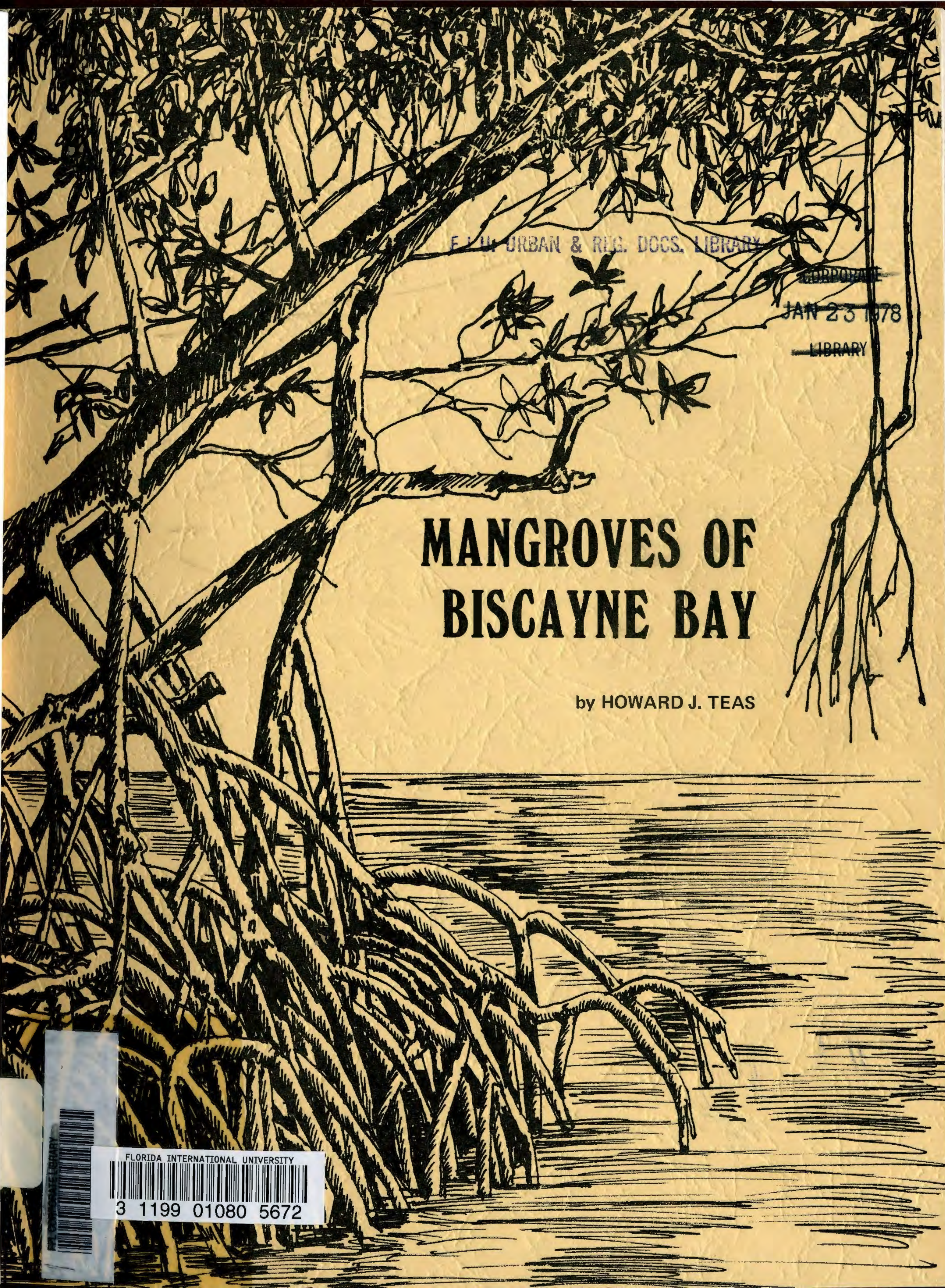

MANGROVES OF BISCAYNE BAY

by HOWARD J. TEAS

gift from W.T. Muir 1-23-78

MANGROVES OF BISCAYNE BAY

A study of the mangrove communities along the mainland in Coral Gables and south to U. S. Highway 1 in Dade County, Florida

Carried out for the
Metropolitan Dade County
Commission

By

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SUMMARY

The mangroves along Biscayne Bay from Coral Gables to the Monroe County line have been classified into major types of communities and their productivity estimated. Five communities were distinguished: Coastal Band, Dense Scrub, Sparse Scrub, White & Mixed and Black Marsh. These produced plant litter at rates of from about 0.5 to 3.9 tons per acre per year. The Coastal Band of mature mangroves along the shore is most productive, the dwarfed Sparse Scrub the least productive on an acre basis.

Areas of each of the five communities was determined by analyzing aerial photographs. Ninety-nine sections of land along Biscayne Bay and the insides of the offshore islands in the study areas have significant stands of mangroves, the total area of which was estimated to be 19,456 acres. The litter (leaves, twigs, wood, fruits, etc.) that can enter the detritus cycle from these mangroves is about 37,000 tons per year. The calculated production of material from the seagrasses of the same part of Biscayne Bay is 248,000 tons, almost 7 times as much as the total from mangroves.

Historical, legal and biological aspects of the bulkhead line were evaluated. It was concluded that the mean high tide line is the most appropriate location of the bulkhead line along Biscayne Bay.

MANGROVES OF BISCAYNE BAY

INTRODUCTION

Background

Biscayne Bay is shown on some maps as the entire Bay within Dade County. This usage is found on Metropolitan Dade County Planning Department maps and appears to have been accepted in defining the Biscayne Bay Aquatic Preserve recently established by the State of Florida. In this report the broad definition of Biscayne Bay will be used except where detailed discussion requires reference to the defined subunits such as Card Sound, Barnes Sound, Manatee Bay, etc. These bodies of water have approximately 35 miles of undeveloped mainland shoreline and more than 15 miles of island shoreland in Dade County (1). Most of this shoreline is dominated by mangroves. See Figure 1 for the principal features of the Bay.

The setting of a bulkhead line along Biscayne Bay will determine the limits for future fill and land development. It was the decision of the County Commission to support research on mangroves in order to have information about the mangroves and mangrove communities along the Bay to assist in setting the bulkhead line and in evaluating proposed development of lands along the shoreline. This report presents the result of that study, which has been carried out by a contract with the University of Miami. It was the intent of this investigation to provide ecological information on the types and distribution of mangroves, the productivity of the various types of mangroves, and the amount of nutrients exported to the Bay; to assess the relative contributions of the Bay's

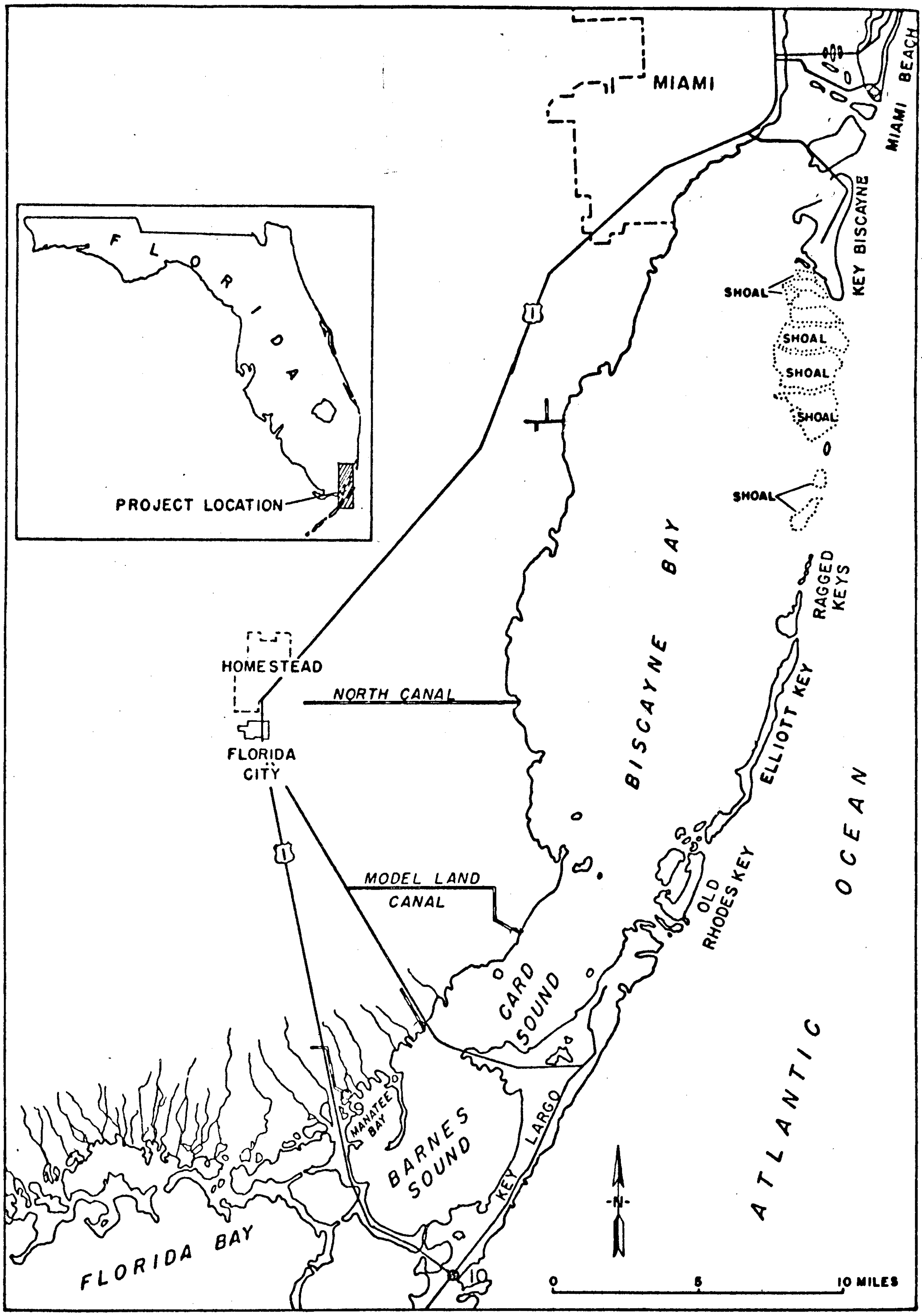


Figure 1 Principal Features of Central and Southern Biscayne Bay

mangrove and grass bed detritus cycles and to consider whatever biology of the mangrove area is pertinent to the location of the bulkhead line and to control of land use along that line.

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 (2). Mangroves reach their maximum development and greatest luxuriance in Southeast Asia, Indonesia and Borneo (3).

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 adaptations 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 fresh water environments (3).

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 lists a total of 4 genera and 8 species for the mangroves of the western hemisphere (4).

Florida mangroves are made up of 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 erectus 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 make only a small contribution to the energy budgets of Dade County mangrove areas and are not considered in this study.

All three species of mangroves occur in the southern part of Florida. Their distributions within the state were reported by Savage (5). 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. The 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.

Many mangroves do not require a saline environment. Several genera and species of mangroves have grown and reproduced in freshwater for more than a century at the botanical garden at Bogor, Indonesia, and for more than 50 years in a botanical garden at Hamburg, Germany (6). In the United States Dr. John H. Davis, Jr. carried Florida Red mangrove propagules to the National Botanic Garden in Washington, D. C. in 1933 (7), where these plants, or possibly their progeny, were found to be alive and apparently reproducing in 1973 (8). It is reported that these mangroves were watered only with Washington, D. C. tap water. In parts of Everglades National Park, Red mangroves are currently growing and reproducing in water that has a lower salinity than Coral Gables tap water (9). (see Figure 2).

Mangroves are usually considered to be plants that require standing water to live; however, there are Red mangroves in the Miami area that are growing above mean high tide at some distance from the nearest seawater; for example there is a large Red mangrove in the front yard of a home at the corner of N. Bayshore Drive and NE 81st Street shown in Figure 2. At Dade County's Matheson Hammock Park there are Red, Black and White mangroves growing in a grassed area beside a parking lot, apparently above MHW. See Figure 3. It is reported that these trees were in place prior to and survived filling of the area (10).

