastrous effects in erosion of the beaches to the south. The effect over the years of this inlet and other inlets to the north has all but taken the beach out of Miami Beach.

In 1925 the old wooden bridge connecting Miami Beach to the mainland was replaced by the Venetian Causeway as it now stands. This causeway, originally constructed as a private toll facility, runs across five artificial islands constructed at the same time and Belle Isle which was a natural island. The waterways between the islands are traversed by bridges and fill sections. This construction might have been disastrous except that fill for the islands was taken from the adjacent shoals deepening the entire area between the MacArthur and Venetian Causeways from an average of 4 feet to 8 feet and providing a wide channel 8 feet deep along the north side of the causeway. This would have greatly enhanced the east-west circulation in the area and tended to equalize the flow along the Miami and Miami Beach shores.

As filling activities progressed northward a borrow channel 8 to 10 feet deep was created along the entire eastern shore of the Bay. On the west side of the Bay the Intracoastal Waterway was constructed 8 feet deep and 75 feet wide. Land fill along the Miami side was less continuous than on the Beach, so no definite borrow channel was created, just a series of borrow pits.

During the latter part of this period as the city grew northward, the 79th Street Causeway was constructed. Although this causeway with this type of construction would normally have constituted a considerable obstacle to circulation, its effect was minimized by its location very near the nodal point where tidal flow from the south meets that from Baker's Haulover.

During this period, the Miami Ship Channel was improved several times by deepening and widening and a line of spoil islands was created along the south side of the channel.

One fortunate aspect of the dredging activities during this period is that the borrow areas were no more than 8 to 10 feet deep. This was due to the limited depth capabilities of the dredges used and to their inability to handle hard material. As a result, only a relatively small portion of the Bay could be filled whether the developers liked it or not.

In 1928, with the crash of the stock market, the development boom burst creating a status quo until after the end of World War II in 1945.

The Post War Years (1945-1975)

As soon as construction materials became available after World War II another building boom hit the Miami area. After nearly twenty years of practically no activity, projects began to be developed to accommodate the rising population. One of the first activities to affect the Bay was the construction of the Rickenbacker Causeway between the mainland and Key Biscayne. This causeway, planned prior to World War II, was mostly on fill with two openings: one a short span near the west shore of the Bay, and the other a long span approximately in the center of the Bay. The stretch between these spans was constructed on fill obtained from a borrow pit located just to the north of the Causeway. This pit was dredged to a depth of over 20 feet in places so that it acts as a trap for detritus. In spite of this, the water quality in the pit is good with only the bottom sediment in an anaerobic condition. Since the area was very close to the inlets to the Bay, not much change was caused in the circulation of the lower bay.

In 1951 the Broad Causeway was constructed across the northern part of the Bay. Although most of the solid fill was constructed in shallow water, this causeway restricted the tidal flow enough to reduce the exchange between the Ocean and the Bay north of the 79th Street Causeway. This caused a problem in that flotsam in the vicinity of Miami Shores is not flushed to sea. No significant borrow pits are associated with this structure.

In 1960 construction was begun on a new port for the City of Miami located just south of the Ship Channel. This port which is still under construction is situated on an island created by filling some of the existing spoil islands. At the present time the island contains about 280 acres. It is surrounded by deep channels and turning basins which tend to increase the circulation in the area.

About the same time, the Julia Tuttle Causeway was built across Biscayne Bay between the Venetian and 79th Street Causeways. This structure has bridges near the east and west ends designed to accommodate navigation with a solid fill approximately 1.5 miles long between the bridges. Fill was obtained from a borrow pit to the north of the embankment. In places this pit is 29 feet deep. The existence of the solid fill concentrates the tidal flow along the sides of the Bay and tends to restrict circulation in the center.

The Outlook for the Future

Although the construction activities of man in the northern portion of Biscayne Bay have been so extensive that it can almost be considered as an artificial waterway, the alterations in the tidal prism and construction of inlets have been such as to improve water quality rather than detract from it. This is in contrast to areas on the Gulf Coast such as Boca Ciega Bay near Tampa where land fills have blocked the circulation. Obviously, the activities have completely altered the biological systems.

With this in mind the State Legislature enacted a law designating Biscayne Bay as an aquatic preserve. This law was signed by the Governor on 11 June 1974. Stating its intent to preserve an essentially natural condition, the law places stringent controls on future work in the bay. Thus, it is not likely that any new structures such as those described here will be build. It is likely that old structures such as the Venetian Causeway will be replaced, but only after careful scientific scrutiny so that the new structures will be an improvement over the old.

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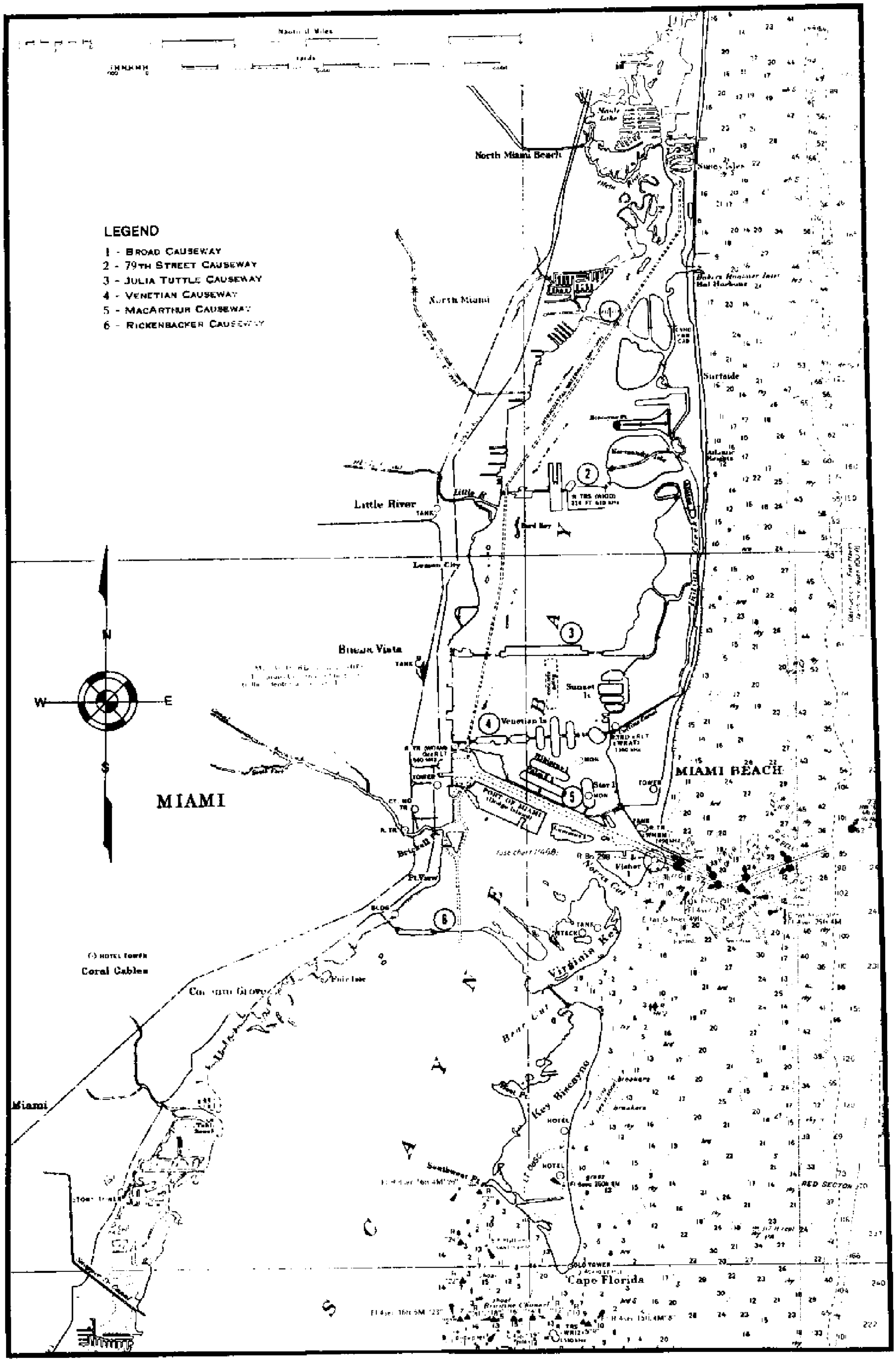

Fig. 1 Area Map (Source: Chart No. 11466, NOAA).

EFFECTS OF WATER MANAGEMENT ON FRESH-WATER DISCHARGE TO BISCAYNE BAY

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ABSTRACT

Prior to development in southeast Florida, fresh water discharge to Biscayne Bay consisted of flow through natural drainageways, overland flow, and coastal underseepage from the Biscayne aquifer. Through the years, the characteristics of the fresh-water flow have changed from natural, sporadic, short bursts of rainy-season flow through the low drainageways and prolonged dry-season coastal underseepage, to regulated discharge through drainage canals and decreased periods of coastal underseepage.

The fresh-water flow to Biscayne Bay has been significantly reduced in quantity and in time, due to extensive flood and water-control measures and water-management practices instituted after the extensive flooding of 1947. By the end of 1962, surface flows could be fully controlled in the Everglades by a system of levees and canals, water-conservation areas, pumps, and flow regulation structures. Thus, since 1953 annual fresh-water flow to Biscayne Bay has been reduced by about 20 percent and the duration of storm-water runoff has also been reduced. Flood control measures in south Dade County have altered the pattern of fresh-water flow to the Bay. Ground-water level recession rates in south Dade County are twice as rapid as they were before the implementation of flood control measures there. This means that the Bay receives fresh-water runoff for only about half as long after a storm as it did previously.

Implementation of planned water-management practices would result in further reduction of fresh-water runoff to the Bay. Further changes in south Biscayne Bay could be expected if urbanization in south Dade County approaches the density of that of Miami and vicinity.

INTRODUCTION

Biscayne Bay is a shallow tropical lagoon about 35 miles long, as much as 10 miles wide, and 12 feet deep (see fig. 1). It is bound on the west by the Mangrove Swamp of the mainland, on the east by a series of barrier and coral islands, on the south by Card Sound, and on the north by Dumfoundling Bay (U.S. Dept. of the Interior, 1973). Tidal range in the Bay is about 2.0 feet at North Miami and Coconut Grove and about 1.6 feet near Homestead and at Elliott Key (Schneider, 1969). Tidal range in the Atlantic Ocean at Miami Beach is about 2.4 feet.

Biscayne Bay receives fresh water from rainfall and runoff from the mainland. Rainfall over the Bay ranges from 46 inches per year at Miami Beach to 64 inches per year at Homestead and probably averages almost 60 inches per year over the entire Bay (U.S. Dept. of Commerce, 1974). The rainfall is seasonal; about 70 percent of the annual total falls during the rainy season, normally June through October. Rainfall varies considerably from year to year. During the last 35 years at the Miami station minimum rainfall was 37 inches in 1956 and maximum; 89 inches in 1959 (U.S. Dept. of Commerce, 1975).

DISCUSSION

Under natural conditions in southeast Florida, fresh-water discharged to the Bay from natural drainageways, by overland flow and by seepage from the Biscayne aquifer. Present day inflow to the bay is, seasonal, from controlled canals and seepage.

Under natural conditions most of the land in southeastern Florida, presently utilized for urban, subground, where flooding during the rainy season was less probable. In the 1900's because of major urban expansion in the vicinity of Miami, drainage canals were extended inland along natural drainageways, and through transverse glades (see fig. 2). Urban areas expanded westward on land formerly inundated or used for agriculture, displacing agriculture to land farther inland to the eastern edge of the Everglades.

The hydrologic regimen of the Lake Okeechobee-Everglades area has undergone continuous modification since settlement began late in the nineteenth century. Before drainage and land reclamation in the northern part of the Everglades, water levels in Lake Okeechobee and those in the Everglades adjacent to the lake were about the same during periods of high water; overflow occurred first at two low places on the south shore when water stages reached 15 feet - outflow along the south shore became general at a stage of about 18 feet. Modification of overland flow in the Everglades began when drainage canals and levees were built around Lake Okeechobee beginning in 1881. Most of the excavation for major drainage canals along the lower east coast was completed by 1932 — canals were either uncontrolled or inadequately controlled, and continuous drainage resulted in lowered ground-water levels and sea-water intrusion into the Biscayne aquifer in the Miami area (see fig. 3). After the 1943-45 drought, major canals through the coastal ridge were equipped with control structures, which prevented overdrainage during dry periods and prevented additional or reduced existent sea-water intrusion.

Extensive flooding which followed the heavy rains of 1947 demonstrated the need to improve the water-control systems. The 1947 flooding led to the establishment in 1949 of the Central and Southern Florida Flood Control District, whose functions were to furnish flood protection to urban and agricultural lands during rainy seasons and to provide facilities for conserving water for alleviation of the effects of drought. Work on new water-control facilities in collaboration with the U.S. Army Corps of Engineers proceeded during the 1950's; water Conservation Areas 1 and 2 were enclosed by levees in Palm Beach and Broward counties (fig. 1). By the end of 1962, water Conservation Area 3 was enclosed on the south side and for the first time, surface flow in the Everglades north of the Everglades National Park could be fully controlled. Conservation Area 3 was considered fully enclosed by July 1967. Additional changes and modifications in the water-management structures are planned for construction as needed. One of the modifications planned is to provide the capability of moving water to south Dade County during dry periods. Another planned modification is to backpump to the water conservation areas a part of the excess storm water that normally would flow to Biscayne Bay. The water conserved by backpumping would help sustain higher water levels during the dry season.

The prime effect of the water-control works in south Florida has been to facilitate the flow of water out of the Everglades by means of the canal system, thereby changing the spatial and temporal distribution of runoff from the Everglades. Prior to 1961, flow southward toward the Everglades National Park and south Dade County through the Tamiami Canal outlets, based on the 1941-61 record, averaged 252,600 acre-feet per year through the Levee 30 to Levee 67A section, 128,900 acre-feet per year through the Levee 67A to 40-Mile Bend to Monroe section. During 1962-68, average annual discharge through the Levee 30 to Levee 67A section was reduced to about 63,200 acre-feet, the discharge through the Levee 67A to 40-Mile Bend section increased to about 323,600 acre-feet, and the discharge in the 40-Mile Bend to Monroe section remained about the same. Adjustments in operation of canals and control structures to meet changing needs have changed the amount, timing, and distribution of seaward discharge of the Miami Canal which drains the Everglades and transects the coastal ridge. Reduction in flow to the ocean began with completion of the levee systems east of the three conservation areas in 1953. Discharge to the ocean through Miami Canal was reduced an average of 185,000 acre-feet per run-off year for 1956-65. Overall reduction of fresh water flow to the ocean since 1953 as a result of flood and water-control measures is about 20 percent of the fresh water that otherwise could have been discharged to the ocean in southeastern Florida (Leach, et al. 1972).

Before drainage, water levels were near or at land surface along much of the coastal ridge area. The principal effect of pre-1945 land-reclamation practices was the lowering of ground-water levels throughout the coastal ridge and interior areas. Overdrainage of many coastal areas allowed sea-water intrusion of canals and the Biscayne aquifer, the source of nearly all potable water in the area. During 1945, after a prolonged drought, salty water moved up the Miami Canal and intruded the Biscayne aquifer in the vicinity of the Miami well field, when water was being withdrawn at 30 Mgal/d (million gallons per day). The overdrainage has been arrested and, since 1954, water levels have tended to stabilize in most of Dade County (see fig. 3). Yearly peak water levels in coastal areas are considerably lower than in pre-flood-control times, and yearly low water levels are higher than in pre-management times. Thus, in 1971, in a similar dry season to 1945, and following installation of the salinity control structure in Miami Canal at Northwest 36th Street, water was being withdrawn at 95 Mgal/d; minimum water levels near the center of the field were lower than in 1945, but sea-water intrusion was controlled (Benson and Gardner, 1974). The improved conditions of well-field production and salinity control are results of salinity barriers in canals and replenishment of water in well-field areas from canals. Similar conditions prevail at other near-shore well fields in the southeast Florida area (Hull, 1975).

The effects of the new canal system and flood-control practices on the hydrology of south Dade County were also marked by a change in the recession rate of ground-water levels. Figure 4 shows selected graphs of parts of the water level recorded at well S-182, a short distance north of Canal 1 (see fig. 1 for location), to contrast the recession rates before and after Canal 1 and the salinity control S-21 was completed in December 1961. The graphs show that the recession rate for part of June 1961 (pre-canal construction) was about 0.2 foot per day, half the 0.4 foot following canal construction. The increase in the rate of recession indicates that the duration of runoff to the bay has been appreciably reduced.