Very few higher plants are able to tolerate more than trace amounts of salt (sodium chloride) within their tissues. Mangroves have special adaptations that enable them to live in saline waters. Red mangroves avoid the problems of elevated internal salinity through root selectivity, that is, the cellular membrances of their roots allow very little salt to pass into the plant (11). Red mangroves have internal salt concentrations of only 1/100,000 that of seawater. Black and White mangroves have much less efficient salt exclusion root membranes than the Reds; they take in water that has a salt concentration from 1/1000 to 1/10,000 that of seawater. In the Black and

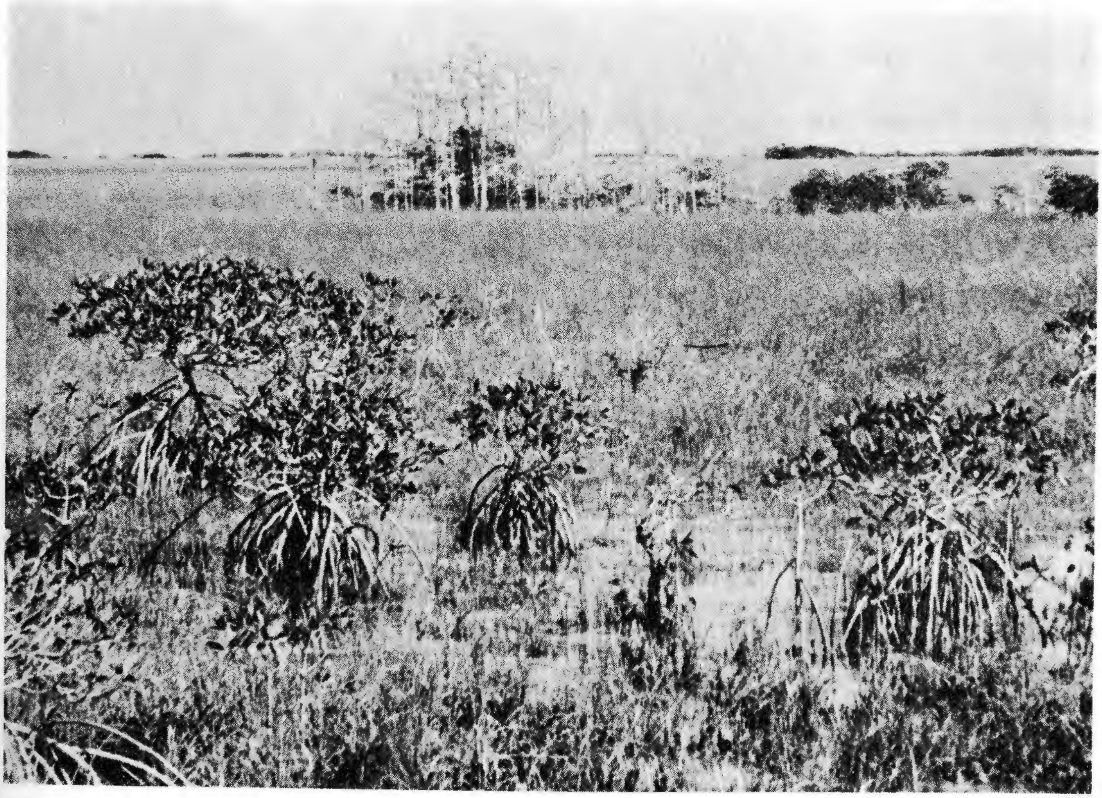


Figure 2 Red Mangroves Growing in Fresh water in Everglades National Park (above) and

Large Red Mangrove Growing on Dry Land at N. Bayshore Drive and NE 81st St., Miami

Figure 3 Red, Black and White Mangroves Growing on Dry Land at Matheson Hammock Park

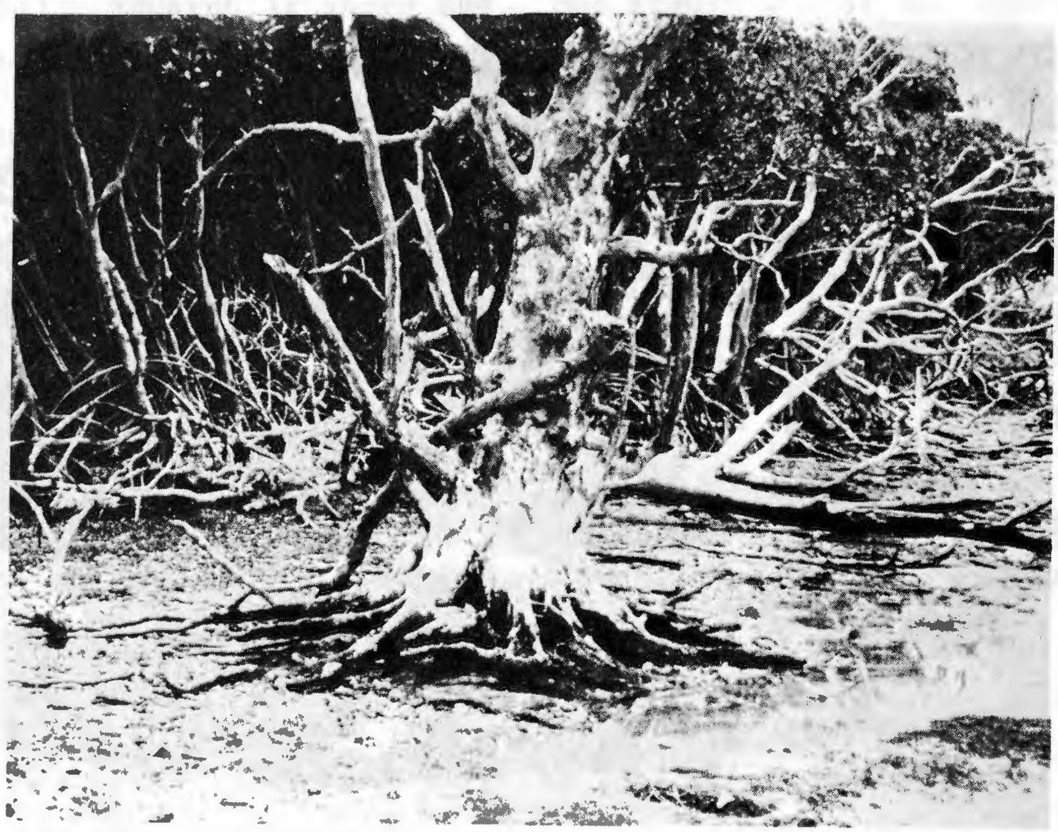


Figure 4 Storm Damaged Mangroves and Eroding Shoreline, Card Sound

White mangroves, the salt that is taken up by their roots is secreted from the surfaces of the leaves through special glands. This secreted salt can be seen as small crystals on the leaves of Black mangroves when there has been no rain for a day or two. Salt secretion on the leaves of White mangroves occurs in the same way, but is less obvious than in the Blacks.

Mangroves usually grow in soft muddy soils along protected shores where they are not subject to strong wave action; however, Avicennia can become established and survive in relatively high energy coastlines as in New Caledonia (9) and is a successful pioneer species in some rocky substrate shoreline areas in Dade County, for example on the north side of the Julia Tuttle Causeway.

The width of the mangroves along Biscayne Bay varies from less than one hundred feet to more than a mile. In many areas they are drained by small tidal creeks. Along much of Biscayne Bay's western shore mosquito ditches criss-cross the mangrove areas. These were originally dug about 35-40 years ago to control mosquitoes and sandflies by drainage of surface water where breeding occurs and by allowing fish to enter and feed upon the larvae. These ditches typically have been redug once or twice since then.

An important factor that has determined the width of the bands of mangroves along the shoreline is the erosion caused by hurricanes and storm tides. In the Matheson Hammock Park, stumps of mangroves can be seen well beyond the present shoreline at low tide. It is difficult to determine the extent of the receding beach line, but estimates at Cocoplum by Tabb and

Roessler (12) and by Reark (13) indicate that erosion of the mangroves may have been more than 200 ft. since the early 1920's. Evidence of recent storm damage and shoreline erosion is shown in Figure 4.

Mangrove detritus food chain

The conversion of fallen leaves and other litter from estuarine plants by an array of organisms and their role in detrital food chains have been appreciated for several years (for example 14, 15, 16). Plant "litter" such as leaves, bark, twigs, etc. becomes broken mechanically and is digested biologically to form small particles that remain in suspension in water. These particles of plant remains are termed "detritus." Important work in this field was done at the University of Miami by Heald (17) who studied the production of litter and detritus in a mangrove forest in Everglades National Park, and by Odum (18) who followed detritus cycling in the food web organisms in the same area.

Heald found that Red mangrove leaves were generally reduced to detrital size or decayed into soluble materials within a year. Degradation was most rapid in brackish water where leaf feeding crabs and other invertebrates were numerous. He reported that mangroves contributed approximately 3.6 tons of leaves and twigs per acre in a year. Amphipods and crabs were found to be important feeders on mangrove litter that are responsible for breaking large pieces into smaller ones. Bacteria and fungi as well as an array of invertebrates, and fishes, birds and other higher animals utilize detrital material directly or indirectly.

Tides of Biscayne Bay

The tides of the Biscayne Bay area have been studied by Schneider who reported in 1969 that the elevation of mean high water (MHW) was 1.5 ft. in central Biscayne Bay, and about 0.9 ft. in the lower Bay (1). The mean tidal range (mean high to mean low tide) was 2.0 ft. in Central Biscayne Bay, and 0.5 ft. in the southern part. Updated MHW information is provided on a Dade County Public Works Department map (19). The tidal ranges are plotted for several points in the Bay in Figure 5. It can be seen that there is a dramatic change in tidal excursion between Homestead and Card Sound. Biscayne Bay apparently consists of two parts that differ widely in their tidal characteristics.

The literature on mangroves indicates that tidal flushing is important to their healthy growth. The reduction or blocking of tidal flow to mangroves by highway construction or by diking has killed large areas of mangroves in the past. Indeed, the limitation of tidal circulation by diking, usually combined with pumping water to maintain continuous high water level, has been a standard means of killing mangroves prior to filling them for land development. It is rare to find living stands of mangroves without tidal flushing (20).

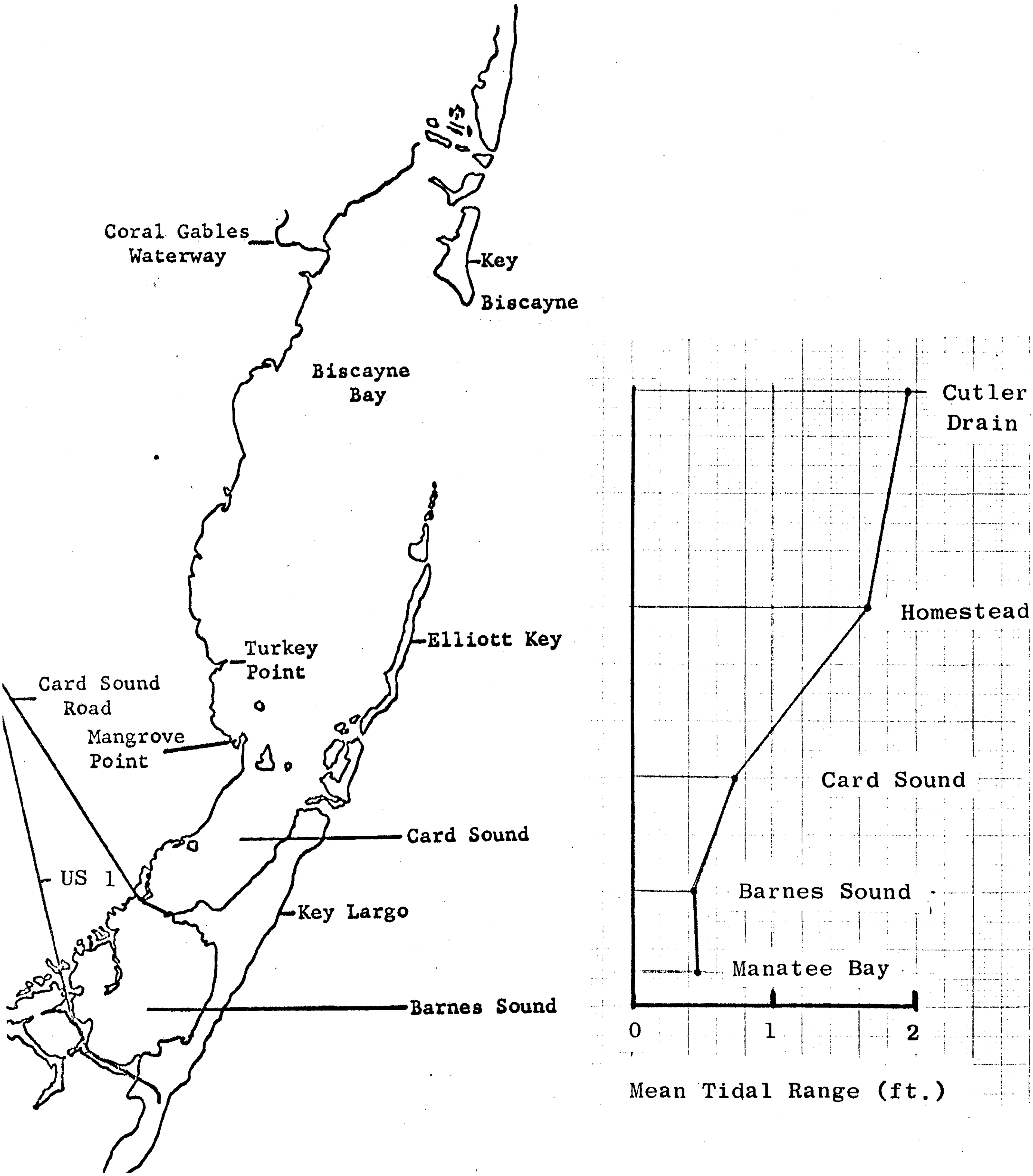


Figure 5 Mean Tidal Range
in Biscayne Bay

METHODS

Sampling areas and stations

Forty-six sampling areas were established from the Coral Gables Waterway to south and west of U. S. Highway 1 at Barnes Sound. Stations in Coral Gables, although not included in the study area, were utilized for intensive (frequent) sampling that would not have been practical for most of the more remote areas. The sampling areas were distributed along the coast so as to include examples of various community types. In each area, sampling stations were established at which leaf decay and litter production were measured. Litter pan samples were collected at four week intervals; leaf decay bags were sampled at two weeks, four weeks or eight weeks. The sampling areas are summarized in Table 1 and their locations shown in Figure 6.

At the start of the study many sampling areas had to be established within a short period of time. Subsequently, a few of these were abandoned because of vandalism or when more detailed checks indicated that the areas were not actually representative of the communities intended.

Leaf Crop Estimates

The mangrove tree adds photosynthetic products to its trunk, bark, roots and branches, but the principal contribution to the detritus cycle over a small number of years is the leaves that fall. The three species of Florida mangroves lose their leaves a few at a time (although more in some months than others).

Table 1 Sampling Areas for Litter Pans, Leaf Decay and Community Characterization Measurements

Mangrove community type	Sampling area no.	Litter pan sampling frequency*
Coastal Band	1	H
	2	H
	7	H
	10	L
	11	L
	12	L
	13	L
	14	O
	15	O
	18	L
	19	O
	22	H
	23	O
	24	H
	28	O
	29	O
	32	M
	33	M
	37	O
	38	O
	41	M
	42	M
Dense Scrub	5	H
	8	L
	9	L
	20	H
	21	L
	30	L
	31	L
	34	M
	35	M
Sparse Scrub	43	O
	44	O
Black Marsh	26	H
	27	L
White	3	H
	16	L
	17	H
	39	M
	40	M

* H = high intensity, i.e. every 2 weeks
M = medium intensity, i.e. every 4 weeks
L = low intensity, i.e. every 8 weeks
O = not sampled for productivity

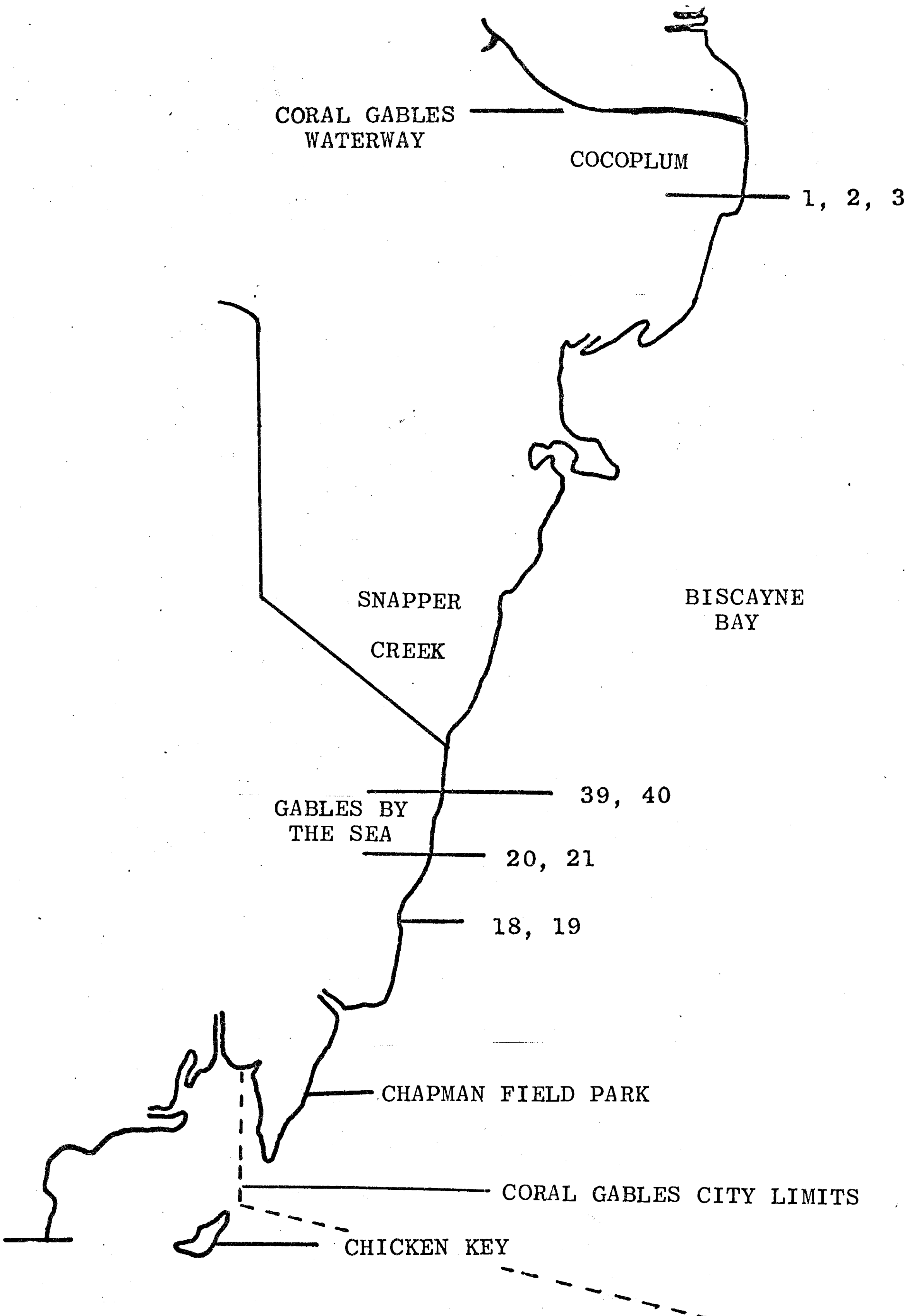


Figure 6 Sampling Areas in this Study

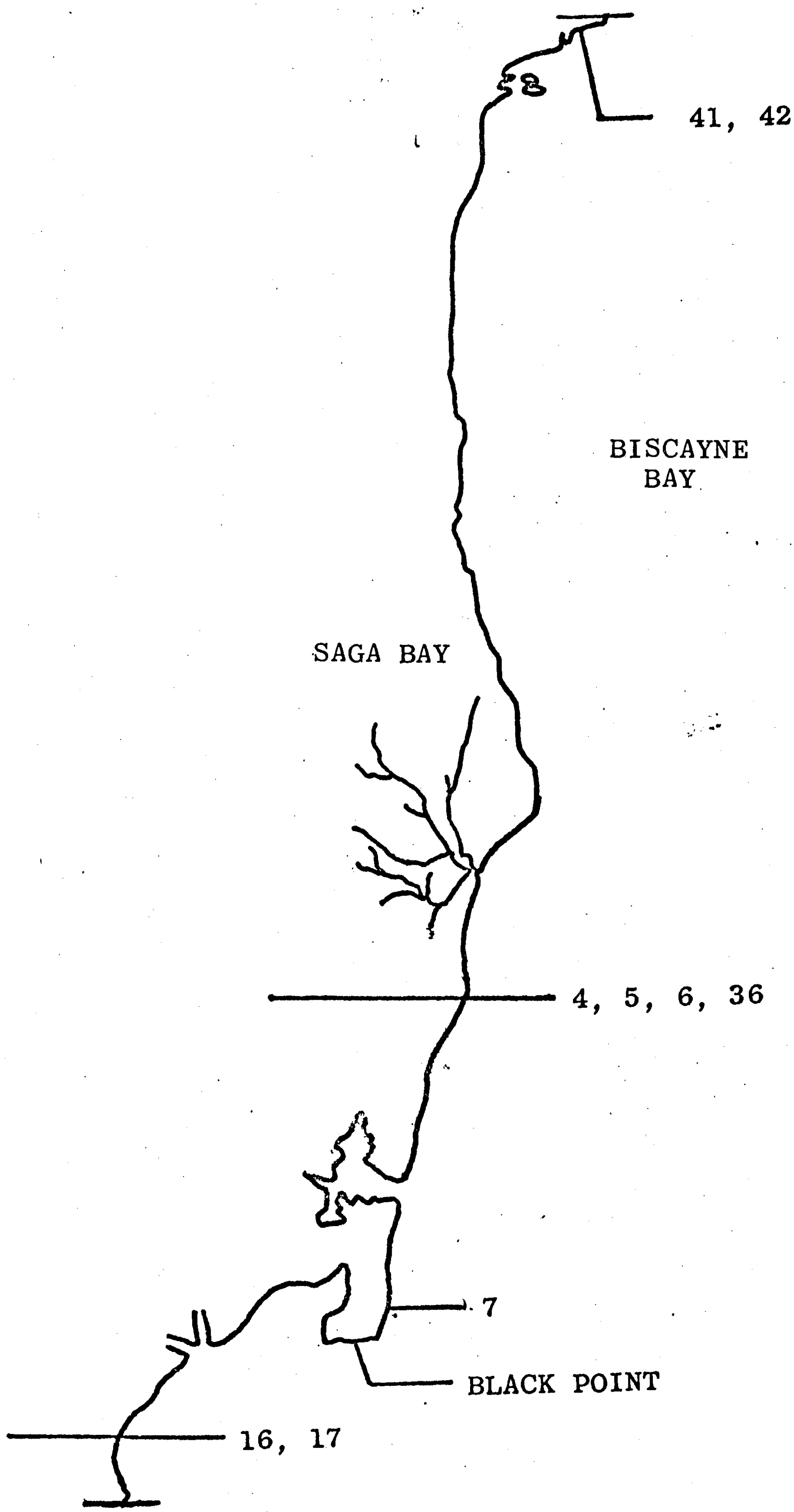
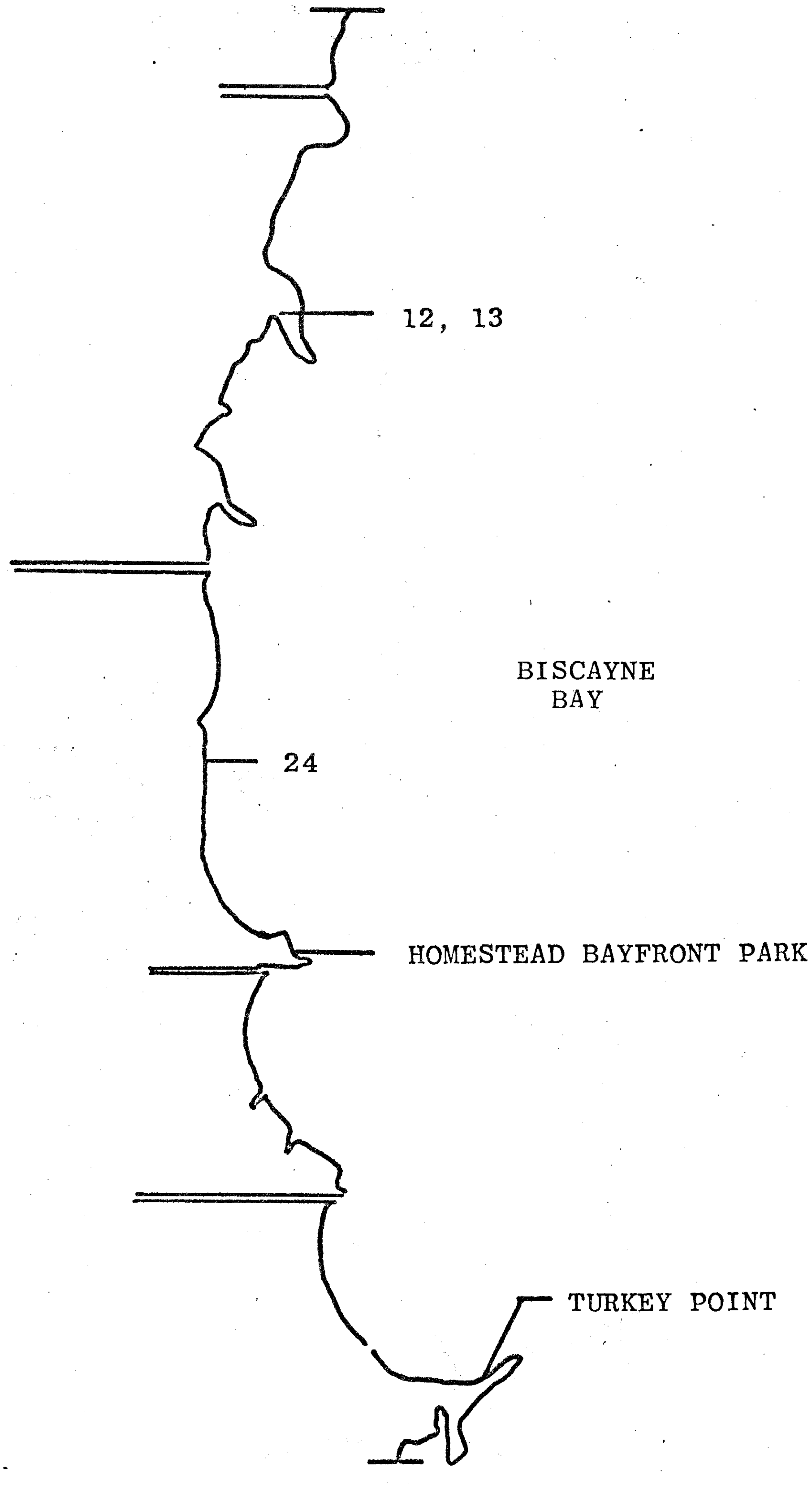


Figure 6 cont.