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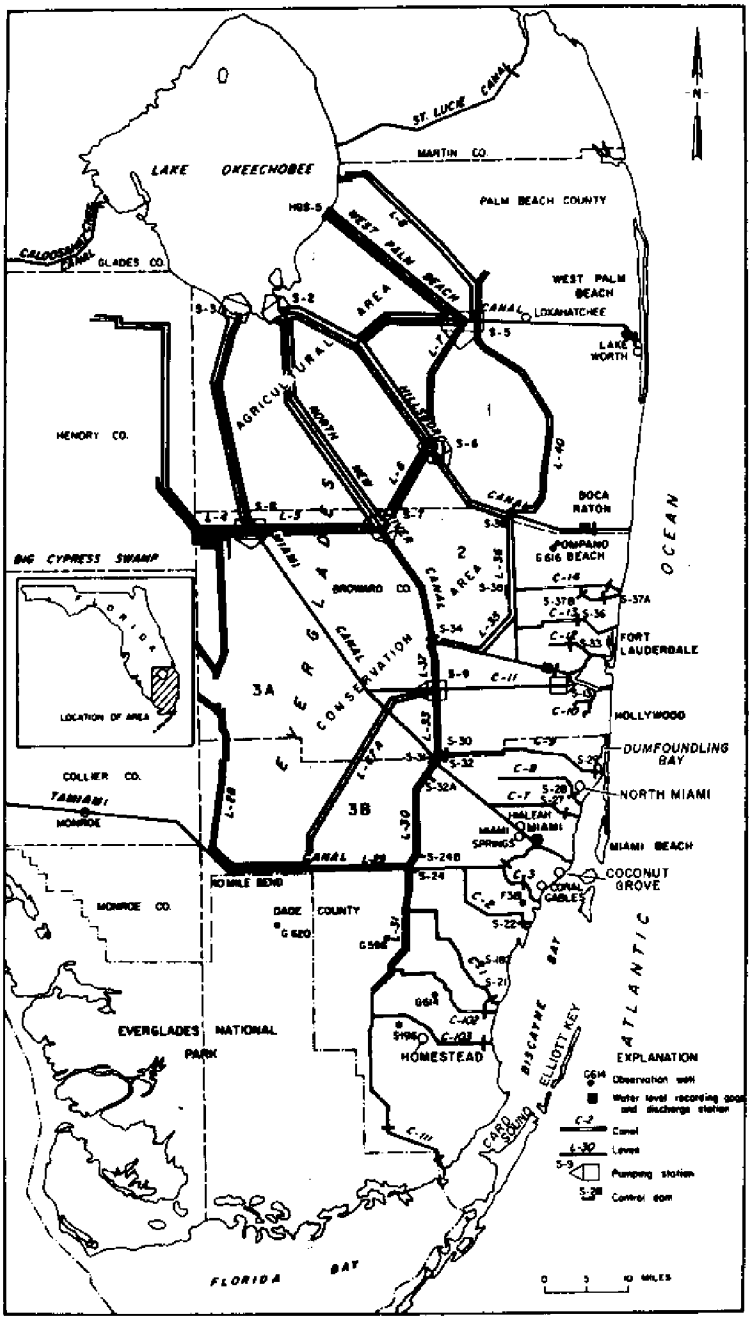

Figure 1. Central and Southern Florida Flood Control project structures and hydrologic features in southeastern Florida.

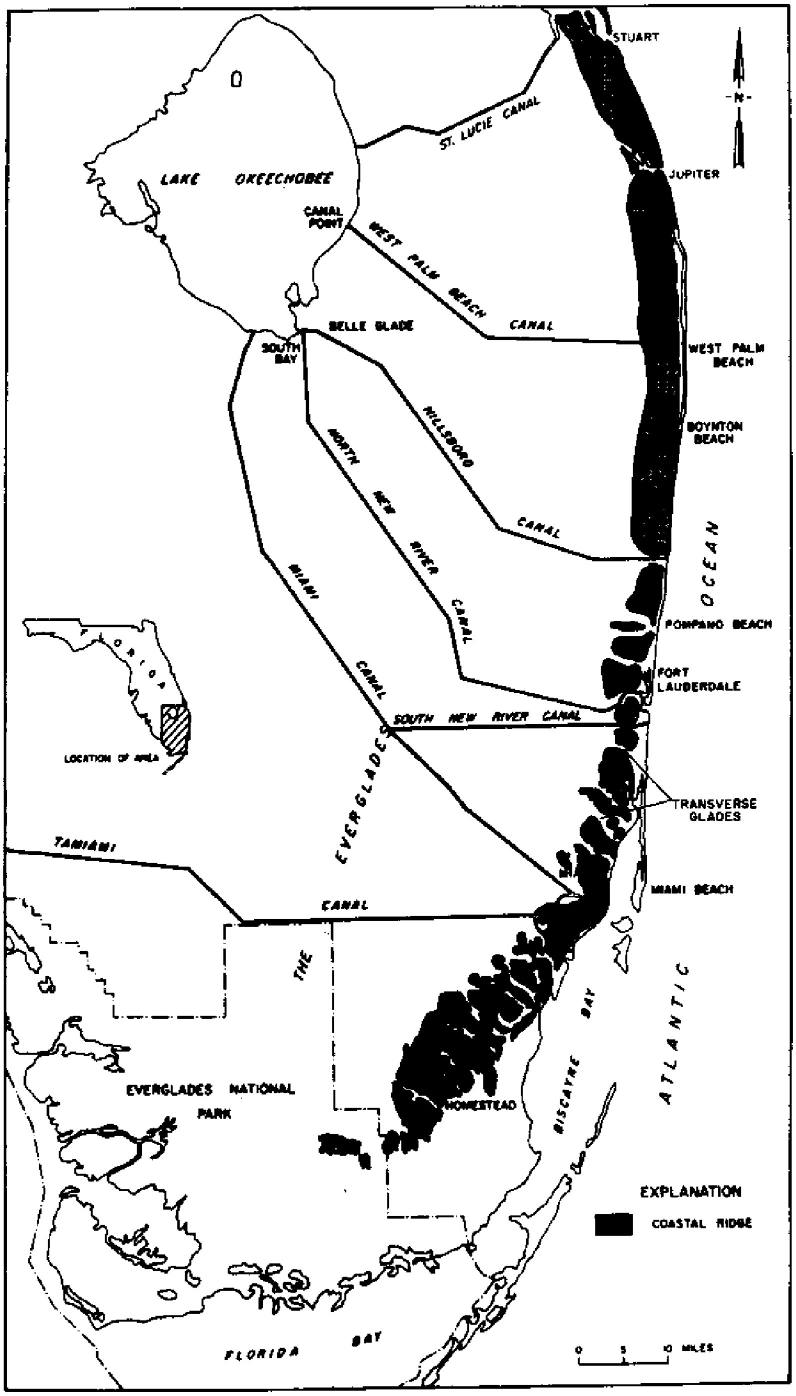

Figure 2. Florida's lower east coast showing the configurations of the natural drainageways (transverse glades) and locations of major canals through the coastal ridge.

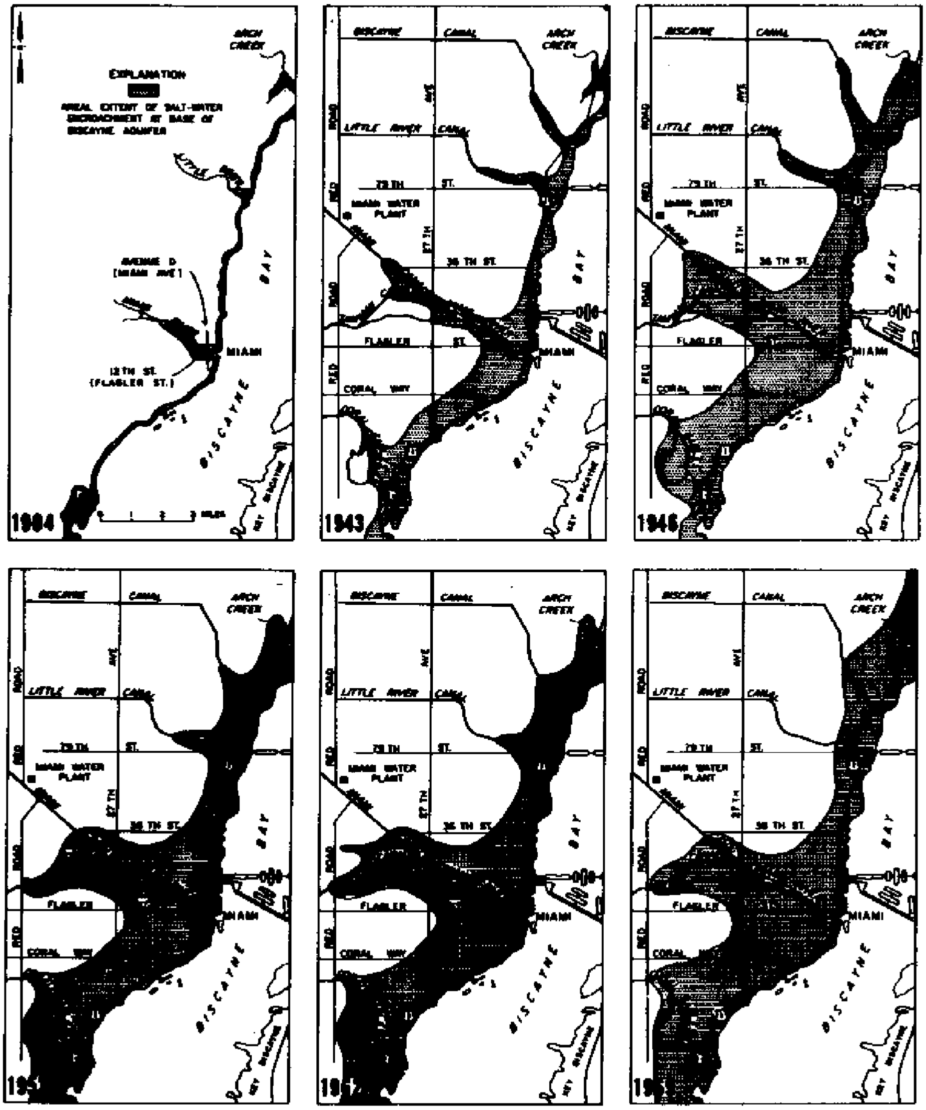

Figure 3. Miami area in eastern Dade County showing the sea-water encroachment at the base of the Biscayne aquifer 1904-69.

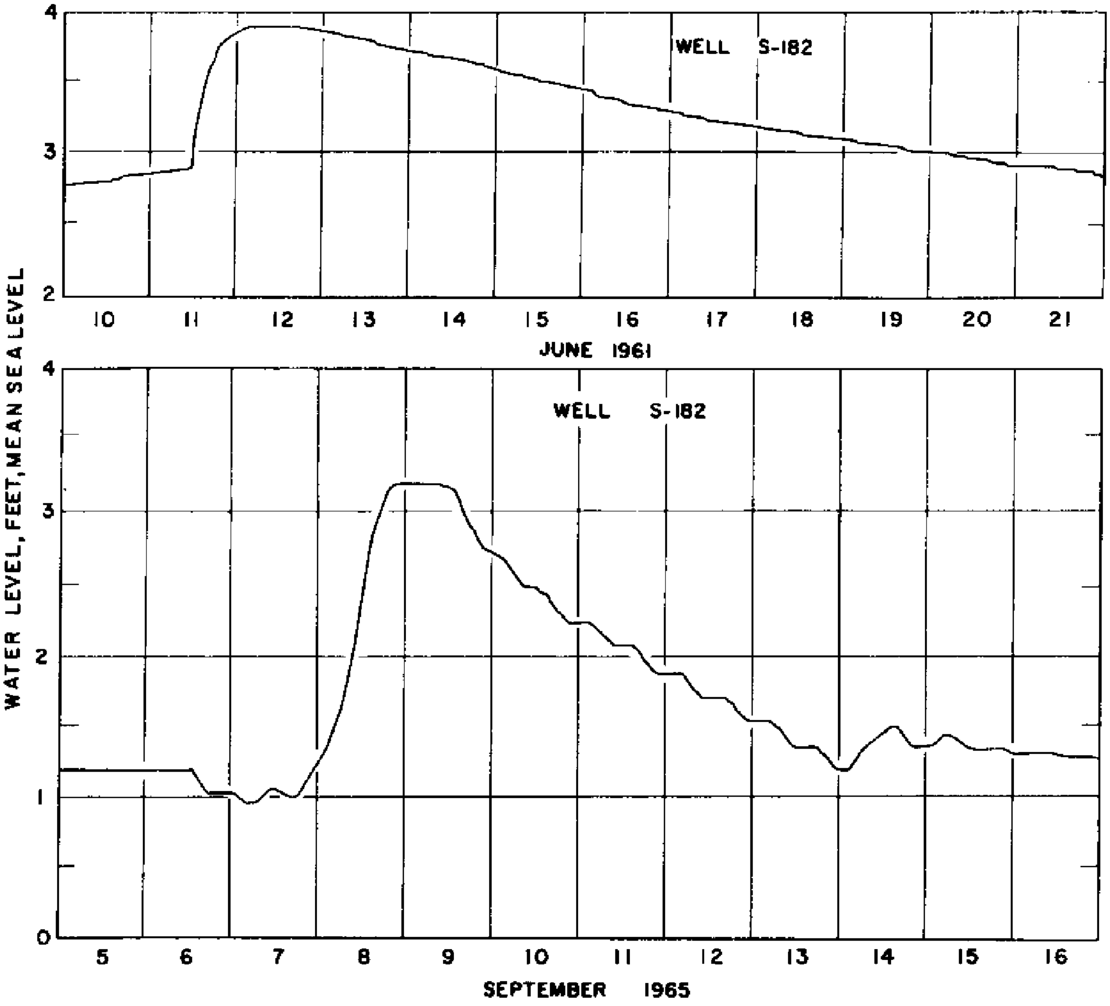

Figure 4. Hydrographs of well S-182 showing water-level recession rates before and after construction of Canal 1.

MAN'S IMPACT ON THE CHEMISTRY OF BISCAYNE BAY

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ABSTRACT

Water quality data for Biscayne Bay have been evaluated with respect to man's impact. The major data collection effort in the Bay has been performed by the Dade County Department of Pollution Control. Three years worth of data have been evaluated and no real trends can be identified. Lack of long term information, plus the absence of data on certain parameters make evaluation of water quality in Biscayne Bay very difficult.

Pollution inputs to the Bay are probably due to runoff water from the metropolitan areas. These contaminants are introduced to the Bay via canals and river systems. Data are presented which reflect characteristics of stormwater runoff, and resultant canal water quality degradation. A summer time peak in most of the quality parameters is noted, which reflects stormwater effects.

Data are also presented on specific metals e.g. aluminum and zinc, and the water quality aspect of each is discussed. In addition values for oil and grease in a canal system are shown as indicators of contamination from motor craft operation. The Coral Gables Waterway has been used as the model canal system in this paper.

In summary no real trend in water quality of Biscayne Bay can be determined. Long term monitoring of certain water quality parameters has not been undertaken, hence a good data base is non-existant. The parameters currently being monitored in the Bay area are of questionable use and should be augmented with materials which are common to storm water run-off.

INTRODUCTION

Biscayne Bay, located in southeast Florida is a shallow bay bounded on the west by the Florida mainland and the east by small barrier islands. To the north the bay extends as far as Dumfoundling Bay and to the south as far as Card and Barnes Sound. For the purposes of this report only those parts of the bay north of Card Sound will be considered. Furthermore the bay will be considered to be comprised of two sections; that is the north section, or north of Rickenbacker Causeway; and the south bay section being south of Rickenbacker Causeway. As will be discussed later the north section is characterized by heavy, and dense development close to the water. The south section is predominantly undeveloped around the shore areas of the bay.

The temperature of Biscayne Bay varies between a seasonal high in the upper 80's, occurring during the warm summer months, and low values in the upper 60's in the winter. Winds are predominantly from the east and southeast; except when coldfronts pass through the area. The physical constraints on the Biscayne Bay system do not appear to significantly effect the chemistry of the bay. The effects of the wind and warm temperatures on the bay will be discussed in later papers in this symposium.

Several agencies have been monitoring the water quality of Biscayne Bay for many years. An excellent summation of these data collecting efforts has been compiled by Rosendahl (1), and the reader is referred to his work for a complete bibliography on the monitoring and research programs in the bay. A few programs however, have been responsible for collection of most of the water quality data currently available. The Dade County Pollution Control Department has been monitoring certain parameters in Biscayne Bay since 1971. They have collected data on dissolved oxygen, biochemical oxygen demand, pH, temperature, phosphates, and total coliforms. Most of the stations monitored by the Pollution Control Department have been in the north bay section, as defined earlier. Test sites have been located on Key Biscayne, and as far south as Gables by the Sea. Most of the south bay area is not monitored continually by the Dade County Pollution Control Department. In addition the Pollution Control Department monitors the same water quality parameters in several of the tributary canals which enter into the bay. Data from these canal systems have also been collected since 1971.