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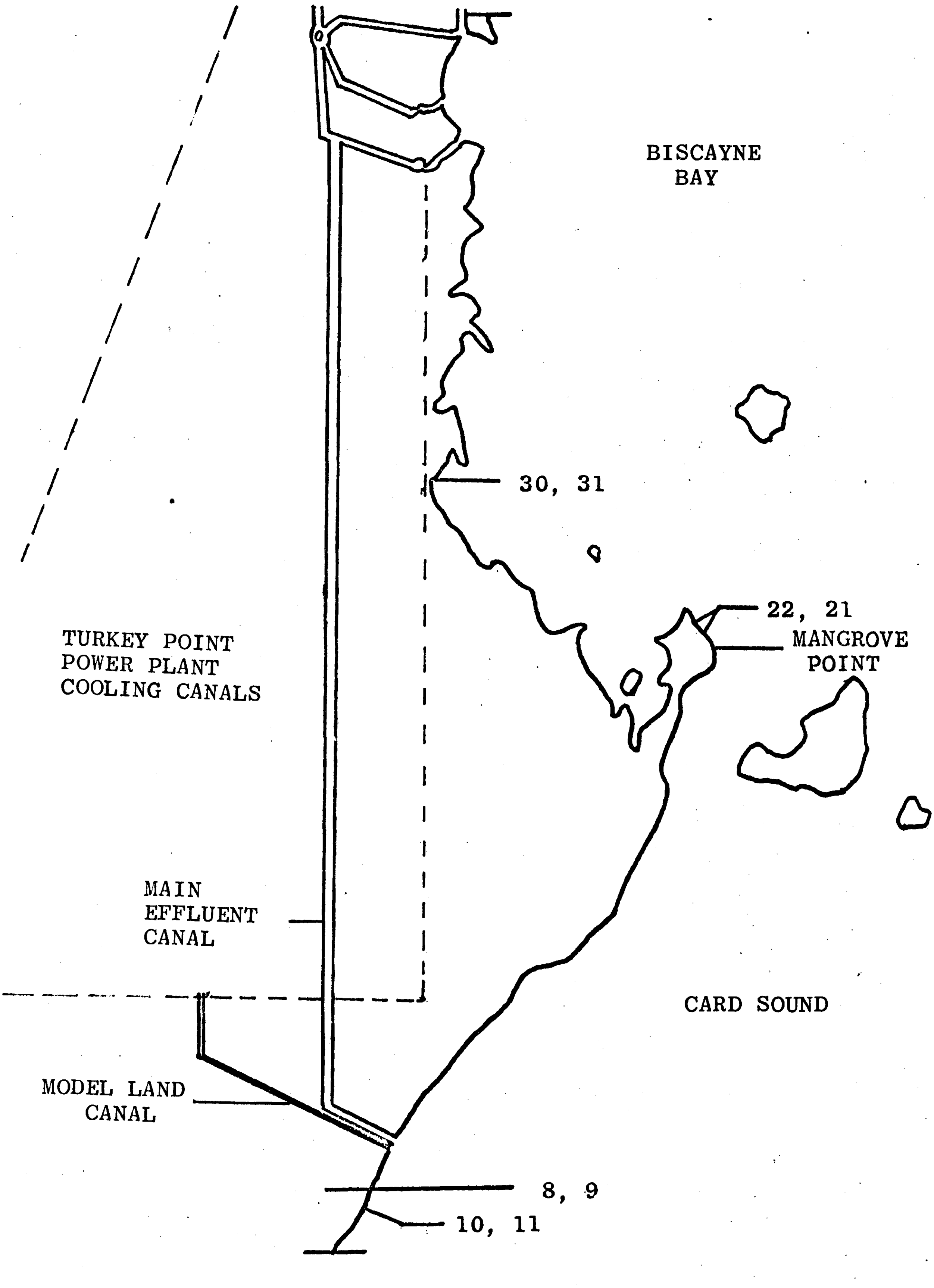

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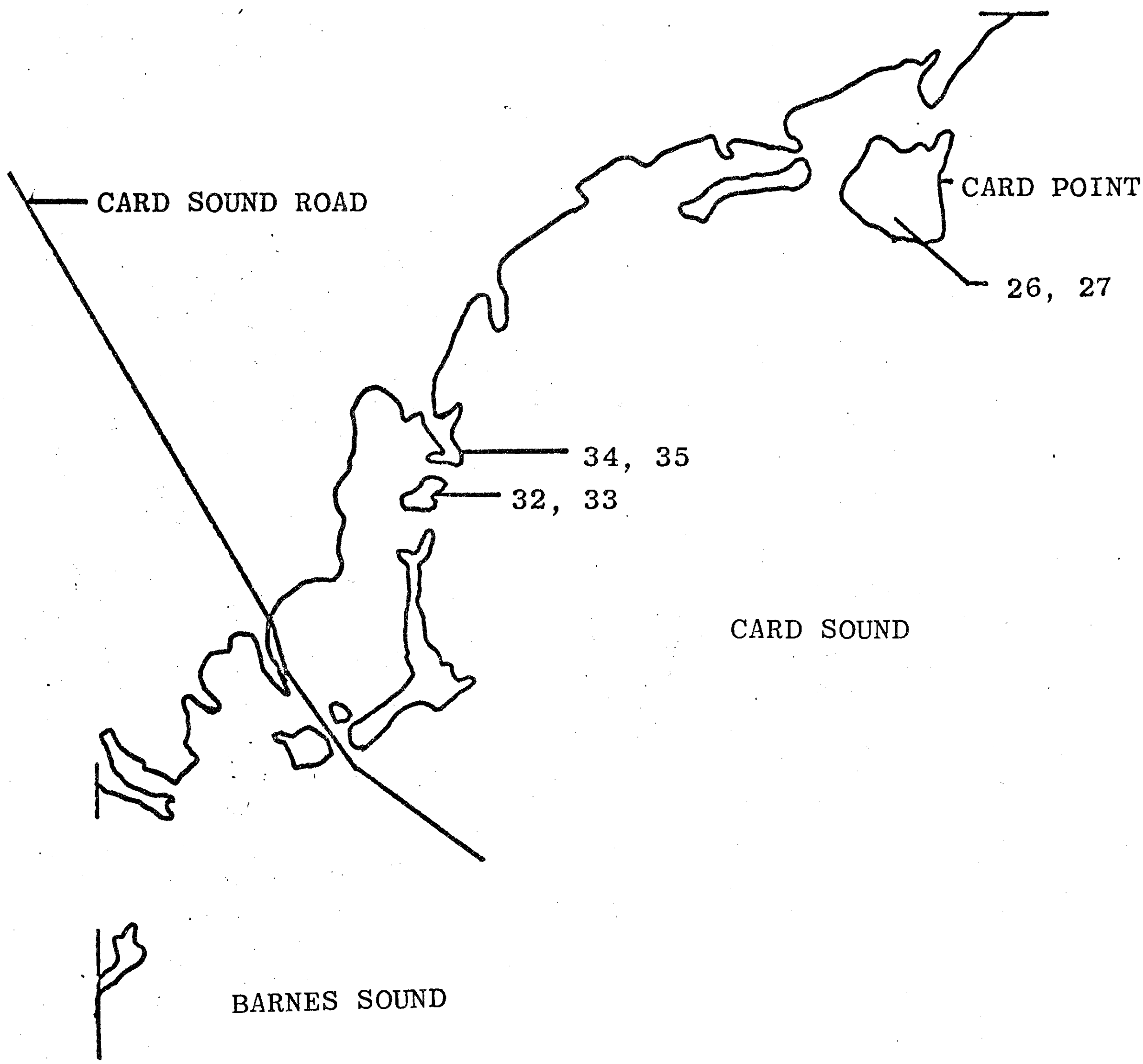

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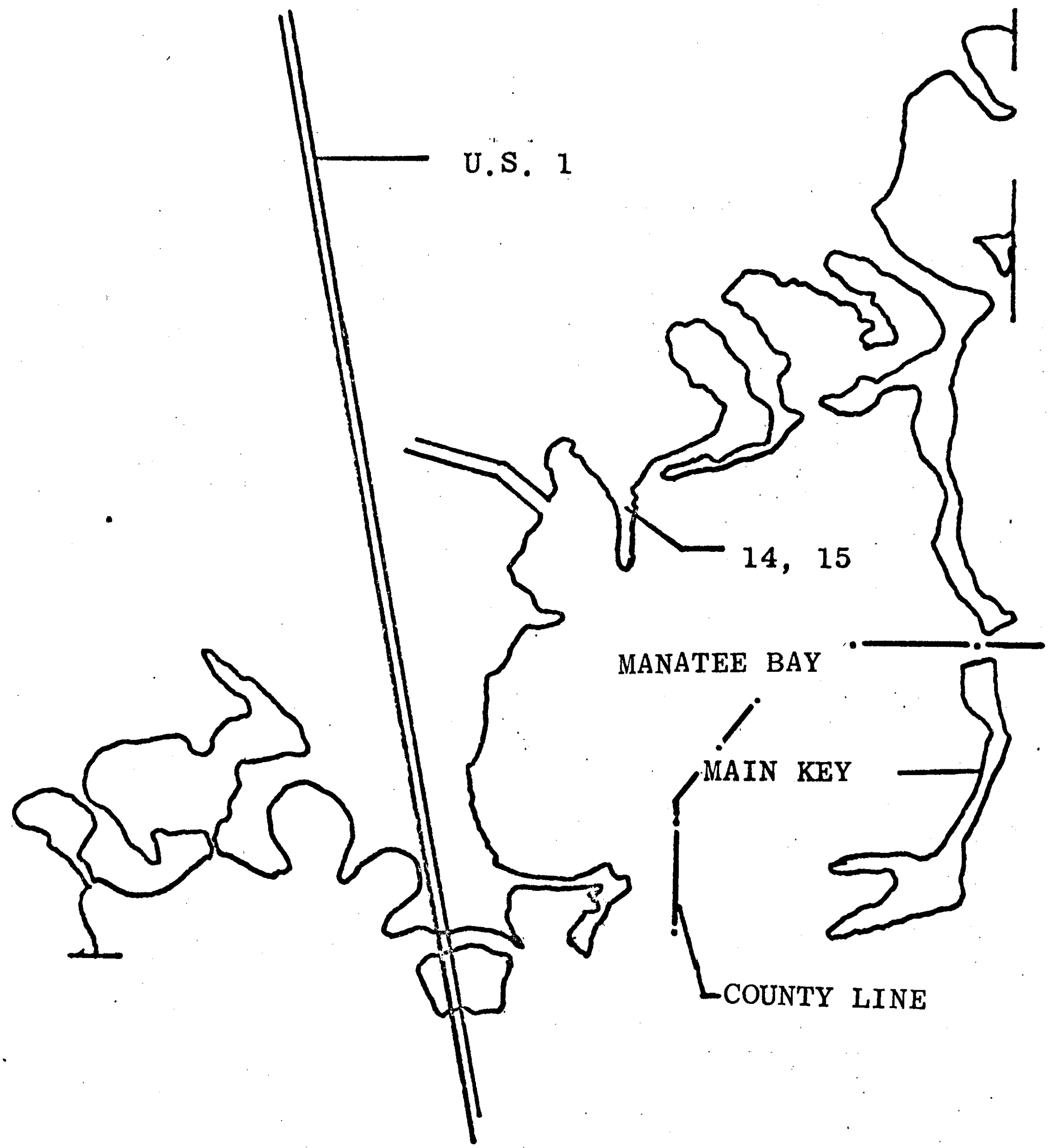


Figure 6 cont.

The amount of material that a tree contributes to the detritus cycle can be estimated from the cumulative collections of litter pans. However, collecting, separating and weighing the material from litter pans periodically during a year is time consuming. Correlation of field data with experimentally determined factors permits rapid estimates of productivity to be carried out. Two methods in addition to litter pan collection were used to obtain estimates of mangrove leaf production:

(1) Leaf harvest. The weight of leaves over a square unit of ground was determined by harvesting and weighing all the leaves in a given area. For this a four legged tower of pipes was erected at a typical location in the forest. Then, by means of a ladder and clippers, the branches bearing the leaves within a prism, consisting of a square yard from the ground to the top of the canopy, were harvested and the total leaf area and weight determined in the laboratory. The annual yield of leaf material will equal this leaf crop if leaves average one year on the tree, as is apparently true for Red mangroves (21). Actual field and laboratory measurements were made utilizing metric units. For this report all data have been converted to the more generally understood English pounds, feet, acres, etc.

(2) Optical method. In this method simultaneous photocell readings were made with calibrated paired silicon solar cells within the forest and

outside in full light on a clear or uniformly cloudy day at a time when there was little wind. Readings were transmitted from the under canopy location to the base station in open light by radio. The equipment used is shown in Figure 7. The optical measurements were correlated with leaf harvest data. This method uses a gross correlation of standing crop of leaves and per cent light transmission. Since the method is empirical, light quality differences and the portion of light absorption that is due to trunks and branches of trees are not evaluated separately.

Litter Pans and Litter Production

Estimating the contribution of a forest to the detritus cycle involves measurement of all the tree-originated material that falls to the ground or water. Estimates of leaves, twigs, bark, flowers, fruits, etc. were obtained from the accumulated material in collecting pans attached to wooden stakes that raised them above the tides. Litter pans in place are shown in Figure 8, litter pan collection and sorting are shown in Figure 9.

Litter collecting pans, which were rectangular plastic dish pans approximately 10" x 12" and 6" deep, had holes drilled in their bottoms to allow rainwater runoff. Groups of five pans were clustered 25 feet apart in an area. In some cases, when they were first put out, the stakes were too short so that the high spring tides inundated the pans, washing away the collected leaves and other litter, in one case stranding a small fish. Such pans were raised by replacing the stakes with longer ones.

Figure 7 Taking a Light Reading with Photocells

Figure 8 Litter Pans in Black Marsh (above) and Coastal Band (below)

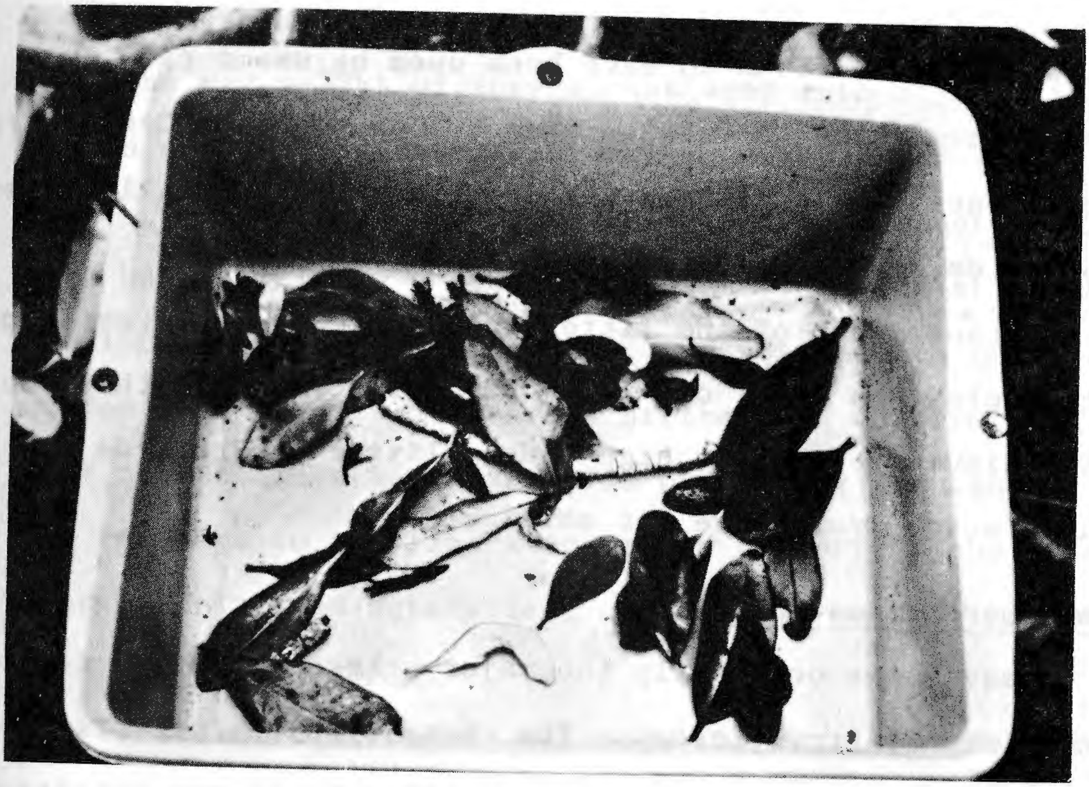


Figure 9 Litter Pan Collecting and Sorting in the Laboratory

A few pans were found to have been used by swamp rats as warehouse-cafeterias for Red mangrove propagules. Samples from litter pans that contained rat droppings and partially eaten propagules were discarded.

Because much of the litter in the scrub mangroves is produced below the level of any litter collection pan that would not be inundated by the high tides, litter pan records for sparse scrub areas were not obtained.

Leaf degradation bags

Leaves are ordinarily the major source of litter from the trees in a mangrove forest. The rate at which red, black and white mangrove leaves enter the detritus cycle was investigated for the different mangrove environments in which leaves may fall. The general principle is that as the leaves are eaten by crabs, insects, snails, etc. and the pieces of leaf become small enough to be washed out of the bag by the tide or rain, said particles are small enough to be considered as detritus (17). The loss of leaf weight from the original sample weight is an indication of the amount of material that has become detritus. A known fresh weight of a single species of leaves was put into a nylon mesh bag, 16" x 20", which was sewn closed and taken to the field. Leaves of Red and White mangroves were obtained as freshly fallen leaves on the ground or as ready to fall yellowed leaves from the trees. Yellowed leaves of Black mangroves were not available in sufficient numbers. In this case mature green leaves were used, which delayed decay and detritus formation about 1 week compared to yellowed just fallen leaves.

The dry weight of leaves that went into degradation bags was determined from a sample that was oven dried in the laboratory. The bag mesh had approximately 3/16" diameter holes. Each bag containing a leaf sample was tied down at ground level by means of nylon fishing line attached to roots or wooden stakes through grommets at the four corners of a bag. Leaf harvest bags were harvested by cutting the lines, and bringing the bags to the laboratory where the dry weight of residual leaf material was determined. A leaf degradation bag sample is shown in Figure 10.

The distribution of leaf bags for detritus production estimates was based on the species composition of the mangrove communities, as follows:

Community	Leaf bags of these species
Coastal Band	Red, Black, White
Dense Scrub	Red
Black Marsh	Black
White, mixed	White

Detritus production in a Coastal Band community involved three types of leaf bags: some contained Red leaves, others contained Black leaves, and others contained White Leaves. In the case of a Black Marsh, only bags containing Black mangrove leaves were used. Leaf degradation bags were not placed in Sparse Scrub.

Soils

Soils were described in terms of the major constituents: silica sand, calcareous sand, marl, peat, etc. A soil auger was used to obtain samples for profile analysis. Depth to

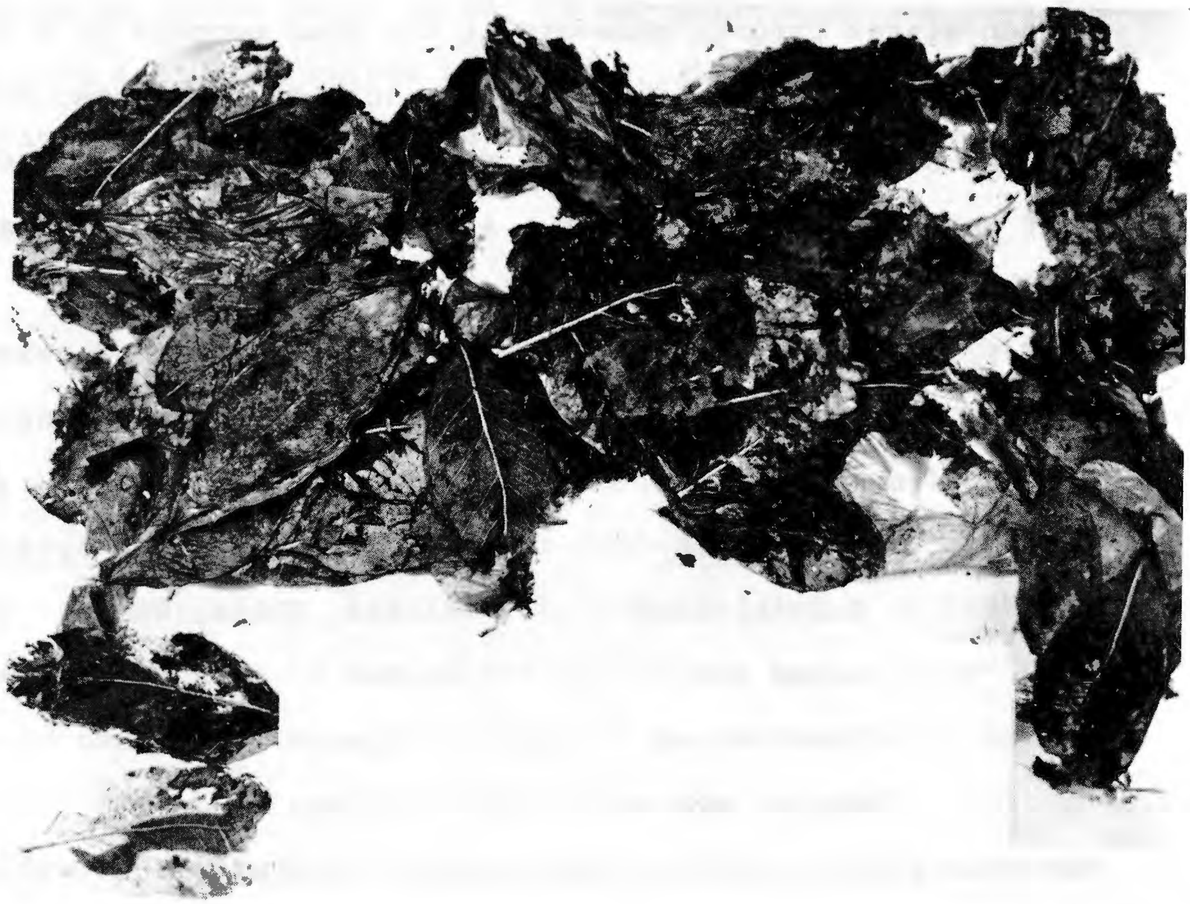


Figure 10 Black Mangrove Leaves at Area 6 After 24 Weeks

rock was measured with a 3/8" steel probe. Soil samples for analysis were taken with a garden trowel at the surface after removing litter; they represent the top 2-4 inches. Moisture was measured by oven drying at 225° Fahrenheit; organic matter was determined by combustion at 930° Fahrenheit; soluble phosphate was measured by a standard method (22) on samples dried at 160° Fahrenheit; pH was measured on an aqueous aliquot of the sample dried at 160° by the procedure of Llewellyn (23).

Elevations

Elevation determinations require sight lines and bench marks, neither of which is frequently found in the mangrove forests or swamps. Use was therefore made of elevations wherever they were available. Some elevations of community types were obtained by correlating field elevations on surveying maps with on site and aerial photographic analysis of mangrove community types. This method was possible in the case of the Cocoplum and Snapper Creek properties where elevations were available from M. B. Garris surveys.

Elevations were known from an east-west transect along the midline of T568 R40E 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 survey of Toussaint & Associates carried out in connection with the Turkey Point power plant cooling water canal system. The locations of the cleared lines from this 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 points within a community that obviously corresponded to the bottoms of small creeks were disregarded.

Estimation of areas of Mangrove Community types

Photography of the mangrove shoreline of Biscayne Bay was obtained through a Dade County contract with Pan American Aerial Surveys. Color transparencies (9" x 9") were provided at a scale of approximately 1 inch = 1000 ft. The aerial photography covered all parts of the mainland portion of Dade County that study of aerial photos and topological maps indicated might contain mangroves, from Coral Gables south to the Monroe County line. In cases where there was a question of significant mangroves in a given section, the conservative approach was followed, so that several of the sections included in the photographs do not have mangroves.

Mangroves were classified into five community types or categories by examination of the Aerochrome color (AC) and false color infrared (FCIR) photography by the use of a magnifier and stereo viewer. The interpretation was related to extensive "ground truth" information. FCIR film has different spectral sensitivities and color range compared to regular AC film, thus is very useful in diagnosis of mangroves.

The extent of the mangrove communities as determined on the color and FCIR aerial photo films was noted on a Dade County black and white aerial photograph (scale 1 inch = 300 ft). Subsequently the areas of the marked community were measured for each land section. Mangroves were classified into the following community types or categories:

Coastal band

Sparse scrub

Dense scrub

Black marsh

White and mixed

Areas of open marl soil or "salina" were excluded since they have no or only very sparse mangrove growth (24). The relatively tall mangroves that grow along tidal creeks were considered to be extensions of the Coastal Band. The "White and mixed" mangrove is the most variable of the five types. Toward the bay it meets the Dense Scrub and on the upland side, often well above MHW, it intermingles with salinity tolerant shrubs, Casuarinas and some hammock species. Relict mangroves upland of salinity dikes or levees were omitted from area estimates because they could have no significant role in Biscayne Bay's detritus cycle.

An indication of the appearances of the AC and FCIR transparencies is shown in Figure 11 as black and white reproductions.