Several other agencies including the U.S. Environmental Protection Agency, the Department of the Interior, Geological Survey and the National Park Service have monitored various water quality parameters throughout the bay in conjunction with Florida Power and Light's construction of the nuclear power plant at Turkey Point. Most of the data however, were concerned with assessing the impact of the power plant on Biscayne Bay. Thus while some inference as to water quality in the system can be made, without long term monitoring no trends can be determined.

It should be noted here that while this paper deals with man's interference with the chemistry of Biscayne Bay other parameters will also be discussed. As was noted earlier microbiological indicators of pollution, i.e. coliforms, will also be discussed as they to reflect mans impact on the bay. The principle chemicals that will be discussed in this paper are the macronutrients; nitrogen, and phosphorus. There are very few data available on other elements and their occurrence or inputs to the bay.

Figure 1 shows a composite of water quality data collected from 1971 - 1973 by the Dade County Department of Pollution Control. These data will be discussed briefly here to give the reader some background as to fluctuations in typical pollutant concentrations at certain stations in the bay. It can be noted that there are 4 stations represented from the 48 currently being monitored by the Department of Pollution Control. The stations were selected as being representative of the other monitoring stations within the bay area. From a water quality point of view only 2 parameters shown in Figure 1 are of interest, that is the total coliform count, and phosphate concentration. Dissolved oxygen, pH and temperature fluctuate quite randomly, and are purely a function of the physical forces in the system. The values for BOD are quite low in all cases, and reflect the rather insensitive nature of the BOD analysis. The total coliform counts, as shown are useful indicators, even though somewhat insensitive to contamination from various land use forms. It can be noted that the only station in the south bay i.e. Gables by the Sea, shows very low values of coliform throughout the three years, while stations in the north bay section do show values somewhat higher. It should be also noted that the suggested standard for water contact in Dade County is 1000 MPN total coliform count. As more data are collected, a better time dependent trend can be determined. Figure 1, however seems to indicate the trend of increasing coliform levels at most stations, probably reflecting the increased development in the Biscayne Bay area.

The phosphate data are rather constant with time for the 3 years of data presented. There seems to be a pronounced seasonal fluctuation, with higher values being reported in the rainy summer months. This phenomenon will be discussed later, as it is seen that the same type of phenomenon occurs in the canal systems draining to the bay. The values however do not seem to reflect any trend with time other than perhaps a slight increase in the north bay section. Throughout most of the year the absolute value of phosphate is rather low. During the seasons when the levels increase, values are recorded as high as 0.5ppm. This level is quite high and could allow for an excessive amount of algal growth if phosphorus is limiting primary production in Biscayne Bay. Without comparable data on nitrogen values however, it is difficult to project the limiting situation in the bay.

In summary then, it can be seen that certain chemical pollutants in the bay may be on the increase, probably due to the increased development in the Biscayne Bay area. It also is obvious that very few parameters have been monitored on a long term basis, thus making it difficult to evaluate the exact water quality situation in the bay. In addition data that reflect more closely, pollutant inputs have not been collected, and hence are not available for evaluation. Determinations of trace metals and hydrocarbons are essential as they are principle contaminants in runoff waters which probably represent the main input to Biscayne Bay. It also appears that the main pollutant inputs to the bay enter through the many canal and river systems. The rest of this paper will discuss the water quality parameters that have been monitored in these canal systems.

DISCUSSION

An important consideration in evaluating the chemical composition of Biscayne Bay with regard to water quality is the input of pollutants. Due to the large metropolitan area surrounding Biscayne Bay several large chemical pollutant inputs are occurring. Nonpoint sources due to stormwater runoff probably are the major contributors of chemical pollutants to the bay. In the north bay area where the development is in close proximity to the bay waters, runoff probably occurs directly from streets and surrounding development. In the central and south bay area chemical pollutants undoubtedly enter the bay predominantly through canal and river systems.

Certain quality parameters have been monitored on several canal systems draining to Biscayne Bay by the Water Quality Laboratory at the University of Miami. Much of the work was centered on the Coral Gables Waterway, as this system was considered to be a model of canal drainage to Biscayne Bay from a typically developed section of Miami. The Coral Gables Waterway receives stormwater drainage from a large area of Coral Gables through stormwater interceptors. These empty into the waterway over its entire length. In addition much of the area bordering the Coral Gables Waterway is currently being serviced by septic tanks, and much of the drainage from these tanks reaches the waterway and hence Biscayne Bay. Some of the more pertinent parameters will be reported on here in an attempt to illustrate the type of loading that could be expected from canal systems being developed in the same manner as the Gables Waterway.

Figure 2 shows typical water quality data collected at a site midway in the Coral Gables Canal. The data were collected for a year from the summer of 1974 to the summer of 1975. Representative values of nitrogen, phosphorus, and indicator bacteria are shown for that period. It can be noted that the indicator bacteria show very high levels in the canal especially in the summer rainy months. The values then translate to high coliform values in Biscayne Bay. In addition the macronutrients also appear to follow the seasonality of high in the summer, and lower in the winter. The best parameters, once again, for observing this seasonality are the phosphate concentrations and total coliform count. These appear to reflect stormwater input into the canal as well as seepage from septic tank leaching fields during periods of high water table. Comparing the concentrations in figure 1 with those of figure 2 it is seen that the various chemical pollutants become more dilute, as the material passes down the canal systems. However, during the seasons of high rain intensity and high pollutant input, the canal system, as well as Biscayne Bay appear to be appreciably degraded.

Because the water quality of the Coral Gables Canal System and subsequently Biscayne Bay appears to be governed by inputs from stormwater runoff, a study was performed to examine the characteristics of stormwater runoff. Table 1 shows the summation of water quality characteristics from 3 test sites in the Coral Gables Area. All three of these test areas drain into the Coral Gables Waterway. It can be seen that the coliform bacteria counts are extremely high in all cases. Orthophosphate and nitrate nitrogen also appear to be extremely high, and this of course is reflected in the resultant concentrations in the canal itself. It also should be noted that drainage from area #2 which was 100% paved appeared to contain the highest concentrations of pollutants. Thus it appears that paved areas, that is parking lots or streets, pose a rather high potential for contaminating surface water systems.

Table 2 shows the loading rates of the various pollutants from residential areas of Coral Gables. It can be seen that over 8 pounds of nitrogen, and 2 pounds of phosphate per acre of pavement per year drain into the Coral Gables Waterway. Once again these pollutants are readily transported to Biscayne Bay via the canal system.

As was mentioned earlier, specific chemical pollutants which drain into the canal system, and subsequently reach the bay have not been monitored as extensively as have nitrogen, phosphorus and bacteria. Recent work on the Gables Waterway analyzing zinc and aluminum with respect to water quality has just been undertaken. Too few data have been collected to date to observe any yearly trend similar to those observed in other water quality parameters. However absolute values of the concentration of these elements can be seen in table 3. The data were collected from 10 stations on the Gables Waterway and show relative concentrations of aluminum and zinc. It can be seen that aluminum levels vary from undetectable, to as high as 4ppm. Zinc remains a little more constant than does aluminum varying only from about .07 to somewhere around 0.5 ppm. These two elements were chosen for analysis in part because very little is known about aluminum in natural systems, and it is a rather toxic element. Zinc on the other hand is relatively nontoxic, and is common in most systems at fairly high concentrations. Table 3 indicates that the overall zinc level is low in the Gables Waterway, and that the aluminum levels can run very high at certain stations at certain times of the year. It should again be noted that the samples have only been collected through the early fall, and hence do not indicate yearly fluctuations. As a point of reference the water quality standards for Dade County set a limit of 1 ppm zinc; while no standards are written on aluminum.

Another parameter that has not received much attention with regards to water quality, is oil and grease. The Coral Gables Waterway, as is the case with most other water systems draining to Biscayne Bay receives heavy boat traffic. In addition many boats are moored in these canal systems, which results in additional input of oil and grease. Because of the variety of hydrocarbons present in oil and grease it is very difficult to monitor each form. Therefore the most expidient analysis is to use a total extraction method, and measure the total hydrocarbon content. Table 4 shows a listing of 6 stations in the Gables Waterway with average values of total extractable oil and grease. The extraction is this case was performed with methylene chloride. It can be seen that values of oil and grease fluctuate between 10 and 20 mg l^{-1}. As a reference point, the effulent standard for Dade County is set at 30 mgl^{-1} total oil and grease. Several sites in the waterway have recordings as high as the effulent standard. Undoubtedly, stormwater runoff accounts for much of the oil and grease, however, much of the daily boat traffic, and operation must also account for a sizable portion of the oil and grease present.

The pollutants that have been reviewed in this section ultimately reach Biscayne Bay. The ecological effect of these chemicals, while being discussed in other papers in this symposium have not been fully evaluated. Work by Waite & Greenfield (2) has shown a decrease in pollution tolerant forms of phytoplankton towards the Biscayne Bay end of the waterway. This indicates that the Gables Waterway is relatively contaminated, and that Biscayne Bay is less contaminated compared to the Waterway. This is understandable, considering the dilution capacity of the canal system as it moves toward the bay. It is more difficult to evaluate ecological harm due to these chemical contaminents in the bay itself because of so many overlapping factors.

It appears therefore, that the principal loading of pollutants to Biscayne Bay is via the canal systems and the Miami River. This in turn is due to inputs in runoff water from the land use forms in the Miami Area. Consequently the only procedure for controlling inputs of these contaminants to the bay is through land use reform and planning. Also much more data are needed to evaluate exactly the effects of runoff from various land use forms as they impinge on these canal systems and subsequently the bay. Data that have been collected on the Gables Waterway offer good insite as to potential harm of the various forms of development. Recent federal grant money to cities for analyzing stormwater impact will aid in this data collection. It is obvious however, that careful thought should be placed on exactly which chemical contaminants should be monitored, as many of the common water parameters do not reflect actual contaminant input. Many specific contaminants should be monitored such as certain trace metals, hydrocarbons etc. instead of general indicator type parameters. This will aid in the analysis of the potential for harm to Biscayne Bay.

While data collected from model systems, such as has been studied here, will aid in planning of new land use forms in the South Dade area, there should also be concern for control of existing systems. The north bay area, as well as part of the south bay area are already fully developed, and runoff from these areas has been draining into the bay for several years. The possible control mechanisms for runoff inputs however are poorly developed at this time. It is however, imperative that some effort be placed towards evaluating possible alternatives for treatment of this runoff water.

In conclusion then, it has been shown that the principal chemical contaminants of Biscayne Bay probably have reached there by runoff from urban activity. This runoff most probably enters the bay through the canal and river systems feeding the bay. It is therefore quite possible to alter this input by controlling runoff from existing developed areas, and planning new developments such that runoff is minimized. The exact environmental harm of these chemical contaminants in Biscayne Bay is very difficult to evaluate at this time because of the overlapping physical and biological interactions. It is assumed however, that some environmental harm is going to occur due to the input of these chemicals whether it is defined scientifically or not. It is therefore advantageous to initiate programs to preclude the entrance of these contaminants to Biscayne Bay while further research on the definition of the system itself is underway.

ACKNOWLEDGEMENTS

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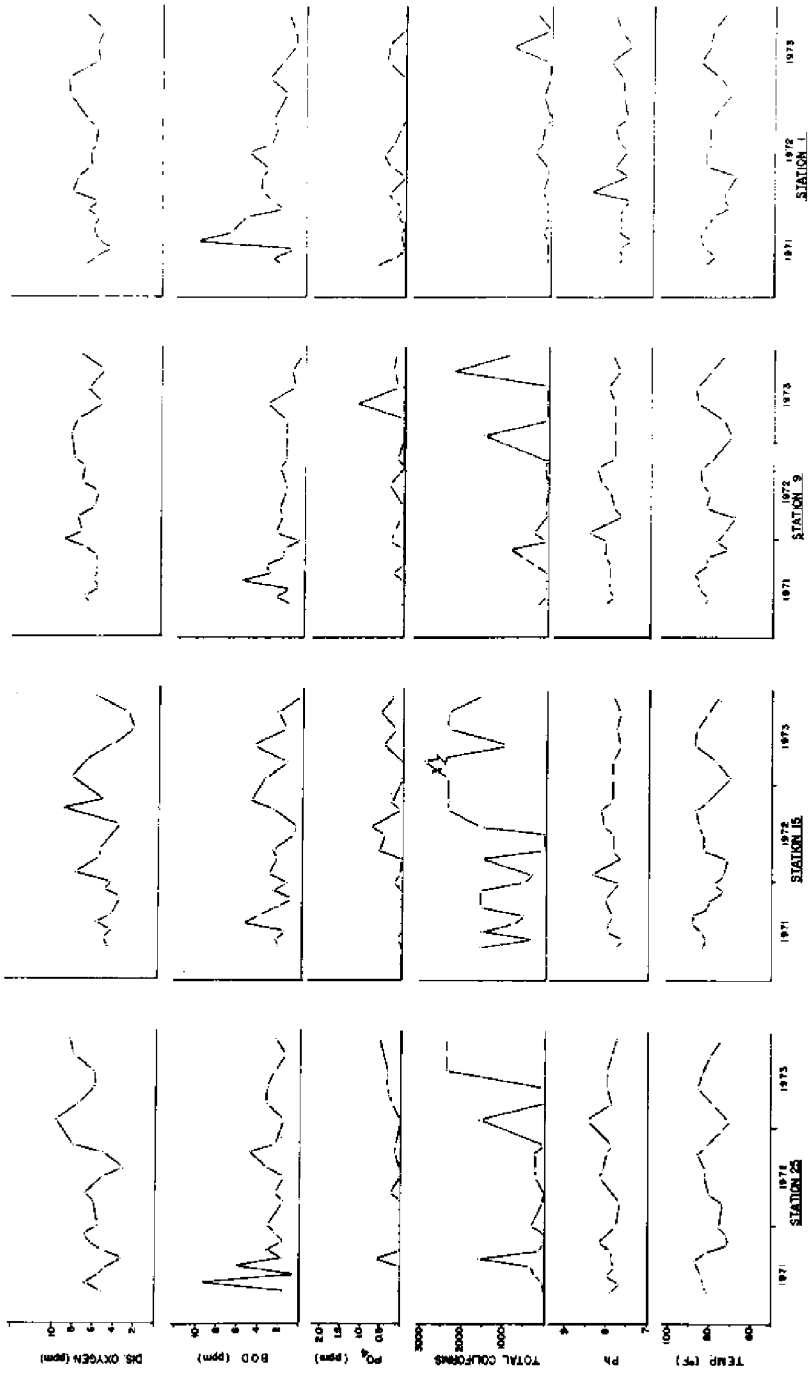

Figure 1. Water quality data at selected sites in Biscayne Bay 1971 - 1973. From Dade County Dept. of Pollution Control

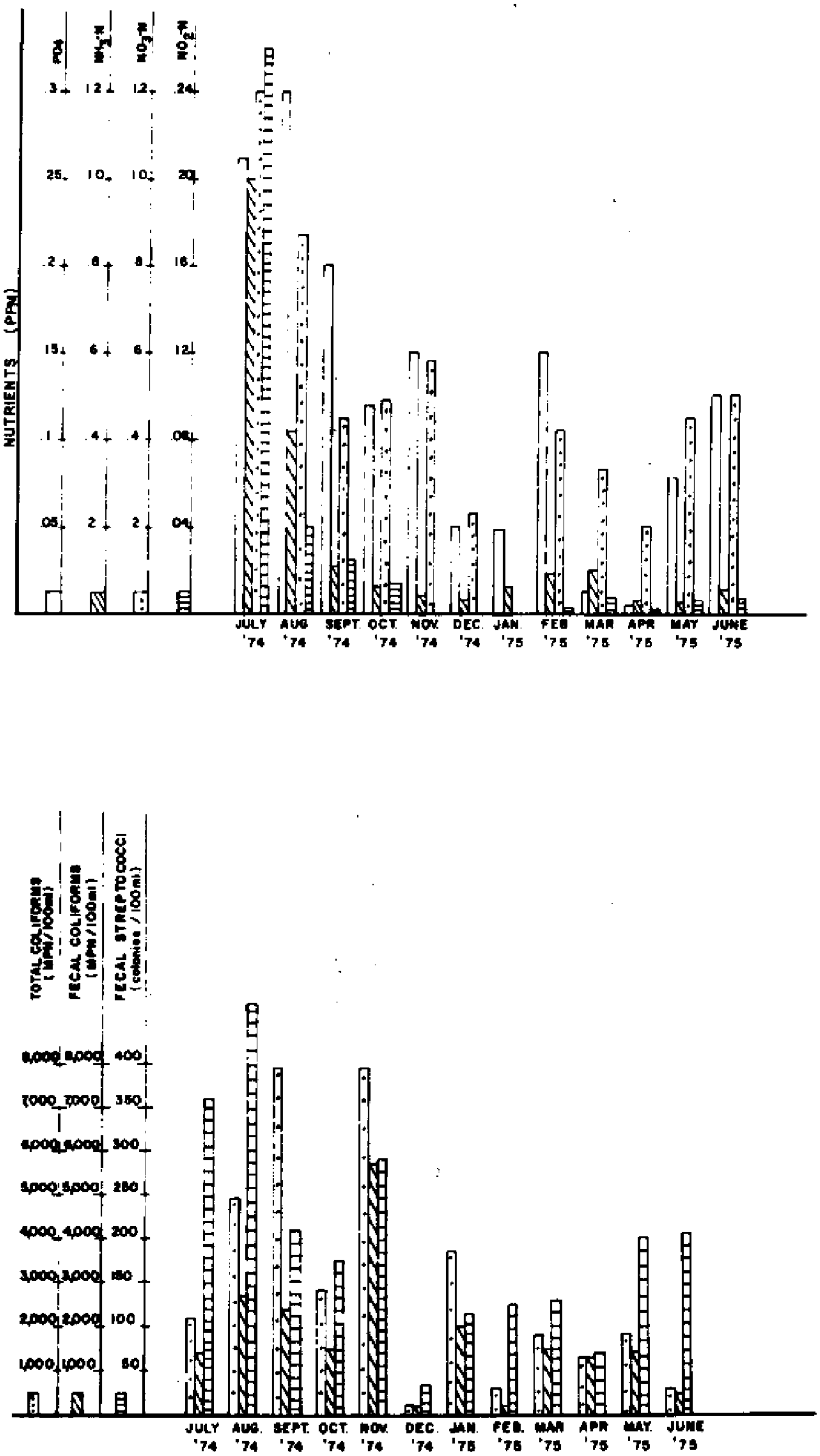

Figure 2. Typical water quality data, midway in the Coral Gables Waterway

TEST SITE	SIZE (ACRES)	PAVED AREA (%)	TOTAL COLIFORM (MPN)	FECAL COLIFORM (MPN)	FECAL STREP. (org/100)	ORTHO PHOSPH. (mg/l as P)	NITRATE NITROGEN (mg/l as N)	NITRITE NITROGEN (mg/l as N)	AMMONIA NITROGEN (mg/l as N)
AREA #1	251	62	5,067	3,628	695	0.15	0.60	0.05	0.27
AREA #2	1	100	50,463	49,752	1,218	0.83	0.67	0.06	0.44
AREA #3	1	60	19,446	16,380	1,050	0.57	0.83	0.03	0.21

Table 1. Water quality characteristics of stormwater runoff into the Coral Gables Waterway.

PARAMETER	LBS/YEAR/ACRE PAVM'T	ORG/YEAR/ACRE PAVM'T
TOTAL COLIFORMS		31.8×10^{10}
FECAL COLIFORMS		22.9×10^{10}
FECAL STREPTOCOCCI		42.4×10^{9}
PHOSPHATE PHOSPHORUS	2.01	
NITRATE NITROGEN	8.20	
NITRITE NITROGEN	0.67	
AMMONIA NITROGEN	3.67	

Table 2. Pollutant loading values due to stormwater runoff from residential areas.

METAL		SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9	SITE 10
ALUMINUM (ppm)	avg.	0.69	1.25	0.69	0.91	0.94	1.13	1.04	1.15	1.34	1.59
	high.	1.00	2.00	2.00	2.30	2.50	4.00	4.00	4.20	4.20	5.00
ZINC (ppm)	avg.	0.24	0.17	0.15	0.17	0.14	0.16	0.18	0.18	0.16	0.18
	high.	0.59	0.27	0.18	0.27	0.21	0.25	0.33	0.34	0.34	0.22

Table 3. Aluminum and zinc concentrations in the Coral Gables Waterway.

PARAMETER		SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6
OIL and GREASE (mgl^{-1})	avg.	20.40	11.20	17.60	13.80	15.20	19.00
	high.	35.00	17.00	24.00	23.00	30.00	26.00

Table 4. Total extractable oil and grease in the Coral Gables Waterway

MAN'S IMPACT ON SEDIMENTARY ENVIRONMENTS AND PROCESSES

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ABSTRACT

During the past 75 years, man has dramatically modified the morphology, sedimentary environments, and sedimentary dynamics of Biscayne Bay, especially that portion north of the Key Biscayne-Coconut Grove area. Man's impact results mainly from five influences: creation of artificial cuts across Miami Beach, obstruction and modification to the natural sediment movement on the ocean beaches, dredge and fill projects for waterways and land fill, construction of drainage canals across marginal freshwater marshes, and causing increased turbidity.

Construction of Baker's Haulover cut (1925) and Government Cut (1905) across Miami Beach have altered the shore sediment budget and caused changes in the salinity and circulation of northern Biscayne Bay. These changes have in turn caused erosion along portions of the ocean beaches and major changes in the sedimentary environments of northern Biscayne Bay.

The construction of inlets through and seawalls, groins, and jetties along the ocean-facing beaches from Miami Beach to Key Biscayne has obstructed both natural sediment drift along the shore and erosion-accretion cycles transverse to the shore trend. Most seriously affected are the beaches south of Government Cut. These have been cut off from natural beach sand replenishment for the past 50 years and are rapidly eroding.

Dredge and fill projects in northern Biscayne Bay have dissected this once shallow, elongate mangrove-rimmed bay into a lagoonal complex in which deep moats and channels border the dredged and seawalled fill islands and Bay margins. Unbulkheaded environments influenced by dredging are a persistent source for the gradual re-introduction of turbidity (particulate suspensions) into the water column. Dredge and fill projects in central and southern Biscayne Bay are scattered and have had only local impact on Bay environments.

Drainage canals criss-crossing bay margin swamps and margins have caused freshwater marl flats and swamps to yield to mangrove swamps or upland scrub environments.

A marked increase in turbidity of the Bay waters has accompanied urbanization of the northern and central Bay sectors. Although this may have been initially caused by dredging operations in the mid-twenties and large volumes of raw sewage discharge in the 1920-1955 period, some other influence is perpetuating high turbidity levels today. Of the possible influences, re-release of dredge spoil and the loss of "turbidity inhibitors" should receive focused study.

Resultant from this impact there have been major changes in the sedimentary environments of and marginal to northern and central Biscayne Bay and minor changes to the south. Especially serious is (1) the conversion of large portions on the northern Bay bottom from a sea-grass stabilized shelly mud to a mobile soft to flocculent ooze bottom, and (2) the destruction of a major percentage of the turbidity and energy adsorbing mangrove swamp shoreline along northern Biscayne Bay.

Future research must focus on (a) fine-grained sediment dynamics and (b) mapping the spatial and temporal gradients of the bio-sedimentary environments. Also urgently needed is an effective mechanism to input present and future knowledge of this unique urbanized Bay system into regulatory guidelines.

INTRODUCTION

Man's influence on the morphology, sedimentary environments, and sedimentary dynamics of Biscayne Bay has nearly entirely occurred during the past 75 years. There are five main ways in which man has modified sedimentation.

1) Creation of artificial cuts across the seaward barrier islands and deepening natural cuts through the seaward margin have altered the shore sediment budget and caused changes in salinity and circulation of northern Biscayne Bay thus modifying bottom sedimentary environments.

2) Ocean-facing beaches of the sand islands bordering northern Biscayne Bay are severely eroding, partly because of natural processes and partly because of sand loss into the Bay through artificial cuts and sand drift blockage of seaward extending jetties.

3) Dredge and fill operations have dissected northern Biscayne Bay into a lagoonal complex, eliminated the mangrove swamp fringe from most of the northern and much of the central Bay sector, created spoil islands and shoals throughout the Bay, and been both a short-term and persistent source for increased turbidity.

4) Drainage canals have connected fresh water marshes and marl flats in the marine environment.

5) Increased turbidity in the north and central Bay sectors accompanied urbanization. This has caused major changes in bottom sedimentary environments, substrate mobility and dynamics of fine particulate sediment and adsorbed pollutants.

Some of man's modifications have had an immediate and direct effect on the morphology, sedimentary environments and sediment dynamics of the Biscayne Bay area. Other changes, as persistent turbidity and beach erosion, are indirect results of man's intervention, and the exact cause is difficult to determine.

In assessing man's influence on the morphology of Biscayne Bay and on the contained sedimentary environments and processes, there are four important questions that must be addressed and resolved. These are:

1) What was it like before man's presence? What was the influence of the environment or process on the system? What were the natural trends of the system?

2) What were the direct effects of a man-induced modification?

3) What were the indirect effects--either to adjacent environments or at a later time? What indirect effects might a modification cause?

4) Of those detrimental changes to the system, is the original, formative cause perpetuating the detrimental change, or is the detrimental change now being perpetuated by some other influence of subsequent urbanization.

Each of these questions must be properly addressed and resolved to achieve a meaningful understanding of man's impact on Biscayne Bay--one that can be used both to design a proper urban development program for southern Biscayne Bay and to create a cost-benefit evaluation for the recovery of northern Biscayne Bay.

ARTIFICIAL CUTS ACROSS SAND ISLAND BARRIERS

Prior to 1900 Miami Beach formed a complete sand barrier between the ocean and Biscayne Bay as far south as Norris Cut at the south end of what is now Fisher Island. Norris Cut was a very shallow washover that had developed very little since its formation in the great hurricane of 1835 (Chardon, this volume). Thus, prior to man's development of Biscayne Bay, Bear Cut, separating Virginia Key and Key Biscayne, was the first major tidal pass through the long sand island barrier.

In 1905 Government Cut was cut across the south portion of Miami Beach (Figure 1). The separated southern tip, with fill added in the 1920's on the bayward side, became Fisher Island. The original cut was small and not supported by jetties. Sand rapidly worked bayward along both sides of the jetties. "Originally 18 feet deep and 60 feet wide, Government Cut was enlarged to a depth of 20 feet and a width of 300 feet in 1912. The depth was increased to 25 feet in 1925 and 30 feet in 1930. The jetties were extended to their present length between 1926 and 1929, 4000 feet for the north jetty and 300 feet for the south jetty." (Hannon, et al, 1972)

The Miami Shipping Channel, extending from Government Cut across Biscayne Bay to the mainland shore, was 18 feet deep by 1915, 25 feet by 1925, and 30 feet in 1930 (McNulty, 1970). Between 1920 and 1925 Carl Fisher constructed deepwater channels on the west and south sides of Fisher Island with the hopes of making the island a great deepwater port. Though never realized, he converted Norris Cut, separating Fisher Island

and Virginia Key, from a shallow tidal washover to a tidal channel 15 to 20 feet in depth across most of the pass.

As the shipping channel was extended westward across Biscayne Bay towards the mainland, Lumis and Dodge islands and McArthur Causeway accumulated as spoil islands. Subsequent construction of tributary shipping channels and island bulkheading led to the completion of Dodge Island in 1961. This opened as Miami's port facility in the late 1960's.

Government Cut and the Miami Shipping Channel are presently being deepened to 42 feet.

Baker's Haulover, the narrow sand neck at the north end of Miami Beach was artificially breached in 1924-1925 to aid fishing boats and tourist charters. Jetties extend seaward from the beach only a short distance.

Three striking changes have resulted from the construction of Government Cut and Baker's Haulover. Natural sand nourishment to adjacent beaches has been disrupted by Government Cut jetties; at Baker's Haulover sand is being swept into Biscayne Bay and lost from the beach system; and the salinity, circulation and sedimentary environments of northern Biscayne Bay have changed as these cuts increased exchange with offshore water.

Government Cut, with granite jetties extending three-quarters of a mile seaward of the shore and a 30 foot channel trough, has provided an essentially complete block to the natural southerly drift of beach sand. Sand has built up along the shore of South Miami Beach producing an exceptionally wide and stable beach from the north jetty north to about 14th Street. To the south, sediment starvation has caused serious beach erosion on Fisher Island and Virginia Key for the past 50 years (Figure 1) and is beginning to adversely effect the beaches of Key Biscayne. This is discussed in the next section.

The small jetties extending seaward from Baker's Haulover cut are not a serious obstacle to the natural southerly drift of sand nourishment in the nearshore zone. Much of the sand passing the inlet, however, is swept into the channel and deposited as a flood tide sand delta within the Bay. This loss of sand from the beach system is sufficiently great to necessitate (a) artificial nourishment of the beaches south of Baker's Haulover, (b) repeated dredging of Baker's Haulover cut and channel, and (c) occasional redredging of the intracoastal waterway smothered by the growing sand tidal delta.

The construction of Government Cut and Baker's Haulover cut and the deepening of Norris Cut has converted Northern Biscayne Bay from a seasonally brackish, seasonally hypersaline shallow environment of sluggish circulation into a bay in which near normal salinities are maintained. This has had a profound effect on the bay bottom and bay margin sedimentary environments (Teas, Wanless and Chardon, this volume).

SHORE EROSION

There are three main types of natural shorelines in the Biscayne Bay Region--rocky limestone, mangrove swamp and sandy beach.

Rocky Shorelines

Rocky shorelines are along the seaward side of the seaward bounding islands from Soldier Key to Key Largo and along the mainland shoreline in the Snapper Creek area. This Pleistocene limestone rock erodes only very slowly through biologic corrosion and is not a problem.

Mangrove Shorelines

Mangrove swamp shorelines occur along the more protected portions of Biscayne Bay. They are naturally eroding or accreting primarily depending on their exposure to storm waves. Berberian (unpublished data), studying sequential charts of southern Biscayne Bay and Card Sound, found that northward facing swamp shorelines had moderately to severely eroded in historical times, whereas southward and westward exposed shorelines had remained stationary or accreted. The mangrove shore fringe provides a very important energy buffer against hurricane storm waves but is commonly severely damaged by them (see Warzeski, this volume). Mangrove shorelines have generally been totally destroyed in areas of bay margin dredge and fill programs. Elsewhere they appear unaffected by urbanization (see, however, Teas, this volume). The U.S. Geological Survey estimated that the coastal mangrove forest of about 15 per cent of Biscayne Bay had been destroyed as of 1973 (U.S.G.S., 1973). Most of this destruction took place in northern Biscayne Bay during dredge and fill operations of the mid 1920's to late 1940's.

Mainland Beaches

Sandy beaches occur at scattered intervals along the mainland shore of Biscayne Bay from Coconut Grove south to Barnes Sound. Beaches of Biscayne Bay and Card Sound are fine quartz sand; those of Barnes Sound are shell hash. Except where artificially nourished or maintained, mainland beaches are only a thin veneer of sand over an eroding mangrove peat platform or swamp margin. These beaches have fared well during urbanization except where small boat or drainage canals have disrupted the natural southerly drift of sand or where dredge and fill operations have directly obliterated them. These beaches are naturally migrating landward and are in part dependent on sand reworked out of the mangrove peat deposits for nourishment.

Ocean Beaches

Since the 1926 hurricane that ended Miami's first growth boom, beach erosion has been a serious and persistent problem along the developed ocean facing beaches of Miami Beach, Fisher Island, Virginia Key, and Key Biscayne. A part of this problem is caused by man's attempting to obstruct the natural trend of the system; part results from man's modification of sand movement.

Miami Beach is a narrow sand island barrier which was, prior to man's involvement, naturally migrating slowly landward or stationary. Superimposed on this gradual trend was a shorter term beach cycle. The beach zone would erode during major storms and the winter season and naturally restore itself during quieter periods between. Construction of seawalls and hotel fronts near high water mark during the early 1920's left the structures and the beach earmarked for trouble during the 1926 hurricane. These structures both blocked the natural erosion-accretion cycle of the beaches and obstructed gradual natural landward migration of the island. Despite the construction of extensive groin systems along Miami Beach, the beach has never returned to its original state because (a) the seawalls, once exposed to surf action, reflect much of the wave energy and sand seaward, (b) the groin systems shift the zone of longshore drift to an offshore bar causing potential sand replenishment to bypass the groined beach zones, and (c) the beach was dependent on sand recycled by gradual landward migration. Today, sand is carried landward of the beach system by wind and storm surge and permanently lost from the system.

Baker's Haulover at the north end of Miami Beach has diverted large amounts of the natural beach sand nourishment into Biscayne Bay causing accentuated erosion along the beach to the south.

Government Cut jetties are an essentially complete block to the natural southerly drift of beach sand and have prevented natural sand nourishment to Fisher Island, Virginia Key, and Key Biscayne for the past 50 years. The Corps of Army Engineers (1966) estimate that about 50,000 cubic yards of sand per year is drifting southward past Baker's Haulover every year. Probably about this same amount is being blocked by Government Cut jetties from nourishing the barrier island system to the south. The direct and indirect sequence of results from this blockage are striking and over the next ten years will become an extremely serious problem.