The areas of the communities on each section were outlined with colored wax pencils. These were then drawn on translucent

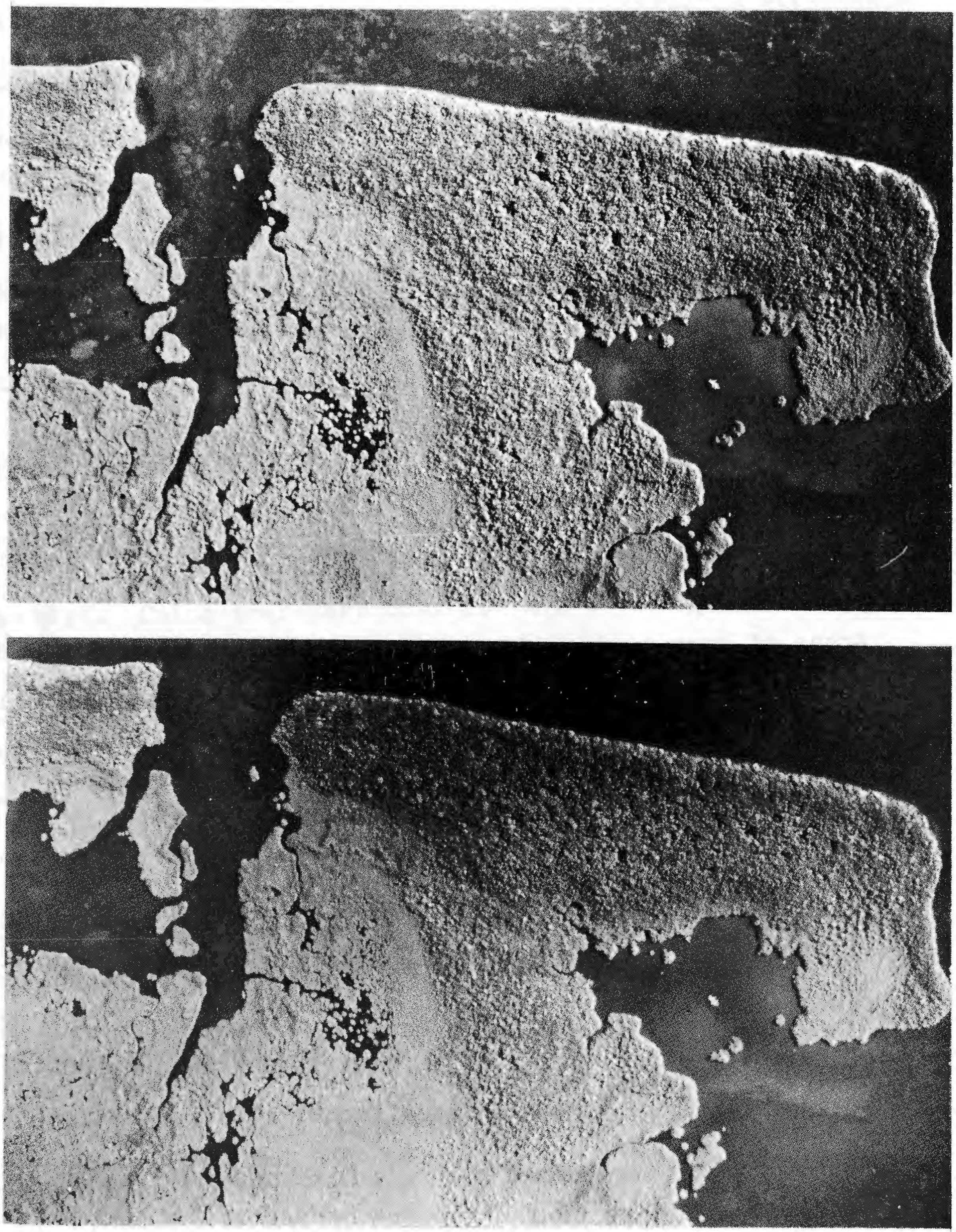


Figure 11 False Color Infra Red (above) and Aerochrome Films of Black Point Area

tracing paper (Albanene, K & E brand) and each community cut out with scissors and weighed separately on an analytical balance. This method was used rather than a planimeter because of the large areas involved. Five to seven reference standard areas were cut and weighed for each sheet of Albanene paper. This paper proved to be relatively uniform in thickness: the coefficient of variation (Standard Deviation of the mean on a percentage basis) averaged 2.5 per cent for samples within the same sheet. The Dade County aerial photograph scale of 1 inch = 300 ft. was used for area calculations. Examples of aerial photography and the area estimation process are shown in Figure 12.

Estimation of the area of Biscayne Bay between the Coral Gables city limits and the county line was made from an official Dade County map, using the Albanene paper.

The original study did not call for work with the mangroves of the islands at the east side of the Bay. However, for comparing the total contributions of the marine grasses and the mangroves of the Bay, it became apparent that the mangrove detritus production on the west (inside) shore of these islands should be included. Inasmuch as AC and FCIR photography was not available, the mangrove areas and communities were marked on black and white Dade County photographs (1 inch = 300 ft.) using current direct knowledge of the mangrove areas in these Keys. For other areas a black and white photomosaic was used; however, with less satisfactory results than where the regular 1 inch = 300 ft. and AC and FCIR photography were available.

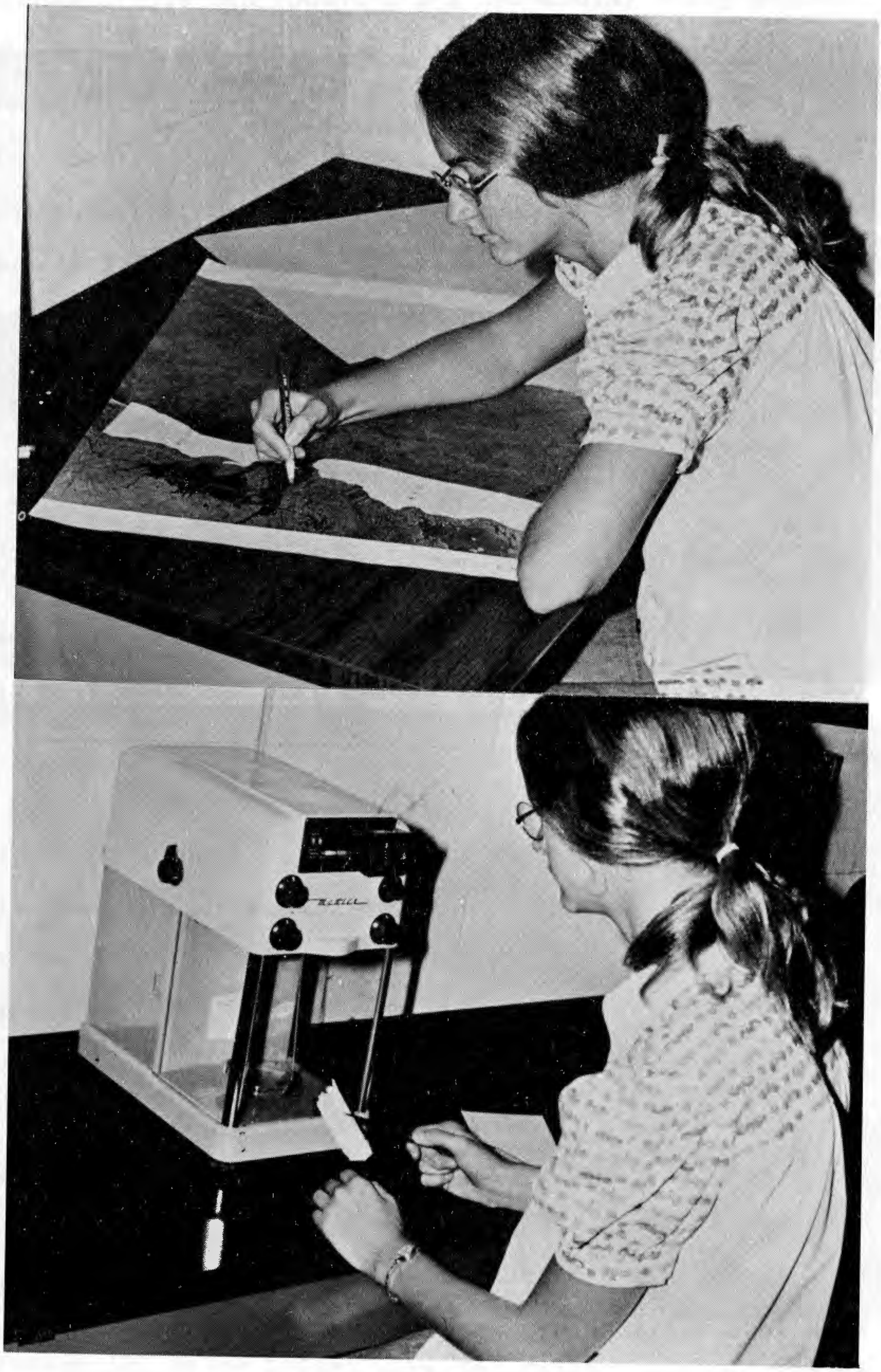


Figure 12 Mangrove Community Marking and Area Estimating

MANGROVE COMMUNITIES

Zonation

Mangroves are usually found between the levels of equinoctial high tides and 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 is 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 and to soil maturity along an accreting shoreline (3). 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 (25). Mangrove zonation does not occur where rainfall is less than 70 inches per year (3).

True zonation would thus not be expected to occur along Biscayne Bay. In zoned Asian mangrove forests, the tidal ranges are typically 8-12 feet, whereas Biscayne Bay mean tidal ranges vary from .43 to 2.02 feet (1). Other factors such as the alteranation of wet and dry seasons in South Florida reduce the likelihood of salinity gradients as important zonation inducers, although, as Davis notes, soil salinity in which the mangroves' roots grow may be much less variable than is the salinity of surface waters (26). Nevertheless, mangrove community differentiation along Biscayne Bay does occur and is probably based on such factors as soil type, elevation, drainage, water currents, salinity tolerance, seed supply and species competition.

Davis has described a succession of Florida mangroves from the seaward pioneer Red mangroves behind which is a mixed Red and Black forest that gives way to White mangroves on higher ground (26). Along Biscayne Bay, such successional zonation is difficult to find; the mangrove areas have been too disturbed by man's activities and by hurricanes.

Community types along Biscayne Bay

The mangroves along the western shore of Biscayne Bay have been examined and classified into five communities for this study. Other classifications of mangrove communities have been made in the Keys and along the east, south and west coasts of peninsular Florida (26, 27).

A number of community parameters such as tree height, type and depth of soil, salinity of water, elevation of soil, and species percentage composition were measured and compared statistically by computer methods. Although some of the measurements correlate well with community type, detailed statistical comparisons are not appropriate because of the selection involved in community sampling sites.

The mangroves that are found along the western side of Biscayne Bay (including Card and Barnes Sounds) can be divided into the following major communities:

Coastal Band

Dense Scrub

Sparse Scrub

White and Mixed
Black Marsh

It is obvious from field observations that these categroies are useful; however, every acre of mangrove along the Bay does not fall sharply into one of them. Transition zones are sometimes found between some communities, for example between Coastal Band and Dense Scrub. Occasional local scrub mangrove areas are found that are predominantly Black scrub, White scrub or a mixture of all three species, rather than the Red mangrove dominated Dense Scrub or Sparse Scrub.

Mangrove communities sometimes undergo changes in character. Examples have been found of established "pure" Black Marsh 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 Red seedlings may in time replace the Black trees in these areas because <u>Avicennia</u> is intolerant of shading, whereas <u>Rhizophora</u> thrives in partial shade (3). Another example of a community in transition is the occasional very dense stand of fast growing "opportunistic" White mangrove seedlings that appear to be crowding out young slower growing Red mangroves.

<u>Coastal Band</u>

The Coastal Band community is the band of mature mangrove closest to the Bay. Along parts of Biscayne Bay the Coastal Band forest shows evidence of having been eroded by past storms or changes in currents. Typically this community is from 100 to 500 feet wide. The Coastal Band grows higher than the other community types, with an average of 35 feet north of Turkey Point and 13 feet along Card and Barnes Sounds (see Table 2). Soil depths are similar in both regions. Typical trunk diameters of the large specimens of Red mangrove are 13-18 inches, Black are 30-36 inches, and White are 10-18 inches. The Black mangroves probably average at least 5 feet 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. (Table 3). A photograph of Coastal Band is shown in Figure 13. Typical Coastal Band mangroves are found at Cocoplum, Snapper Creek and Black Point.

The soil elevation of the main part of the Coastal Band is about 0.8 feet. Along the shore there is often a narrow berm of sand, shells and plant litter that has been thrown up by the waves. The berm averages about 0.5 feet higher in elevation and is richer in organic matter than the more landward portions (see Table 4).

The Coastal Band community corresponds to the "mature Rhizophora consocies" of Davis (26) and is similar to the fringe forest of Snedaker and Lugo (27). The soil in the Coastal Band contains more soluble phosphate, has a lower pH and contains more organic matter than is the case for the other communities along Biscayne Bay. Comparative data are shown in Table 5.

<u>Dense Scrub</u>

Scrub forests along south Biscayne Bay are dwarf-form, predominantly Red mangrove of two very readily distinguished

Table 2 Heights of Trees in the Mangrove Communities

Community type	Height* (ft.)
Coastal Band	
North of Turkey Point	35.
South of Mangrove Point	13.
Scrub	
Dense	5.7
Sparse	3.2
White and mixed	19.
Black Marsh	19.