1. The original natural beach of Fisher Island is essentially completely lost, exposing the rubble land fill behind at the shoreline. The shoreline is eroding 5 to 15 feet per year even though made of rubble limestone and even though shielded by Government Cut jetties from northerly winter storm waves (Hannon, et al., 1972). The subtidal sand reservoir seaward of the island has been completely stripped away exposing the pre-existing limestone surface.

2. All of Virginia Key beaches have severely eroded during the past 70 years. The northern portion has retreated over 300 feet, partly in response to sediment starvation and partly in response to sand loss to the deep dredged portions of Norris Cut. Two major beach nourishment programs in 1969 and 1973 by the Corps of Engineers have attempted to offset this erosion. The latter program implanted 13 granite rubble groins along the beach and infilled with 100,000 cubic yards of sand.

3. A broad seagrass stabilized platform extended nearly one mile seaward of Virginia Key Beach. Nearly 80 per cent of the seagrass bed has been lost during the past 30 years because of inadequate natural sediment renourishment to the offshore platform (Figure 2). Much of the sand floor exposed by seagrass bed loss was very fine and has been swept into suspension and carried from the system. As a result, the shallow seagrass stabilized offshore platform, once protecting the beaches from offshore wave energy, is now rapidly deepening, leaving the beaches exposed to increased storm waves and erosive processes (Wanless, 1975).

4. As sediment is depleted from the northern area, Key Biscayne is beginning to feel the effects of sediment starvation. Serious shore erosion on Key Biscayne presently is limited to the northern shore of Key Biscayne (Crandon Park). This shore was nourished in 1969 and has since been maintained by a careful recycling program for sand blown landward from the beach system. The sand tidal deltas on the seaward and landward ends of Bear Cut have been extensively remobilized into the littoral drift system during the past ten years.

5. Sand for the 1969 renourishment programs on Key Biscayne and Virginia Key public beaches was derived by cutting a sand borrow pit 1,500 offshore of northern Key Biscayne (Figure 3). On most beaches this standard 1,500-foot distance is well beyond the zone of active littoral drift. In this case, the pit cut into the shallow littoral sand platform, partly taking sand destined for beaches to the south and partly cutting in the grass stabilized portions of the platform. Several serious changes have occurred on this littoral platform since 1969. First, the borrow pit has slowly migrated landward (van de Kreeke, personal communication) causing additional erosion of the seagrass beds. Second, sand eroded from the borrow area has, during the past year, spread rapidly across the broad

seagrass bed landward causing massive smothering of the seagrass carpeted bottom. The author is seriously concerned that this smothering will be followed by a sequence of events similar to that documented off Virginia Key's beaches.

Beaches along the developed central sector of central Key Biscayne have evolved much the same problems as the developed beaches of Miami Beach--resulting from bulkhead construction too near high water mark.

A striking zone of beach erosion can be seen at Cape Florida, the south tip of Key Biscayne. The lighthouse, built some distance inland in the early 1800's was nearly lost to the sea during Hurricane Betsy in 1965. Severe erosion at the point probably results from two causes. First, the Cape Florida Channel, bordering Key Biscayne, was extensively deepened and enlarged in 1949-1950 in deriving land fill for the southern third of Key Biscayne. Second, a seawall constructed at that time extends from the lighthouse on around the bayward side of Key Biscayne. These two changes (a) create a deep channel into which sand, carried to the Cape, is easily lost from the beach system and (b) eliminate the narrow beach along the western side of the Cape which may have served as a landward sand reservoir to the Cape.

DREDGE AND FILL PROJECTS

Nearly one half of the surface sedimentary environments within and marginal to northern Biscayne Bay have been directly altered by dredge and fill operations during urbanization. This intensity decreases southward, and south of Key Biscayne and Coconut Grove dredge and fill modifications are few and scattered. South Biscayne Bay, Card Sound, and Barnes Sound are largely in their natural form except for northern Key Largo, the Card Sound road, the inland marsh south of Turkey Point, and along U.S. 1 at the south end of Barnes Sound. Dredgings were for two purposes--to create waterways (with resultant spoil island byproducts) and to provide landfill (with resultant borrow pits).

Waterways

The first significant dredging operation in Biscayne Bay was a small channel extending "across the shallows between the mouth of the Miami River and Cape Florida in the late 1890's" (McNulty, 1970).

The intracoastal waterway is maintained as a dredged channel from the north end of Biscayne Bay, south along the western side of Biscayne Bay to Rickenbacker Causeway. To the south, it only maintained by dredging across Featherbed Bank, Cutter Bank at the south end of Biscayne Bay, and Card Bank at the south end of Card Sound. Unbulkheaded spoil islands and shoals parallel the margins of the dredged portions (see base map). Unlike other dredge and fill programs, the intracoastal waterway must periodically be redredged to maintain navigable depth.

In addition to the intracoastal waterway, numerous smaller dredged waterways with adjacent spoil banks extend westward from the intracoastal waterway to the mainland. The oldest is perhaps that extending into the Deering estate just south of Rickenbacker Causeway. Chicken Key (south of Shoal Point) is dredge spoil from the canal and basin extending into Cutler power plant. A barge canal joining the intracoastal waterway and Turkey Point nuclear power plant is the largest and most recent major dredged tributary waterway.

By far the most massive dredging program in the Biscayne Bay area has been the sequential deepenings and expansions of the Miami Shipping Channel. The present three year dredging project is deepening the channel to 42 feet from the offshore margin of the continental shelf to the mainland turning basin. This has stressed available sites for dumping spoil. While earlier dredgings have provided spoil for filling the southern corner of Miami Beach, Fisher Island, McArthur Causeway, Dodge Island and Lumis Island, the current program has dumped spoil on two large offshore sites, on the beach at the south end of Miami Beach, over a large area at the north end of Virginia Key, on the mainland at the head of the channel and on Lumis Island. Suitable dredged sands were also used for the 1973 Virginia Key beach nourishment program.

Other dredged channels across Biscayne Bay provide pathways for pipelines and electrical conduits. A pipeline channel extends from the mainland to Virginia Key and a second pipe corridor crosses Biscayne Bay to central Key Biscayne.

Land Fill

Dredging operations for the purpose of obtaining land fill have most extensively modified northern Biscayne Bay. Major modifications occurred between 1919 and 1927 with the creation of the numerous residential fill islands bordering McArthur Causeway, Venetian Causeway, and 76th Street Causeway, the filling and bulkheading of most of the mainland shore from the Miami River north to 76th Street Causeway, and the bay shore of Miami Beach north to Bal Harbour. Subsequent projects have filled and bulkheaded most margins of northern Biscayne Bay, the mainland shore from the Miami River south past Coconut Grove, and scattered areas to the south.

Six causeways further dissect northern Biscayne Bay. McArthur Causeway (1926), Venetian Causeway (1926), 76th Street Causeway (1940), Rickenbacker Causeway (started in 1942), Broad Causeway, and Julia Tuttle

Causeway (1959) each contain long strips of roadway fill bordered by deep borrow channels. Additional dredging in conjunction with Rickenbacker Causeway created land for the Miami Marine Stadium on the west side of Virginia Key.

Two land fill operations have significantly modified the morphology of adjacent tidal passes. The rounded south end of Virginia Key was dredged up from sediment of the sandy tidal bars in Bear Cut. The southern third of Key Biscayne, once a low complex of sand ridges, mangrove swamps and brackish ponds, was filled in 1949-1950 with sediment from the adjacent Cape Florida channel and Safety Valve flats. Bulkheading the bayward side eliminated the narrow sandy beach, inhibiting natural fluctuations of sand around the Cape.

The bay side of central Key Biscayne was filled and bulkheaded during the late 1940's and early 1950's, the southern part being molded into a series of finger canals.

This extensive and varied assemblage of dredge and fill operations has caused major direct and indirect changes on the morphology, sedimentary environments, and sedimentary dynamics of the Biscayne Bay region.

1) Each dredge and fill operation has directly destroyed the existing bottom sedimentary environment in the area of dredging and directly smothered an equal or greater area where the spoil or fill was deposited. In addition, fine muds carried in suspension from the dredging operation blanket a much broader area. Some dredge and fill projects have carefully controlled the release of suspended sediment and cause only minor stress on adjacent environments. Other projects have spread tons of silt and clay sized mud across adjacent grassy bay bottoms. For example, the 1973 shore nourishment of Virginia Key released large volumes of mud into Bear Cut. Grass beds as much as one-half mile from the project were covered with up to two inches of mud.

2) The combined result of dredging for island and bay margin landfill, causeways, port facilities, and intracoastal waterways has converted northern Biscayne Bay from a long shallow mangrove-lined bay open to the south into a dissected lagoonal complex of highly variable depth. Fill islands and much of the shoreline are bordered by deep moats, holes, and channels. Wave reflecting seawalls replace the energy adsorbing mangrove margins.

3) The most serious long-term impact of dredge and fill projects appears to be the creation of three artificial environments that persistently re-release fine mud into the bay waters for many years after the project. (a) Unbulkheaded fill islands and shorelines are gradually eroded both by day to day waves and currents and by storm waves. The large amounts of contained mud are persistently reintroduced into the water column. (b) Shallow spoil banks are similarly in disequilibrium with the wave and current climate and, unless stabilized by mangrove or seagrass cover, are a persistent source for particulate suspensions. (c) The fine muds spread widely across adjacent sedimentary environments during dredging are only partly incorporated into that bottom environment. Much is persistently redistributed via the water column during succeeding years.

DRAINAGE CANALS

Small drainage canals dissect much of the lowlying mangrove swamp, marl flats and freshwater marshes bordering Biscayne Bay. These were dredged to drain lowlying areas in preparation for agriculture use or development or for mosquito control.

Sea water penetration of the drainage canal networks has caused mangrove environments to rapidly expand landward across the scrub mangrove and marl flats behind (see Teas, this volume). Those fresh water marsh zones not invaded by salt water have mostly changed to upland scrub.

SEDIMENTARY ENVIRONMENTS

Early newspaper accounts describe northern Biscayne Bay as having crystal clear waters and a lush seagrass carpet on the shallow bay bottom. Core borings confirm that such an environment existed prior to urbanization. The shelly white muds permeated by seagrass rootlets and holes of burrowing organisms are similar to those found beneath the seagrass stabilized shelly mud bottoms of central Biscayne Bay today.

Seagrass cover was largely lost from all but the very shallow portions of northern Biscayne Bay between 1925 and 1956. Today most of the moderate to deeper bottom areas are covered with a soft to flocculant brownish ooze. Since 1945 seagrass bed loss has spread several miles south from Rickenbacker Causeway. Loss of this original bay bottom environment is related to three influences--boat scour, turbidity and silt smothering. (1) Aerial photographs as early as 1940 show the seagrass beds of north central Biscayne Bay to be disrupted by long streaks paralleling the Bay axis. These reflect erosion by propellers and bottom contact from large boat traffic along the intracoastal waterway. As seagrass beds recover only very slowly (Patriquin, 1975), grass beds have largely been eliminated from areas of heavy traffic by large boats.

More recently, severe bottom scour is extending the length of the intracoastal waterway from daily barge transport of oil between northern Biscayne Bay and Turkey Point. (2) Increased turbidity during early urbanization of Biscayne Bay (discussed below) reduced light intensity at the bottom causing seagrass bed loss. (3) Siltation from dredge and fill projects may have caused seagrass bed loss in portions of northern Biscayne Bay. As suggested by McNulty (1970) much of the destruction of bottom environments of the northern Bay sector may have resulted from the combined stress of urbanization influence and community damage during hurricanes.

Loss of seagrass stabilization left the muddy to sandy substrate more mobile and prone to winnowing which in turn depleted the abundant infauna. Seagrass beds have survived or recolonized some of the shallower areas of northern Biscayne Bay. Extensive recolonization cannot occur until turbidity levels drop significantly or until an effective program of transplanting is implemented.

The seagrass-carpeted bottoms of central and southern Biscayne Bay and the Safety Valve flats have remained largely unaffected by urbanization except where small boat traffic has ripped propeller ruts across the flats. The turtlegrass, Thalassia testudinum, takes 6-8 years to heal these narrow wounds, and, though each rut is narrow, repeated rutting has seriously damaged local areas.

The beautiful coral-algal flats such as found on the Safety Valve just south of Soldier Key have largely died off in the vicinity of Key Biscayne, but continue to flourish from Soldier Key south. As recently as 1966, the tidal bars in Bear Cut and at the north end of the Safety Valve had flourishing communities of coralline algae and finger corals (Porites spp). The living communities have been absent since 1971, but coarse skeletal debris of the environment remains.

Marginal mangrove swamps have extended landward in areas dissected by drainage canals and have been eliminated where directly covered by land fill. Elsewhere, these environments remain largely unchanged (see, however, Teas, this volume).

The freshwater marshes and marl flats landward of the mangrove margin have been extensively modified by man's activities. Salt water invasion along drainage canals has eliminated these environments from most of Biscayne Bay. Along the mainland coast of Card Sound and Barnes Sound, the broad freshwater marl flats and swamps have been isolated from freshwater flow from the Everglades by the fill embankment of highway U.S. 1. The calcitic mud environment, dependent on influx of calcium carbonate charged fresh water (Gleason, 1972), is gradually changing to scrub mangrove or freshwater swamp. The freshwater swamps, no longer in the main flow of Everglades discharge, have yielded either to mangrove or upland scrub communities depending on elevation and association with drainage canals.

TURBIDITY

By far the most noticeable, serious, and complex problem associated with urbanization of Biscayne Bay has been the increase in turbidity of the Bay waters. The influence in turbidity, caused by fine particulate matter in suspension, has largely been restricted to northern Biscayne Bay, although in recent years more persistently turbid waters are noticeable well south of Coconut Grove and Key Biscayne. Barge and tugboat traffic to Turkey Point has somewhat increased turbidity levels in southern Biscayne Bay. The increase in turbidity of Biscayne Bay is serious because (a) high persistent turbidity levels reduce light intensity to the bottom inhibiting desirable bottom environments and biotic communities from returning to and flourishing in northern Biscayne Bay, (b) it shows that previously efficient sediment trapping and bottom stabilizing environments are ineffctive, which means that (c) adsorbed pollutants introduced into the Bay may be widely dispersed through the bay system.

Essentially no attempt has been made to understand and solve the turbidity problem in Biscayne Bay. There are a variety of possible parameters that may influence turbidity levels. Some progress into the problem can be gained by approaching four questions. When did turbidity levels increase in northern Biscayne Bay? What were the possible causes for initial turbidity increases? What is the character of the particulates in suspension? What are the present possible influences that are perpetuating high turbidity levels in northern and north central Biscayne Bay?

Causes

Turbidity levels of northern Biscayne Bay appear to have increased during the 1920's and remained high through the mid 1950's. There were two main sources for particulate suspensions during this period--dredge and fill operations and raw sewage discharge. The massive dredge and fill projects within and along the margins of northern Biscayne Bay during the 1920's must have yielded large volumes of mud to the Bay causing a sharp increase in turbidity and severe damage to the bottom communities. Added to this damage was stress caused by hurricane scouring of the Bay in 1926 and adjustments of the benthic communities in response to the creation of Baker's Haulover cut and Government Cut.

Superimposed on this initial pulse of turbidity were large volumes of particulate suspensions from the discharge of raw domestic sewage into the Bay. With a steadily increasing population, this discharge steadily increased during the 1930's, 40's and early 50's. Minkin (1949) observed "A boat trip in the bay and out the main channel gives the visitor a chance to contrast the dark brown-gray polluted water near the city with the beautiful green ocean water. The visitor has to go out a mile to get to this clear water, and during the trip out he can get the cooling breezes and fine spray of diluted sewage in his face" (see also Dade County, 1960; Milliken, 1949). By 1955 as much as 60 million gallons of raw domestic sewage was discharging into northern Biscayne Bay (McNulty, 1970). Much of this was focused at the mouth of the Miami River. This influence abruptly ended in late 1955 as the treatment plant on Virginia Key began operation.

These are the likely causes for early turbidity in northern Biscayne Bay. High turbidity levels continue in many parts of northern Biscayne Bay today probably because of some combination of the following influences: upland drainage, persistent re-release of muds from unbulkheaded fill islands and spoil banks (described earlier), continuing dredge and fill projects, industrial and ship discharge, bottom scour by boats and ships, and the loss of "turbidity inhibitors".

Turbidity Inhibitors

The natural system of sedimentary environments contained a series of features that tended to rapidly remove particulate suspensions from the water column and to inhibit remobilization of the muddy bottom. Seagrass beds drew particulate suspensions out of the water column by blade baffling of wave and current energy and by trapping particles on delicate epiphyte growths on the blades. The dense seagrass rhizome-root systems stabilized the mud substrate from winnowing during storms. An abundant bottom grazing and burrowing fauna packaged much of the bottom mud into sand sized fecal pellets--much more resistant to redispersion into the water column than the fine mud. At the bay margins, mangrove swamps served as a permanent depository for storm muds, and sponges on the arching proproots filtered much of the day to day particulate suspensions from the water column.