*Averages of the tallest ten trees in transects.

Table 3 Average Species Composition of Typical Mangrove Communities

Community type	Red (%)	White (%)	Black (%)
Coastal Band	79	14	7
Scrub			
Dense	84	6	10
Sparse	95	5	0
White	6	94	0
Black Marsh	0	2	98

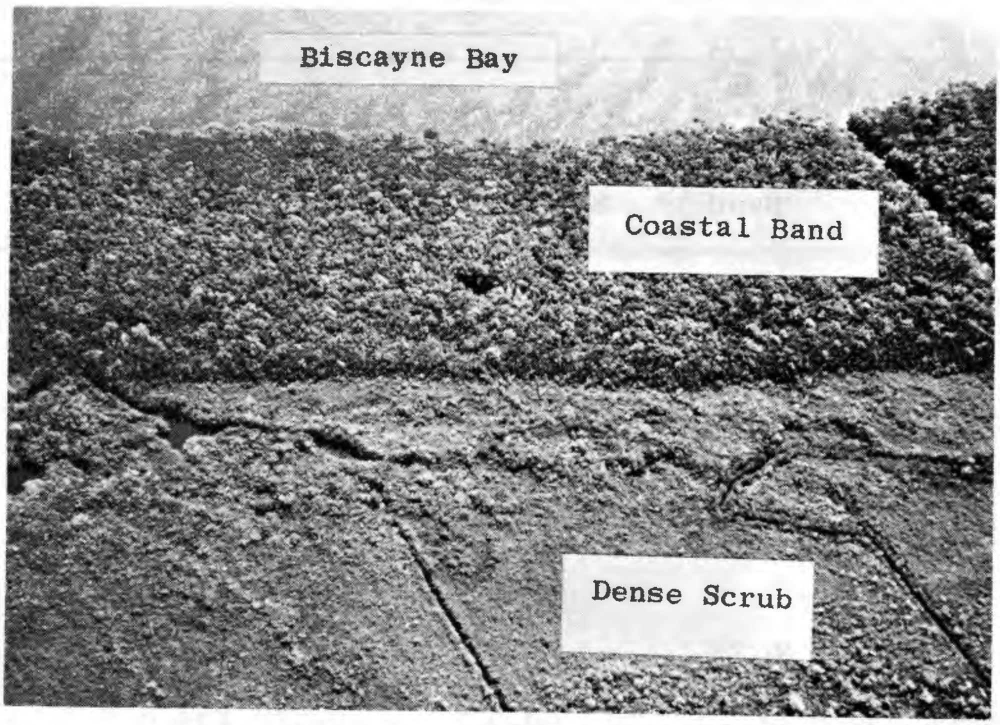


Figure 13 Coastal Band and Dense Scrub at Saga Bay

Table 4 Soil Elevations in Typical Examples of Mangrove Communities*

Area	Mangrove community			
	Coastal Band	Dense Scrub	Sparse Scrub	White & Mixed
Cocoplum property	0.86	0.74	---**	1.75
Snapper Creek property	0.71	0.81	---	1.78
Transect East-West midline of T56S R40E, Section 15	0.78	1.0	---	---
Transect 2 South of Mangrove Point	0.83	0.73	0.18	---

*Elevations in feet above mean sea level.

**Community not present or not extensive enough to analyze.

Table 5 Soil Characteristics of the Mangrove Communities*

Community	pH (H_2O extract)	Soluble PO_4 (parts/million)	Organic matter (percent by weight)
Coastal Band	7.35	10.7	38
Dense Scrub	7.98	4.7	25
Sparse Scrub	8.20	1.3	12
White	7.88	2.0	13
Black Marsh	7.65	12.4	25

*Averages of all determinations

types, Dense Scrub and Sparse Scrub. Davis considered three types of Scrub communities, including a freshwater dwarfed community (26).

Dense Scrub is usually found one hundred yards or more back from the shore. The soil elevation is from 0.74 to 1.0 feet. (Table 4). Trees are closely packed in Dense Scrub, sometimes more than 8 trees per square yard. Several groups of Dense Scrub averaged 5.7 feet high (see Table 2). Often, Dense Scrub grows so thickly that it is almost impossible to walk through.

Typical Dense Scrub is found behind the Coastal Band along most stretches of shoreline; for example, at Gables by the Sea, Saga Bay and Black Point. Figure 13 illustrated the transition between Coastal Band and Dense Scrub.

Sparse Scrub

Sparse Scrub is found principally from Turkey Point south, landward of the taller Dense Scrub mangroves. Sparse Scrub is very clearly different from Dense Scrub. A transition between Dense and Sparse Scrub as well as "degrees" of Sparse Scrub are shown in Figures 14 & 15. Patches of Sparse Scrub are found north of Turkey Point in the almost bare salina areas. Near the shore the trees in Sparse Scrub are found at lower soil elevations than the Dense Scrub (see Table 4); however, Sparse Scrub is also found at higher soil elevations, as noted by Davis (26).

Tree densities found in Sparse Scrub along the transect south of Mangrove Point were 1.7 per square yard (individual

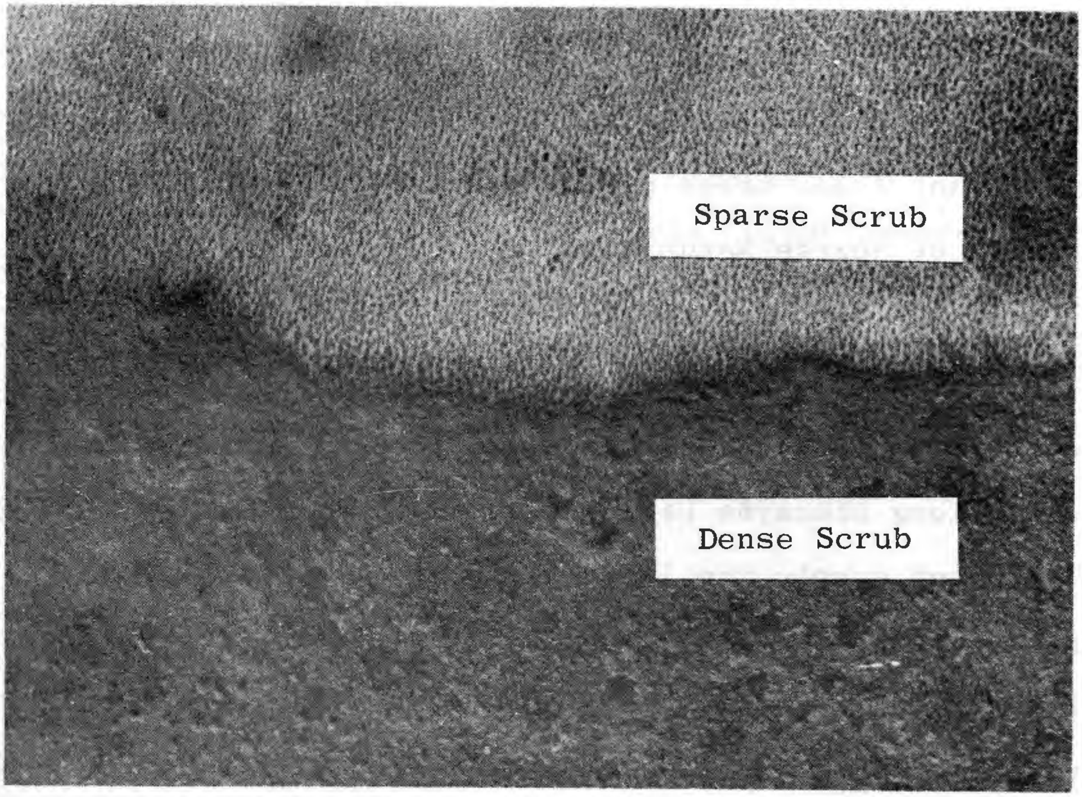
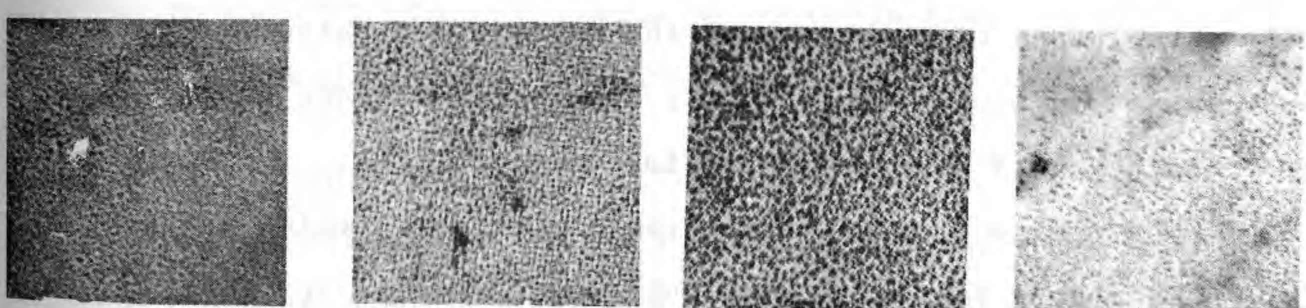


Figure 14 Transition Between Dense and Sparse Scrub Mangrove Communities Along Card Sound



A B C D

A = medium sparse
B = sparse
C = very sparse
D = extremely sparse

Figure 15 Degrees of Sparse Scrub Distinguished trees or small intermingled clumps of trees) and the trees averaged 3.2 feet high (see Table 2). Some Sparse Scrub averages many fewer trees per acre. A series of photographs of a range of Sparse Scrub densities is shown in Figure 15.

Soluble phosphate in the soil of the Sparse Scrub is lower than that in the other communities and the soil of the Sparse Scrub community has the highest pH of the mangrove communities along Biscayne Bay (Table 5). In addition to their poor nutrient supply the lower elevation Sparse Scrub soils are waterlogged, that is, have excess water present. In the Sparse Scrub south of Mangrove Point the soil must be inundated a major part of the time since the soil elevation is below MLW. Waterlogged soils were reported to be the cause of mangrove dwarfing in a New Zealand forest by Macnae (3). As a corollary of soil-induced dwarfing, Macnae cites the taller mangroves along the banks of creeks where the drainage is better. This phenomenon is seen in Dade County Sparse Scrub where causes of the scrub growth form are being investigated (52).

The Sparse Scrub is very likely nutrient limited because of the combined factors of low nutrient levels in the tidal and land runoff waters it receives, the strong phosphate and other ion binding capacity of the alkaline marl soil and in addition the poor nutrient exchange in its waterlogged soils.

<u>Black Marsh</u>

Black Marsh is a community that is often found in shallow basins that concentrate bay waters by evaporation between tides. A salinity of 52 ppt was found at Black Marsh area No. 26 in

May, 1973. Salinities of 80 and greater have been found in Black Marshes. Salicornia, a salt tolerant herb, often grows in the open parts of the Black Marsh. Possibly because of tolerance to higher salinity levels, Black mangroves may form almost pure stands. In some Black Marsh basin areas in the Florida Keys, concentration of seawater sometimes occurs in the dry season to the point where salt crystals form on the surface of the soil. At these sites the Black mangroves are stunted and scrubby.

The average height of trees measured in the Black Marshes was less than that of Black trees in the coastal Red dominated communities (see Table 2). Few examples of Black Marsh were found in Dade County. A typical Black Marsh community occurs at Card Point. No elevations are available in Black Marsh areas. Black Marsh as used here corresponds to the Avicennia Salt-Marsh Associes community of Davis (26). A photograph of a Black Marsh community is shown in Figure 16.

White and Mixed White

The White and Mixed White community is made up principally of White mangroves on marl soil, ordinarily at higher elevation than the other communities, and extends upland to 1.8 - 2 feet and higher elevations. In at least one area, a populatinn of White mangroves is found landward of the salinity barrier dike, growing in fresh water. A White community is shown in Figure 16.