These turbidity inhibitors are largely lost from northern Biscayne Bay. Some mangroves can be returned by planting artificial spoil islands. Seagrass beds with their important pellet packaging fauna cannot return to the moderate to deeper zones of northern and central Biscayne Bay until turbidity levels are reduced. And the author would suggest that turbidity levels will remain high until seagrasses (*Thalassia testudinum*) has recolonized most of the Bay bottom. Therein lies the major obstacle to the recovery of urbanized Biscayne Bay. It should also be the lesson to guide the development and utilization of southern Biscayne Bay.

RECOMMENDATIONS FOR FUTURE RESEARCH

The sedimentary changes in Biscayne Bay associated with urbanization are easily recognized. Shoreline erosion, changing bay bottom and marginal swamp environments, increased turbidity levels and physical modifications to the Bay's morphology can all be documented by sequential aerial photography, core borings or comparison with earlier literature description. Future research should focus (a) on quantifying the rate and magnitude of detrimental changes, (b) on understanding the dynamics of the changed system (and its unchanged counterpart where possible) and (c) determining the cause for initiating and maintaining the change. There are two high priority research needs that must be met to have the capability both to minimize damage during future development and to undo damage from earlier urbanization.

1. Most needed is a workable understanding of the dynamics of the fine-grained sediment system. It is the fine particulates that are most responsive to change, most rapidly dispersed, the cause of turbidity and the transport medium for adsorbed pollutants. Research should be in part interdisciplinary with studies on storm circulation, water column chemistry and trace metal and pollutant analyses. The program should seek qualitative and quantitative understanding of:

a) Turbidity - what are the particulate suspensions in different Bay sectors through the year and at different wave energy levels?

b) Fine-grained sediments - what are the fine constituents of the bottom sediment? What have been historical changes in organized sectors?

c) Turbidity inhibitors - What is the specific influence of sea grasses, pelleters, swamp margins, etc., on drawing suspended sediments out of the water column in different Bay sectors? How has the aerial distribution of these influences changed through time (See 2b below)?

d) Turbidity accentuators - What has caused increased turbidity in certain Bay sectors? What is the relative importance and longevity of these influences?

e) Particulate circulation - What are the rates and patterns of fine grained sediment production, influx, erosion, dispersal, accumulation, and efflux within and between different sectors of the Biscayne Bay system?

f) Cumulative sedimentologic record of circulation and transport-The geometry, historical changes and contained attributes of sediment bodies are (a) a cumulative record of the sediment dynamics and (b) an integrated display of these aspects of the hydrodynamic energy spectrum that move and deposit sediment. This should be carefully studied as a critical compliment to physical oceanographic and sediment transport research.

2. Also of high priority should be careful documentation of the present distribution of bio-sedimentary environments and how they have changed with time. This includes:

a) mapping distribution of bio-sedimentary environments within and marginal to Biscayne Bay to actually determine what is there.

b) determining historical changes in the distribution of bio-sedimentary environments (by sequential aerial photography and core borings) to see what change has actually been associated with urbanization. This should focus on the gradient of change from urbanized (north) to unurbanized (south); and

c) documenting the character and trends of certain bio-sedimentary environments prior to human involvement (by historical maps and analysis of core borings) so as to be able to differentiate natural trends from man-induced influences.

Further research is desired on other problems, such as shore dynamics, but more important is to have what is already known used. Biscayne Bay is unique in many aspects when compared to other urbanized lagoons and estuaries elsewhere in the United States. Existing federal and state guidelines and standards were obtained by studying temperate climate lagoons, river-fed estuaries and open ocean beaches. These standards, in many cases, either are not sufficient or are not applicable to Biscayne Bay. Those local, state and federal agencies responsible for guiding future development must seek the wisdom of scientists that understand a sub-tropical system such as Biscayne Bay.

ACKNOWLEDGMENTS

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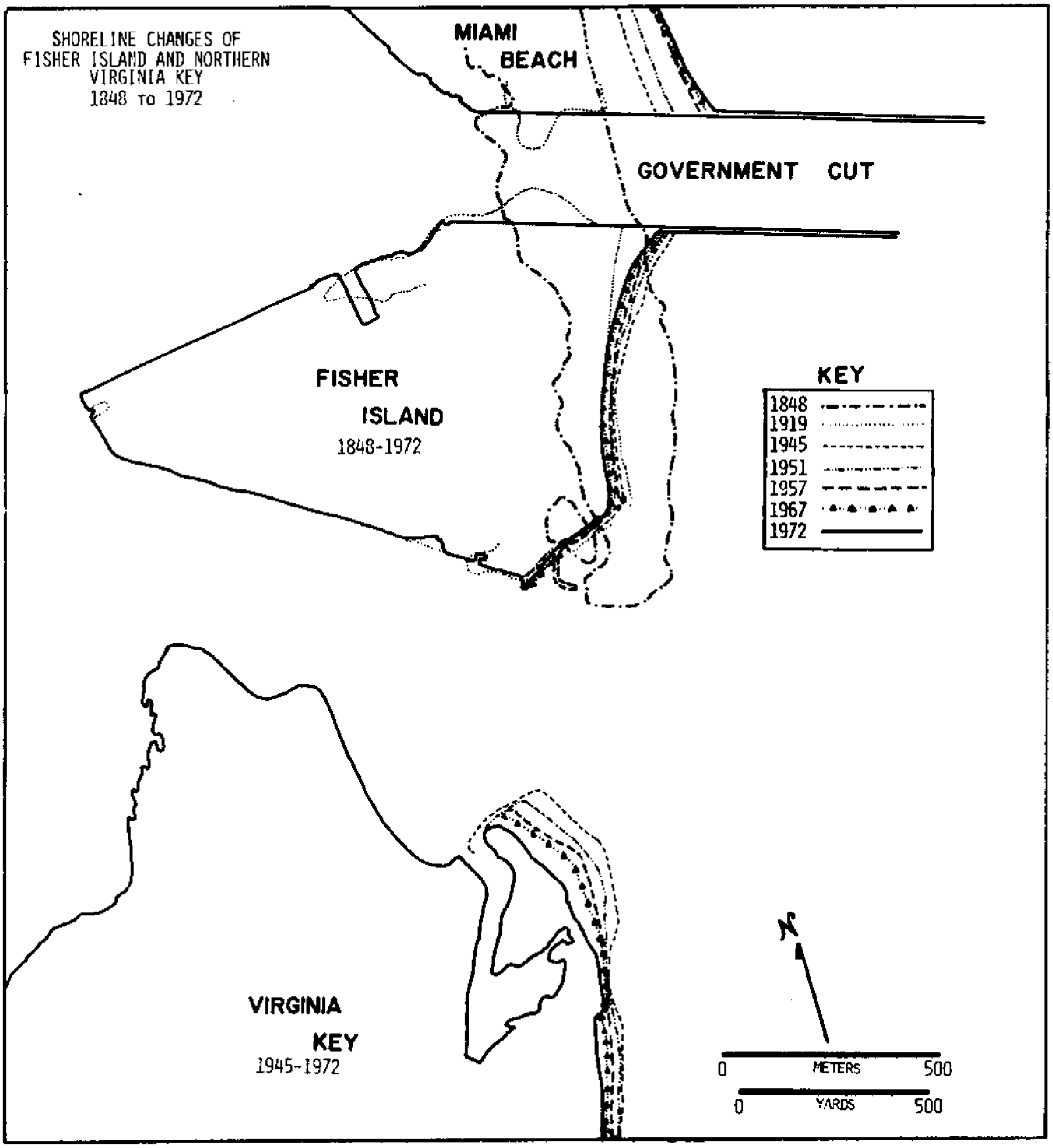

FIGURE 1. Historical shoreline changes of South Miami Beach, Fisher Island, and northern Virginia Key between 1848 and 1972. Partly adapted from Hannon, et al., 1972. Government Cut was dredged in 1905. The seaward extending jetties, completed in 1929, have been a nearly complete block to southerly sand shift causing accretion of South Miami Beach and severe erosion of Fisher Island and Virginia Key Beaches.

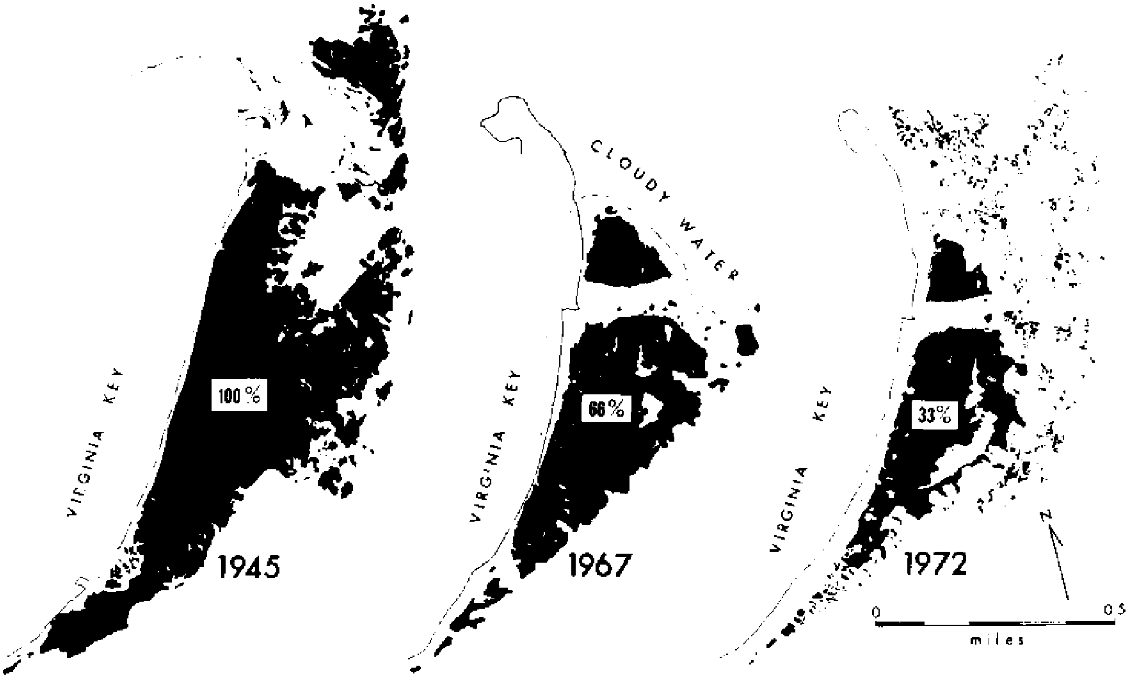

FIGURE 2. Map view of historical changes in sea grass bed cover of the littoral sand platform seaward of Virginia Key beach from sequential aerial photographs. Extensive loss has caused rapid deepening of the platform and erosion of the adjacent beaches.

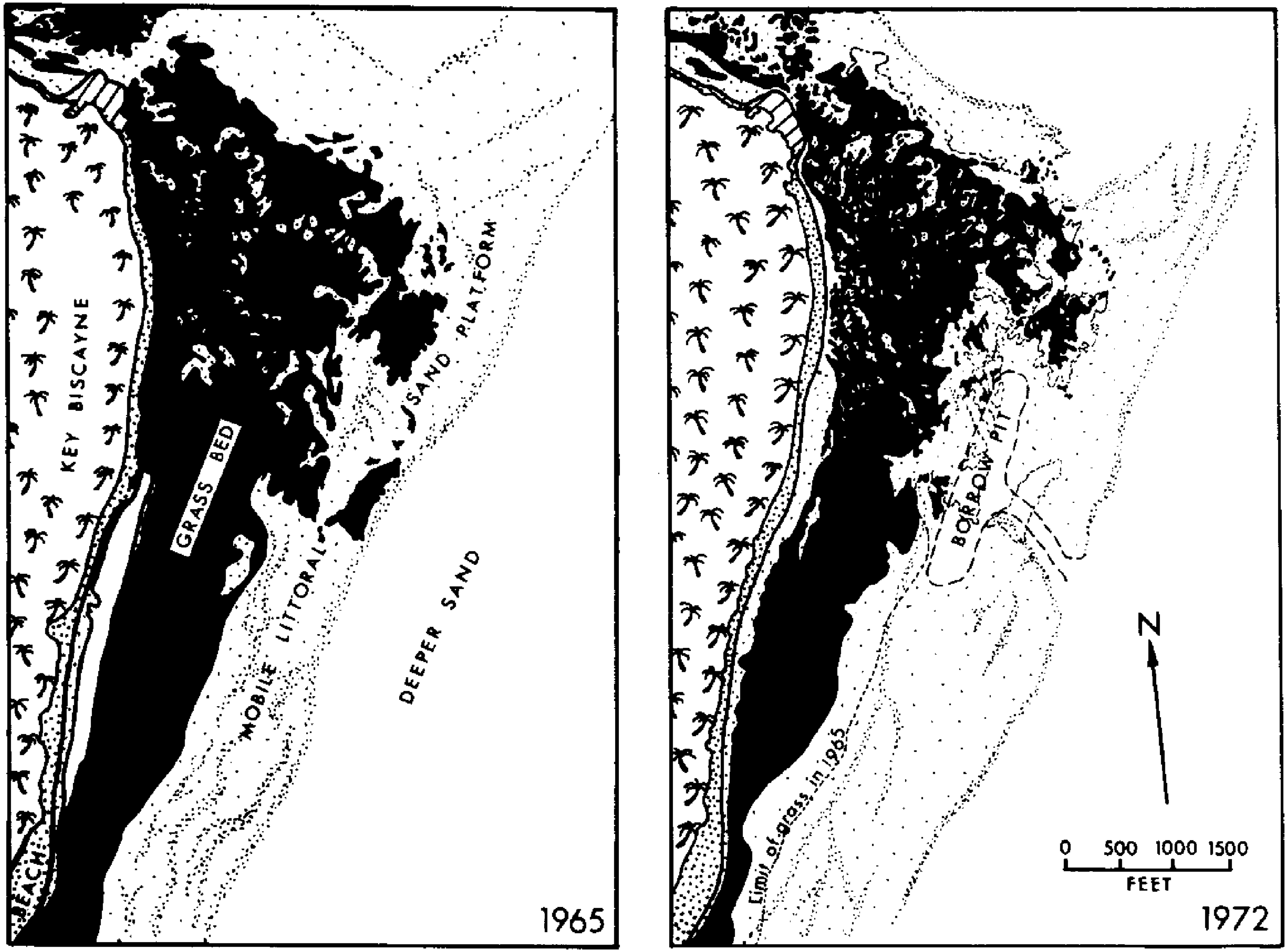

Figure 3. Map view of the nearshore sedimentary environments of northern Key Biscayne in 1965 and 1972. A borrow pit, dredged in 1969, has directly and indirectly caused serious damage to the seagrass cover seaward of this broad shallow littoral sand platform. Data from aerial photographs.

MAN'S IMPACT ON THE BIOLOGY OF BISCAYNE BAY

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ABSTRACT

Biological pollution in Biscayne Bay is a problem requiring rational decision-making.

Drainage patterns to the Bay have been altered leading to increased point-source drainage. Shoreline vegetation and vegetation at the mouths of canals has thus been altered. Canals themselves create new niches for marine organisms and microbial populations. Dredge and fill has had direct and indirect effects on the biota of Biscayne Bay. The primary example being the changes in flora and fauna of North Biscayne Bay. Sewage pollution has caused changes at outfalls. Problems of human pathogens (bacteria, viruses and fungi) associated with sewage outfall are still being studied and patterns of distribution are not clear. Heated effluents have been studied and provide a model of cooperation between industry, government and scientists in defining the problem, gathering data adequate for rational decision-making and finding compromise solutions to pollution of the bay. Pesticides, heavy metals and petroleum products have not been studied intensively in Biscayne Bay and their effect is not fully understood.

Our recommendations are for continued studies on the distribution of natural resources and basic research on energy flow and nutrient cycling in the food-web and the effect of pollutants to inhibit or alter the metabolism of the ecosystems of Biscayne Bay. In the interim we recommend that problems which require decisions should be reviewed by a board of scientists familiar with Biscayne Bay and whose specialties are in the area under discussion. These scientists should be paid for their services and responsible to the community for their input into the decision-making process.

INTRODUCTION

Pollution becomes a problem because living organisms are integrating the environment they live in. If the chemistry of the water is changed, the organisms respond to it. Response patterns also occur to changes in physical or geological parameters. Whereas a change in the biological organisms does not necessarily change the physical or chemical systems, changes to changing environment is a prime characteristic of the evolution of organisms over geological history; so that it is not only man's activities which cause drastic change, but rather change is an integral part of any living system.

The key is how much man can change the system and not alter it to become a less desirable ecosystem lies in the tolerance limits of the species present. The individual species are probably of less value than the role played by the species, but this is a decision-making value judgment for which we need a good deal of functional information on a scientific level. Each organism has a range of tolerance for a specific parameter and a certain point at which it cannot tolerate this parameter. As long as the changes are small and within the tolerance range, the organism will live. A similar pattern is seen for an ecosystem. The key to rational management is to understand these limits and to stay within them in the changes made to benefit man's use of the ecosystem.

In reviewing the history of Biscayne Bay, little thought has been given to staying within the tolerance limits of the ecosystem. We have numerous examples of man's uses of the bay which exceed the limits of the ecosystem. We will review the major ways in which man has changed Biscayne Bay and then present our suggestions for future use.

Much of the previous material presented in this volume outlines the major biological processes which occur in Biscayne Bay. Clearly each of the major constituents of the ecosystem have been effected by man's use and activities of the shoreline and the bay. We will divide the Bay up into shoreline, south, middle and north bay for purposes of description. The major changes in the biota of Biscayne Bay and its shorelines have resulted from drainage, from dredge and fill, from sewage pollution, from pesticide pollution and from heat pollution.

RESULTS

1. Drainage

Prior to major drainage activities in the greater Miami area, during 1900-1925, large quantities of rainwater collected in the interior flatlands called rocky glades and old drainage swales leading to Biscayne Bay. This flowed east until it reached the rock ridge which acted as a partial dam that formed impoundments in the swales. This older fresh-water storage head, which may occasionally have stood 4 to 6 feet higher than at present, poured over and through the ridge of limestone, now known as Miami Oolite, creating springs , seeps and surface runs all along the ridge and pushed the salt front far seaward of its present location (Parker, et al., 1955). Under those conditions fresh-water marl soils formed in the eastern "glades" and swales and over most of the coastal flat land between the ridge and Biscayne Bay.

Tequesta Indians occupied the site, perhaps as early as 2,000 years ago and left signs of their cultural evolution which still remain. At that time their view to the east would have encompassed broad, seasonally flooded, grasslands dotted with cabbage palm hammocks through which passed Arch Creek, Miami River, Snapper Creek and other streams. Large mangroves outlined the course of streams along the seaward end; pond apples and leather ferns probably formed a dense but narrow band in black soil at the seep zone along the eastern toe of the ridge. Cypress and other semi-aquatics grew around the lakes inland from the partially effective rocky barrier of the ridge itself. At very high stages of flooding, cataracts and large boiling springs flowed over barriers at low spots.

Seaward of the coastal marl prairie dominated by grasses there was a barrier forest of red and black mangroves of very advanced age and large size. Since those earlier times most of that early forest has been eroded away by storms and, perhaps, by a rising sea, so that by early 1926 only a small remnant remained. The great storm of September 18, 1926 seems to have destroyed the remaining old forest. The peats from that old forest still can be found under Biscayne Bay at least 600 feet east of the present shore (Wanless, 1969) and in pockets farther offshore (Zieman, 1972), (also Teas, this volume).

Pristine West Indian hardwood hammocks were to be found along the ridge wherever flowing water had carved sinks, channels and caverns. Most hammocks contained ferns, air plants and orchids, as well as other moisture-loving plants. Where the stone was more resistant, hence drier, pines, palmettos and live oaks grew.

In the mid-1800's white settlers came and built homes and gardens for much the same reasons that had attracted the earlier Indians. There was water in abundance, relatively dry, fertile hammock soil, and access by boat to the Bay via creeks. Earliest plantings of mangos, sapodillos and door-yard plants, which still persist were their legacy.

In 1912-13 the Snapper Creek Canal, Coral Gables Waterway, Cutler Canal, etc., were excavated. These canals quickly lowered the water table to near sea level. The lakes dried out and much of the marl soil was farmed. Later springs failed and salt intrusion became a problem. This culminated, in the 1940's by inland advance of the salt front by more than 800 feet per year, abandonment of coastal well fields and a cessation of farming in the coastal marl prairies. Installation of "salt-control" dams near the seaward ends of the canals halted and then reversed the saline intrusion inland, but could not halt the salting of formerly fresh-water marshes seaward of the ridge (see Kohout, 1960, 1967: Kohout et al., 1964).

The post-1940 salt front adjusted to a position near the "toe" of the rock ridge, helped no doubt by numerous farm drainage canals and canals cut during the decades between 1910 and 1940.

There has also been an apparent rise in sea level which, when combined with effects of drainage and loss of an effective coastal barrier berm, now permits tidal intrusion onto most of the Perrine marl prairie. It is not entirely clear to us which major event, rising sea level, diminished fresh water supply, ditching, or a combination of these, has actually dominated, but we believe that drainage was the major factor. The results has been a widespread invasion of the entire coastal tract by tide-disseminated mangroves and associated salt-tolerant animals (Teas and Wanless, this volume).

Prior to drainage the Perrine marl prairie fresh water phase (Figure 1) had sawgrass (Caladium jamaicenses), Gulf spike rush (Eleochris cellulosa),cabbage palm (Sabal palmetto),leather fern (Acrostichum), pond apple (Annona glabra), black rush (Juncus roemerianus), cattail (Typha spp),and primrose willow (Jussiaea peruviana). In the brackish phase of the marl prairie the above plants intermixed with bunch cordgrass (Spartina bakeri), saltmarsh cordgrass (Spartina alterniflora),buttonwood (Conocarpus erectus), white mangrove (Laguncularia racemosa), black mangrove (Avicennia germinans),saltwort (Batis maritima),glasswort (Salicornia begelovii and S. virginica), saltgrass (Distichlis spicata),saltmarsh fimbristylis (Fimbristylis spadicea) and sea-oxeye daisy (Borrichia frutescens).

Relics and living remnants of these plant communities still persist in undeveloped areas along the coast but farming, development and salt intrusion has generally destroyed most of the fresh water communities. Drainage of the swales westward of the ridge has reduced subsurface flow and the remaining hammocks are severely stressed. Ferns, bromeliads and orchids no longer obtain sufficient moisture to thrive, and even the trees show stress and replacement with drier species.

The water budget of Matheson hammock might be restored if a small canal were built from Snapper Creek Canal to the hammock edge and water thus diverted from Snapper Creek Canal allowed to flow through the limestone, via old solution channels, to the Bay. If this attempt at restoration were successful, other hammocks might also be restored in a similar manner. There are three reasons for the suggestion of diverting fresh water from existing canal systems to subterranean flow through hammocks. First, the hammocks would benefit from the increased humidity; second, the underground flow through forests and grassland would tend to "scrub" nutrients, pollutants, bacteria and virus from the water entering Biscayne Bay; and third, the point sources (canal mouths) of fresh water would be partially dissipated to the original spring and "sheet flow" conditions which were found in earlier times (see Kohout and Kolopinski, 1967).

Canals with saltwater intrusion have not received a great deal of scientific attention until recently and these investigations are still in press (see Sallman et al., this volume; and Seigel et al., this volume). The sediments and water as well as fish and certain other organisms are being studied with respect to their microbiology. Fish diseases such as "whirling fish" and fish kills have been reported with increasing frequency in the canals. Human bacteria and viruses (human viruses usually die in salt water) have been found in suprising numbers at times in these canals. The problem of these artificial drainage structures as a new biological habitat which opens to and mixes with the Bay for organisms presents a series of problems which are not yet clearly defined, nor resolved. (1) Drainage previously was sheet run off through shallow vegetation and rock, both of which altered the drainage water. Now drainage comes directly through much deeper canals and is point source run off. These deeper canals contain a different biological compostion. (2) Human and domestic animal microbes survive in the warm water of these subtropical canals. What is the fate of these microbes, and do they enter other animals, especially commercially fished species? (3) The flushing appears to be sluggish in these canals which are predominantly on the western shoreline, especially in northern Biscayne Bay where circulation has been altered significantly. However, larger animals such as fish can freely migrate back and forth from anal to Bay. (4) Much of the natural vegetation such as bottom grasses, fringing mangroves etc., was altered when the canals were constructed and often bulkheaded with fill behind the bulkhead. Often the area has not revegetated so that denuded areas frequently are found.

Hopefully, the studies underway can define the processes occurring in the canals and lead to better guidelines for managing these man-made additions to the Bay.

The interaction of the canals with the Bay ecosystem is complex and not fully understood.

A station in south Biscayne Bay located off Mowry Canal, at which trawling was conducted monthly from July 1968-December 1968, shows the dramatic effect of point source fresh water discharge. In August 1968 the dominant vegetation was the red algae (Digenia simplex)and the number and diversity of animals collected was high. In October 1968 salinity dropped to 5 ppt and the algae were killed. Table 1 shows the before and after discharge catches of algae and animals. The number of animal species decreased by about 50% and the number of individuals decreased by a factor of five.

A second station in south Biscayne Bay located off the mouth of North Canal shows the more subtle effects of point source drainage. Table 2 shows catches from a control station, the station off North Canal, a station located in the thermal effluent of the Turkey Point Plant and a mid-Bay shallow water station adjacent to West Arsenicker Key. Vegetation at the control was dominated by Thalassia testudinum and a complex of red algae; the station off North Canal was dominated by Halodule wrightii; the station in the thermal plume was dominated by microalgae, especially blue-greens in summer and the algae Acetabularia crenulata and Bataphora oerstedii and some Halodule in winter; and the mid-Bay station had Thalassia and Laurencia poitei (see Thorhaug, 1974a).

The catches show that the impacts of point sources of fresh water do not dramatically affect species richness but the numbers of mollusks and crustaceans were lower at the canal station. The heated station, likewise, showed little difference in species richness, although there were fewer kinds of mollusks and more kinds of polychaetes,echinoderms and flatworms. Numbers were markedly lower even though the catch per unit of effort reflects winter sampling and sampling after the effluent was diverted to Card Sound. The mid-Bay station shows greater species richness and most of the gain is in the relatively more stenohaline forms.

2. Dredge and Fill:

The most direct effect of dredge and fill, which includes channel and canal building, causeway and artificial island construction as well as bulkheading and backfilling, is to remove the bottom community in that area. Secondary effects include turbidity and decreased light penetration, causing bottom vegetation to receive less light for photosynthesis. In addition, silting effects on surrounding areas is often severe unless strict precautions are taken. There is an unfortunate cycle to these processes. The seagrasses, discussed by Thorhaug (this volume) as the dominant Biscayne Bay submerged vegetation, act to maintain water clarity and cut down turbidity by their baffling effect. However, seagrasses are often the major plant removed by the dredge and fill process and subsequent increased turbidity and siltation. Therefore, the baffle disappears and turbidity increases, often making it impossible for seagrasses to revegetate because of lack of light.

There are short-term and long-term dredge and fill effects. One additional station in South Biscayne Bay compared to those discussed above under drainage was located adjacent to Homestead Bayfront Park Marina Channel. It illustrates the effect of short-term dredge and fill programs. When the channel was deepened, silt from the operation reduced light penetration at the station. Grasses and algae showed temporary stress but recovery was rapid. Animal catches showed no detectable trends. Thus, this short-term dredge project did not create marked changes in the biota except in the immediate area dredged and filled.

A major long-term result of dredge and fill is continued turbidity and decreased light transmission, such as found in North Biscayne Bay (see deSylva, 1970), which will kill seagrasses and has a marked effect on the fauna. The works of McNulty (1961 and 1970) show the fauna in North Biscayne Bay to be dominated by polychaetes, brittlestars and mollusks. From Smith (1896), the photos of La Gorce (193 and Chardon (this volume) we may assume that North Biscayne Bay was similar to South Bay prior to 1900. Thus a comparison of the flora and fauna from north and mid Bay described by McNulty (1961 and 1970), McNulty, Work & Moore (1962a, 1962b), Moore et al., (1968), O'Gower and Wacasey (1967), Low (1973), and Rosenberg (1975) and that of south Bay by Voss and Voss (1955), Voss et al., (1969), Bader (1969), Bader and Tabb (1970), Bader and Roessler (1971, 1972), Smith (1973), Thorhaug (1974), Thorhaug et al., (1974), Roessler et al., (1974, 1975), Brook (1975), Sprogis (1975), Thorhaug and Roessler (1976) and Hixon (1976) can be used to demonstrate presumed changes which have occurred in North Bay. Also see papers in this volume bv Teas, Humm, Thorhaug, Penhale and Sprogis, Voss, deSylva, and Snedekar and Brook.

However, we cannot specifically identify the source of the changes in North Biscayne Bay because of the multiple stresses which include massive dredge and fill (see McNulty, 1970; and Compton, 1970), causeway and island construction and resulting changes in bottom communities and circulation, sewage pollution adding turbidity as dissolved and suspended solids, excess nutrients resulting in phytoplankton blooms and reduced light penetration for benthic plants, storm discharge from urban and suburban areas, industrial pollutants and increased erosion of shoreline areas from boat wakes.

The work of Rosenberg (1975) compares mid-Bay stations studied by McNulty, Work and Moore (1962) and McNulty and Lopez (1969) in the 1950's and the same area in 1975. The principle changes were an increase in the total numbers of animals m^2 in 1974 but a decrease in the biomass from the 1950's. Thus, more small individuals are present in the area. Animal diversity has increased and polychaetes have increased in abundance while mollusks have decreased. A shift toward smaller more generalized forms has occurred in the animals.

The bottom vegetation has not shown the same pattern. Originally, North Biscayne Bay had a relatively similar bottom vegetation type to South Biscayne Bay. By 1961, when McNulty published his extensive work the floral community had decreased in species and standing crop compared to South Biscayne Bay. Between this study and the present time, certain areas have become denuded of bottom vegetation (Roessler et al., and Thorhaug, unpublished). Unfortunately no quantitative study of the vegetation of North Biscayne Bay has been attempted, so that the above patterns are qualitative rather than quantitative.

In general, the North Bay area has a community of filter feeders such as barnacles, "coon" oysters, tunicates and sponges on piling and seawalls and of small-particle detritus feeders such as polychaetes and brittlestars. Few of the mollusks, crustacea and larger echinoids, that utilize the larger particles of seagrass and mangrove detritus found in abundance in the southern Bay now occur in northern Biscayne Bay. In addition, the clear water, stable salinity forms found near the Biscayne National Monument are absent further north. The middle reach of the Bay is intermediate in nature (turbidity being somewhat higher than in South Bay) and the trend here is toward the North Bay community. Anything more than a generalized qualitative comparison is hampered because a synoptic survey of the Bay with identical gear and methods has not been done except for studies of plankton by deSylva (1970) and the cursory survey of vegetation shown in Roessler and Beardsley (1975).

3. Sewage:

The major study of sewage pollution on the biota of Biscayne Bay by McNulty (1970) compared flora and fauna from November 1953 to July 1961. This was before and after a domestic sewage disposal plant began operation in the fall of 1956. Changes took place after the plant began operating. In an area 100 to 740 m seaward from the outfall benthic macroinvertebrate populations declined from abnormally large numbers of species and individuals to what McNulty calls "normal" numbers on the hard bottom. Soft bottom populations changed qualitatively, but not quantitatively. Zooplankton volumes decreased to about one-half the pre-abatement values. The amphipod tubes declined markedly, but other fouling organisms remained about the same. McNulty concluded that there was no evidence that improved commercial and sport fishing followed abatement, which he interpreted as a long-term detrimental effect from sewage pollution and dredging.

In microbiological studies, human pathogenic enteric viruses have been recovered in and around the bay. There are larger numbers in the sewage effluent area than of Virginia Key in North Biscayne Bay or Miami Beach (see Seigel et al., this volume). This is significant since viruses tend to die in seawater and still they are found in numbers.

Bacterial studies summarized by Sallman *et* al., (this volume) have shown survival of outfall organisms indicating the closer to the outfall, the higher the numbers. The warm waters allow longer survival and higher rates of multiplication of bacteria, presenting problems not encountered in northern waters.

D'amato has shown that even with the present Virginia Key outfall located 4,500 feet offshore that there is a significant movement of effluent into the Bay via Bear Cut, Norris Cut and Government Cut. Proposed pipeline extension evidently will not eliminate the problem. Proposed expansion of the plant further complicates this issue.

Other smaller treatment plants in Dade County contribute effluent to the Bay via canal systems. In addition, viruses have been found in canals in well-sewered areas, presumably from dogs and cats, further complicating the microbial problems in the Bay.

One of the major concerns lies in the safety of humans utilizing water for swimming, wading, etc., which has pathogenic microbial flora present. A second concern is the uptake of these microbes by fisheries organisms which may be eaten by man. The last major problem is the long-term effect of chemical enrichment by the outfalls in the sediment and water of the Bay and subsequent changes in the biota. Do lesser levels of outfall than that studied by McNulty have long-term detrimental effects on the biota? What are the tolerance limits of the Bay to moderate to low sewage pollution levels brought in by tides and wind conditions from ocean outfalls?

As the population of Miami expands, as does the tourist industry, further answers to these questions must be found.

4. Heat

Thermal effluents from industry have been emitted into Biscayne Bay since the Cutler Ridge Power Plant reached full capacity in 1956. This plant was only studied before the release of effluents by aerial photographs. The area which was denuded of vegetation in 1956 was 8.5 ha. By 1973 the area of bare sediment had reached 35 ha. Evidently, this plant acts as a sump for fine sediment. The relationship of this silt to destruction of bottom vegetation is not clear (Smith and Teas, 1976).

The most extensive study of the effects of heat has been done at the Turkey Point Power Plant complex. This is one of the only examples in Biscayne Bay, where the underlying tolerance limits of major organisms were studied along with the effects of the pollutant on the ecosystem. The data was utilized in rational decision making about the siting of the mouth of a second effluent canal.

It is to the great credit of the concerned governmental agencies as well as the industry itself that a final decision was made for disposing of effluents in such a way as to do minimal harm to the ecology of the Bay. In addition, the far-sightedness of the U.S. Energy Research and Development Commission (formerly AEC), Sea Grant, and Florida Power & Light Corporation allowed an opportunity to revegetate the 25 ha denuded by heated effluents. This is the only large-scale example of restoration of a seagrass community in the U.S. today, and provides a model for Biscayne Bay restoration efforts as well as throughout the U.S.

The Turkey Point plant did not have a quantitative investigation prior to the opening of the Grand Canal. However, the events after the initiation of heat were as follows: The *Thalassia* community disappeared in an area of about 9.3 ha off the mouth of the canal, 5°C above ambient. In an area of approximately 30 ha 3 to 4°C above ambient, the *Thalassia* community declined by about 50% and important macroalgae fell to about 30 of the former populations. As a result, selected entities of the animal population increased temporarily, due to feeding on dying plant material. After exploiting this food many mobile forms departed. This, coupled with strong current from the effluent removed considerable nutrients from the area, which then became covered with blue-green algae.

Increased temperature is not necessarily detrimental to a subtropical ecosystem; control and limitation in the essential factor. For example, in the areas were a +3°C isotherm was maintained the macroalgae and grass populations fell markedly in the summer as temperatures exceeded 31°C. However, during the winter months *Thalassia* rebounded. Comparatively speaking the +2°C isotherm was extremely productive, exceeding that of the control stations outside the obvious influence of the thermal plume. This may be due to a number of factors, the increased availability of nitrogen via decaying detritus, modification of circulation and elevated winter temperatures, etc. Regardless of the reason it does indicate that with sufficient understanding and adequate control, man's activities normally detrimental to the environment can be put to productive use.

The catch of animals correlated well with the data on benthic macroplants. Predictive models based on 350 species of animals caught with a 10-foot otter trawl over a period of two and a half years near the Turkey Point effluent indicate that maximum numbers of species and numbers of individuals of benthic macroinvertebrates and fishes will occur near 26°C. About half the species are excluded at 33°C, 75% above 37°C. Laboratory studies on the macrophytes show an optimum near 28°C. Laboratory investigation on lethal temperature limits corroborated filed data on both plants and animals.

Multiple regression analyses of dominant species of mollusks, echinoderms, and sponges indicated that the principle variables related to catch were vegetation and salinity. Those species most closely related to vegetation were near-shore forms, while those related most closely to salinity were offshore forms such as echinoderms, sponges, wormshell gastropods and the checkered pheasant shell. Analysis of variance of the mean number of animals per trawl drag (approximately $100/_{m}2$) indicated that areas elevated 4 to 5°C above ambient produced few specimens of those species of animals which comprised one per cent or more of the total number of macroanimals.

Stations located in areas elevated between 3-4°C had low numbers of animals in the summer, but showed some recovery in winter; however, the average annual standing crop was lower than at control stations.

At stations elevated between 2-3°C, the catches were low in summer, but high in winter and spring; this produced above average annual standing crops. At stations elevated less than 2°C, no statistical differences between controls and affected stations could be detected.

Analysis of total number of individuals of major taxa comprising 80 species of fishes, 147 of mollusks, 66 of crustaceans, 23 of echinoderms and 22 of sponges, showed similar results to those found for the dominant indicator organisms.

Preliminary results from studies of the Card Sound effluent canal, opened in February, 1972, indicated the effluent was 2°C above Bay ambient and carried a considerable load of suspended matter. In the immediate area of the canal mouth, the macroplant community in approximately 2-3 ha disappeared. In the area where the water contained noticeably more suspended matter, the seagrasses decreased in production of dry weight blade material from 20 to 30% that in 1971. Control stations increased 10% compared with 1971, probably due to a slightly warmer winter. However, the animal populations in 1972 at the affected stations were similar in abundance and diversity to those found prior to the canal mouth opening. (Thorhaug, Roessler & Segar, 1974).

A second 9.7 km canal was constructed to discharge heat into Card Sound, and the Grand Canal was closed. The decision of siting of the canal mouth was made by Florida Power and Light Company with input from scientists at the University of Miami, AEC (now ERDA), EPA and Department of Interior as well as state and county agencies. A study before, during, and after release of effluents from this canal was made (Thorhaug et al., 1976). Except in an area of 2 to 3 ha adjacent to the canal mouth, little damage to the benthic community was observed (Thorhaug et al., 1976). This was quite different from the effect of the first canal at Turkey Point and points out the benefits of rational decision with cooperative input from industry, government and concerned scientists.

The thermal tolerances for many of the major species affected by heat disposed in Biscayne Bay have been determined in the laboratory and correlated to field data (Thorhaug, et al., 1971: Thorhaug and Hixon, 1975; Thorhaug, 1976: Thorhaug and Hixon, 1976; Albertson, 19 ; Hoberg, 1975). This is one of the few examples where exact limits of tolerance have been ascertained so that decisions may be made based on quantitative data.

5. Pesticides:

Few studies have been made in Biscayne Bay as to levels of pesticides in the water. Meyer (1972) and Corcoran (unpub.) have found levels of certain chemicals such as DDD, DDE, dieldrin, PCB and Silvex. Present work of Sallman et al., (this volume) promises more data. Toxic levels in certain fishes and invertebrates have been studied at other locations both in field and laboratory. Qualitative indication of pesticide kills of marine invertebrates (Voss, this volume) are available, but no quantitative study has been done to date.

6. Other Pollutants:

Certain other toxic substances such as oil, heavy metals, radioactive materials, chlorine, etc., do enter the Bay waters and could be affecting organisms. Little is known on their affect on tropical or subtropical species or their distribution and levels in Biscayne Bay.

7. Restoration:

Since man's early activities in Biscayne Bay were carried out with almost total disregard for the marine ecosystem there are many areas where the only solution for a viable, natural bay is restoration. Many other areas are marginal and restoration efforts along with cessation of activities causing damage might bring back a natural community. Cost of restoration also provides a measuring stick for the cost of measures designed to ameliorate the pollutant in an area where the decision-making on a new impact is being made.

In general, the bottom and certain physico-chemical parameters must be suitable for restoration. The problem then is to restore the major vegetation to provide a suitable food, shelter and water quality base into which the animals may return. Restoration techniques presently underway in Biscayne Bay include seagrasses, mangrove and shoreline modifications such as rip-rap and less bulkheading.

Seagrass restoration is now possible on a large scale. Efforts in North and South Biscayne Bay (Thorhaug,1974; Thorhaug & Hixon, 1975) have shown that thousands of seeds have taken root and grown in areas previously denuded by man's activities. Thalassia, the dominant species in the Bay is most feasibly planted by seed, although a technique for plugging has been devised by the Florida Department of Natural Resources. Plugging has the following unfortunate features: (1) existing beds of seagrasses are utilized to obtain the plugs, thus doing damage (2) plugs do not expand laterally to create growing beds as do seeds (3) the present method is limited to water in which one can wade (4) prodigious amount of hand labor which creates a high cost per acre.

The seeding method of Thorhaug, has none of the above drawbacks. Optimum location for revegetation is a peaty sediment such as found along the Western side of Biscayne Bay. Studies show that areas of high current, extensive wave action or very coarse sediment are less optimum for planting; although these areas, once planted, are often excellent for expansion of the community.

Qualitative observations have shown a large recolonization of these replanted areas by certain invertebrates and fish which are members of the Thalassia community. No quantitative study has been undertaken in this area, but it is necessary to ascertain the restoration potential of the Thalassia community. Planting of other grasses is also underway.

North Biscayne Bay is capable of being restored in many areas based on our results at 10 stations. The best place to begin restoration would be between the 36th and 79th Street Causeways and work outward from this area.

Mangrove restoration is also a highly viable technique as accomplished by Teas (this volume) in a series of locations around Biscayne Bay. Propagules of three species have been planted in a series of locations including different bottom types, various energy regimes, tidal levels and geographic areas (including Viet Nam via helicopter). Success of growth and maturity has been high, so that a fairly extensive technology now exists in this area. It appears to be an excellent tool for restoration of shoreline in many Biscayne Bay areas.

Other methods for physical restoration of parts of Biscayne Bay have been mentioned in this volume which include causeway, canal, and shoreline modification. Most notable from a biological point of view is the discussion by Voss (this volume) on replacing bulkheaded sea walls by rip-rap. This makes a far better habitat for organisms and in some cases in Biscayne Bay has shown a lobster fisheries potential.

DISCUSSION

An intensive survey of biological resources in Biscayne Bay, especially North Bay would be a valuable first step in evaluating changes which have occurred. However, even these studies would not lead to the capability to predict changes in biota which will occur as the result of management decisions on use of the Bay. The basic processes (photosynthesis, detritus production, nutrient uptake and cycling through the biological feed web) must be learned first and then the effect of pollutants on these processes and tolerance limits of major organisms to each pollutant must be understood before impact can be quantified or predicted.

Thus basic scientific research in food webs, cycling of matter, flow of energy and effects on these systems by pollutants is needed. In the meantime, the advice of competent scientists must be sought and utilized in deciding if a proposed use of the Bay will be a biological catastrophy as predicted by the preservation extremists or an economic boon, comparable to introducing tourists to Florida, as claimed by backers of the proposed use.

In the event that hard management decisions must be made in the absence of the above-named definitive research, then such decisions probably can best be made using a review board composed of responsible laymen and scientists working together.

A recommendation for the intermediate period before a full scientific understanding is available for management is a review board of professional scientists balanced as to familiarity with various aspects of Biscayne Bay, who could evaluate permits for controversial projects if local and/or state scientists and developers could not agree. Such a panel should be paid for their time and must also be held responsible for their decisions so that proper decisions are rewarded and improper ones would be a liability.

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FIGURE 1.

Approximate 1940 boundaries and bay shore community types.

Legend

1 - Tidal mangrove

2 - Marl prairie, brackish phase

3 - Marl prairie, fresh water phase

4 - High hammock

5 - Live oak/pine

6 - Pineland

7 - Marl swale, Snapper Creek Lake

8 - Rockland edge

9 - Sand

10 - Vegetated shallows

11 - Old tidal channels

——— Community margins

⌒ ╌ Creek channels

····· Subaqueous boundaries

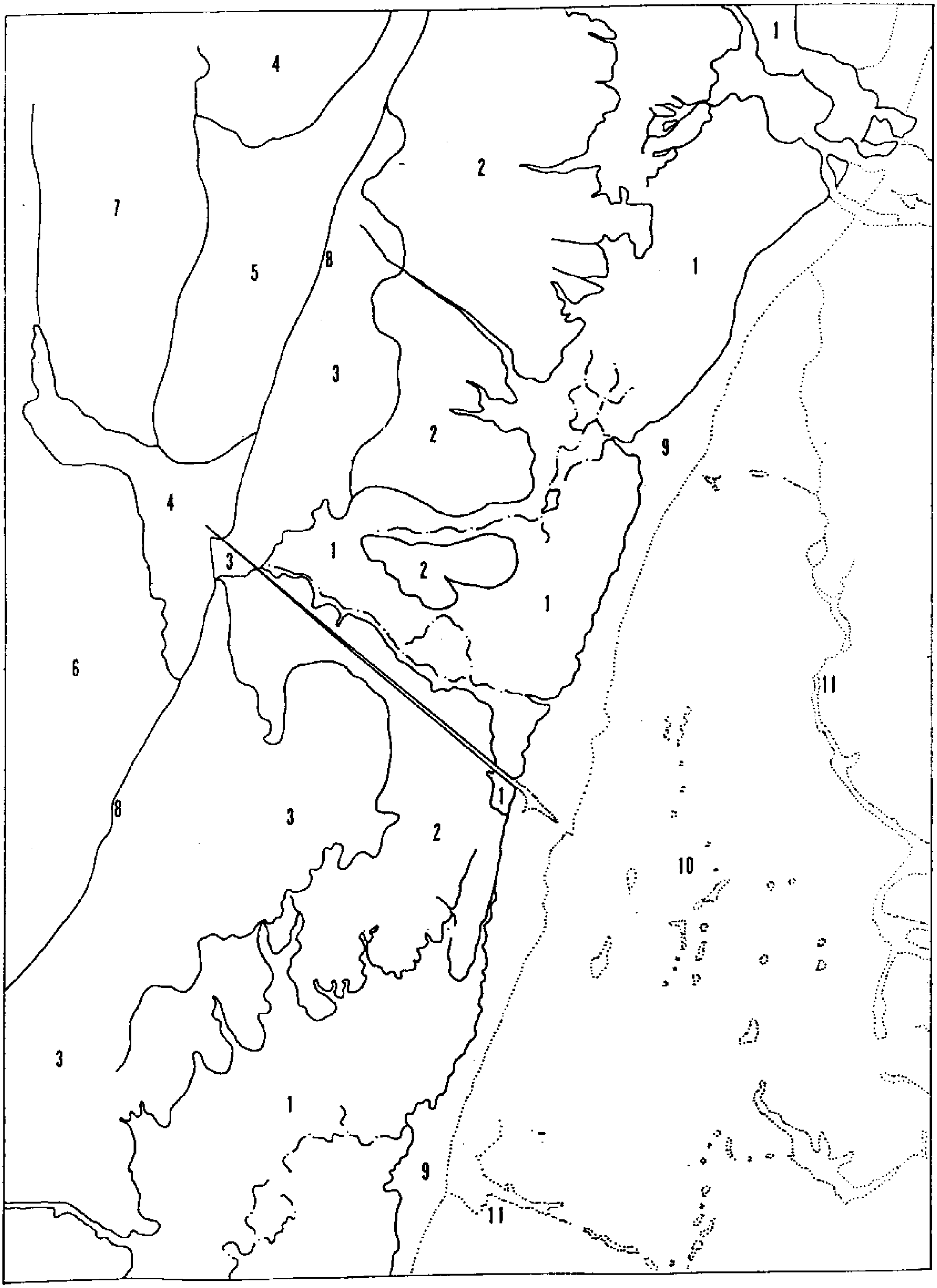

Figure 1

TABLE 1

CATCHES OF VEGETATION AND ANIMALS AT A STATION OFF MOWRY CANAL BEFORE AND AFTER FRESH WATER DISCHARGE

	Before Aug. 1968		After Nov. 1968	
	Species	Individuals	Species	Individuals
Fish	4	123	6	110
Mollusks	18	1114	5	54
Crustaceans	9	323	6	124
Total	31	1560	17	288
Vegetation		46 pounds		33 pounds

TABLE 2

COMPARISON OF CATCHES (NUMBER OF SPECIES AND CATCH/TOW) AT A MAINLAND SHORE CONTROL STATION, A STATION OFF NORTH CANAL, A STATION ELEVATED + 4.5°C OFF A POWER PLANT DISCHARGE CANAL AND A MID-BAY SHORELINE CONTROL STATION

	Mid-bay control		Mainland Shore Control		Canal		Heated Effluent	
Effort[1]	268		247		247		380	
Vegetation (lbs/tow)	6.3		5.7		6.7		0.1	
	Species[2]	Ind/tow	Species	Ind/tow	Species	Ind/tow	Species	Ind/tow
Pisces	27	1.5	22	3.1	22	3.5	19	1.0
Mollusks	79	37.1	58	112.3	57	64.6	49	8.6
Crustacea	34	39.3	28	43.0	23	26.7	24	2.1
Polychaetes[2]	6	0.1	N/D	N/D	5	4.3	17	6.8
Porifera	16	1.3	5	0.47	4	0.05	3	0.01
Coelenterata	4	0.07	1	0.01	2	0.04	2	0.02
Echinoderms	12	2.84	4	0.18	4	0.08	9	0.88
Misc.	2	0.02	2	0.03	2	0.05	4	0.42
Total	180	82.2	120	159.1	119	99.5	127	19.1

[1] Effort for polychaetes - 36 tows at mid-bay control; 0 tows mainland control, 35 tows at canal and 210 tows at heated effluent.

[2] Polychaetes only identified to family.

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