In the White communities areas monitored in this study, the average height was 19 feet. This figure has little meaning in terms of the mature height of White trees in view of the recency of storm seeding of some White community areas. Scrubby

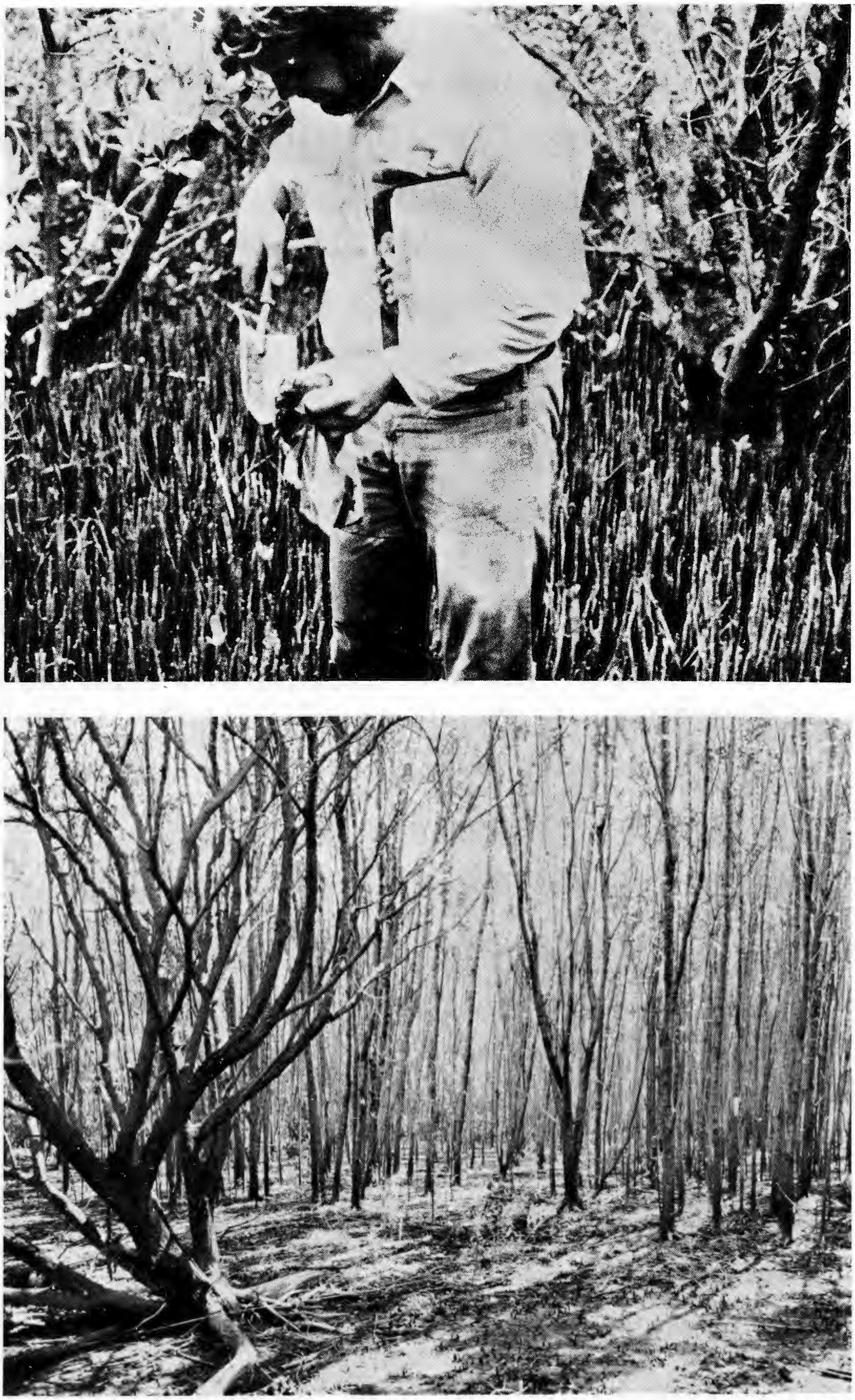


Figure 16 Black Marsh Community (above) and White Mixed Community (below) photo by J. B. Reark

growth of White mangroves is found in saline basins. In some locations White mangroves appear to be less salinity tolerant than Reds and both are less able to grow in hyper-saline conditions than are Black mangroves. Adaptation and local conditions play a role here.

A typical White and Mixed forest is found in upland parts of Cocoplum where portions of it can be seen from the Tahiti Beach Road.

MANGROVE ROLE IN PRODUCTIVITY OF BISCAYNE BAY

Photosynthesis and Productivity

Mangroves as well as other green plants carry out photosynthesis, a process in which carbon dioxide from the air is converted to sugars using light energy from the sun. These sugars can then be oxidized or "burned" as fuel in biological systems. Plants themselves oxidize some of the sugars they produce to obtain the energy needed in carrying out their metabolic processes. The energy from plant photosynthesis is utilized by the animals; indeed, animals including people are sometimes referred to as plant parasites. The extent of our dependence on plants can be appreciated when we consider that, in addition to our food, the fossil fuels (oil and coal) we use are "fossil sunshine", that is, are oxidizable organic matter originally derived from the photosynthesis of plants. Except for nuclear and hydroelectric power, virtually all the materials we use are dependent directly or indirectly on photosynthesis.

The efficiency of plants in producing sugars and cellulose, etc. varies considerably with the species and growing conditions such as climate, fertilization, weed control and irrigation. Crop plants have been selected as being efficient in producing plant material from sunshine and carbon dioxide. Examples of the productivity of crop and other plants are shown in Table 6. It can be seen that efficient, heavily fertilized crops can yield 13-16 tons of dry plant material per acre in a year. This dry weight of plant is what remains after the plants' metabolic consumption of sugars.

Table 6 Production Dry Matter (tons per acre/yr) by Representative Plants from Literature*

Plant	Total
Crops	
Sugarcane (forage variety) (Florida)	15.8
Sugarcane** (Java)	13.7
Corn** (U.S.)	15.9
Sugar beets** (Holland)	13.2
Wheat** (Denmark)	13.2
Miscellaneous	
Giant ragweed (Oklahoma)	6.4
Prairie grass (Nebraska)	2.0
Marine and Marsh plants	
Cattail marsh (Kashmir)	8.8
Spartina marsh (Georgia)	5.2
Water hyacinth (Miss.)	4.9
Turtlegrass (Indian Ocean)	4.9
Turtlegrass (Biscayne Bay)	9.8
Zostera (Marine grass) (No. Carolina)	3.1

Table 6 Continued

Forests	Wood	Litter	Total
Oak Pine (N.Y.)	3.49	1.81	5.3
Pine (Tenn.)	3.96	1.19	5.2
Cypress (Fla.)	2.16	1.66	3.8
Mangroves (Puerto Rico)	1.36	2.12	3.5
Mangroves (Everglades Nat'l Park)	2.83***	3.6	6.4
Mangroves (Coastal Band Dade County)	2.83***	3.91	6.7

---

*Data for this report and references (17) and (27) through (34)
**Annual rate calculated from production during the crop season of 120 or 160 days
*** Calculated from biomass regressions of Golley et al. (32)

In non-fertilized land plants and seagrasses the range is from 2-9.8 tons/acre/year. Clearly, estuarine areas may be highly productive. In forests there can be more photosynthetic product added to the wood of the trunk, roots and branches during a year than falls as litter during that time. Examples of forest litter production per acre vary from 1.19 for pine to 3.91 tons per acre/year for Coastal Band mangroves in Dade County. It is interesting that the most efficient of even the fertilized crops uses less than 5% of the sun's energy (33).

In the oxidation of sugars (or hydrocarbons or elemental carbon or cellulose, etc.) carbon dioxide is the end product; it is the most oxidized form of carbon. The metabolic activities of living organisms tap the energy stored by photosynthesis and produce carbon dioxide.

We use this stored energy from plants in the form of sugar or starch, as flour, or eat it as fresh fruits and vegetables, or burn it as fuel (wood). Some of the stored energy is fed to biological conversion machines (called cows, pigs, chickens, etc.) to give products that many of us consider to be preferable as food to eating plant material directly. The cow is an inefficient machine in making beef for human food: only about one tenth of the plant material a cow eats becomes beef. Although pigs and chickens are more efficient converters of photosynthetic energy to animal protein than cows, the general rule of thumb is that between successive organisms in a food chain there is a 90% loss of energy, that is, each step is approximately 1/10 efficient.

The photosynthetic produce that a mangrove forest contributes to the environment is the leaves, twigs, bark, fruits, etc. together with wood from the occasional wind-damaged or dead tree.

Litter Production by Mangroves

The plant material collected in litter pans for this study was classified by species and separated into leaves, flowers, fruit, propagules, wood, and miscellaneous debris and the amount of dry material in each was obtained by oven drying.

Leaf fall varies with the time of year. It is high along the shore following a strong wind; also, it has been reported that exceptionally dry weather can induce heavier than normal leaf fall in mangroves (27).

The distribution of leaf and other litter components is summarized for the five communities in Table 7. It can be seen that the mature mangroves, predominantly Red, of the Coastal Band, produce the most litter, followed by Dense Scrub, Black Marsh and White and Mixed. The Sparse Scrub community is the most variable in density and therefore in net production of litter. (See Figure 14). The medium Sparse Scrub areas sampled were more productive than the upland, very sparse and extremely sparse examples. In the last case there may be only a few scrubby Red mangrove plants per acre rather than about two per square yard as in the medium Sparse Scrub areas sampled. Because of their small contribution to productivity, extremely sparse

Table 7 Litter Production of Biscayne Bay Mangrove Communities (tons/acre/year)

Community	Leaves Sample	Leaves Average	Other Litter (fruit, flowers, wood, etc.)	Total
Coastal Band	3.46 4.17 2.17 2.68 3.38 2.79 1.85 2.84	2.92	.99	3.91
Dense Scrub	0.81 2.17 1.01	1.33	.67	2.00
Sparse Scrub* medium	.62 .70 .82	.71	.38	1.09
sparse		.42	.23	.65
very sparse		.32	.17	.49
extremely sparse		.14	.08	.22
Black Marsh	1.62 .56	1.09	.15	1.24
White	1.61	1.61	.26	1.87

* Calculated from leaf harvest data

Sparse Scrub areas were not used in estimating total Biscayne Bay productivity.

The production of propagules, the cigar-shaped young plants of the Red mangrove, is extremely variable from tree to tree. Occasional trees, especially ones of the "exposed forest faces" along the roadside or along creeks, are such heavy producers that branches may bend under their loads of propagules. However, these heavy producing trees are not typical. Over large areas of mature Coastal Band forest the numbers of propagules produced are much smaller. Litter pans were placed at typical sites within the respective communities and so sampled few of the very high producing trees. The average distribution of litter from Red mangroves in the Coastal Band was 65% leaves, 19% fruits and propagules, and 16% miscellaneous (twigs, bark, branches, flowers, and stipules). This corresponds to 2.54 tons/acre/year leaves, 0.74 tons/acre/year propagules, and 0.63 tons/acre/year of miscellaneous debris.

The yields of litter for the predominantly Red mangrove Coastal Band, Dense Scrub and Sparse Scrub communities are shown in Figure 17. With this curve it is possible to make rough estimates of litter production from a series of paired light meter readings.

Litter Decay

In this study we checked decay rates of leaves, the major component of mangrove litter. Leaf degradation bags were placed in several locations. The data are shown graphically in Figure 18. Curves were fitted by eye. The data indicate that leaves of all three species decay faster in a wet area than a medium or relatively dry site. Complete reduction to detritus

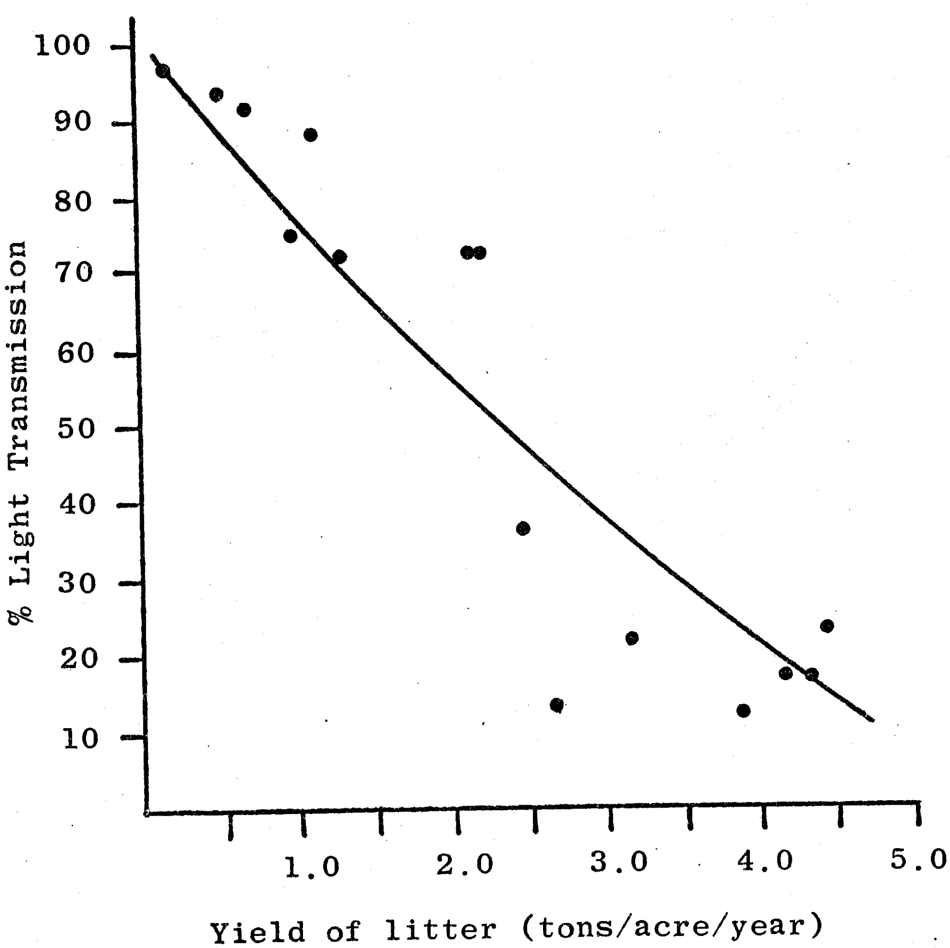


Figure 17 Relationship of Light Transmission of Canopies to Yield of Litter

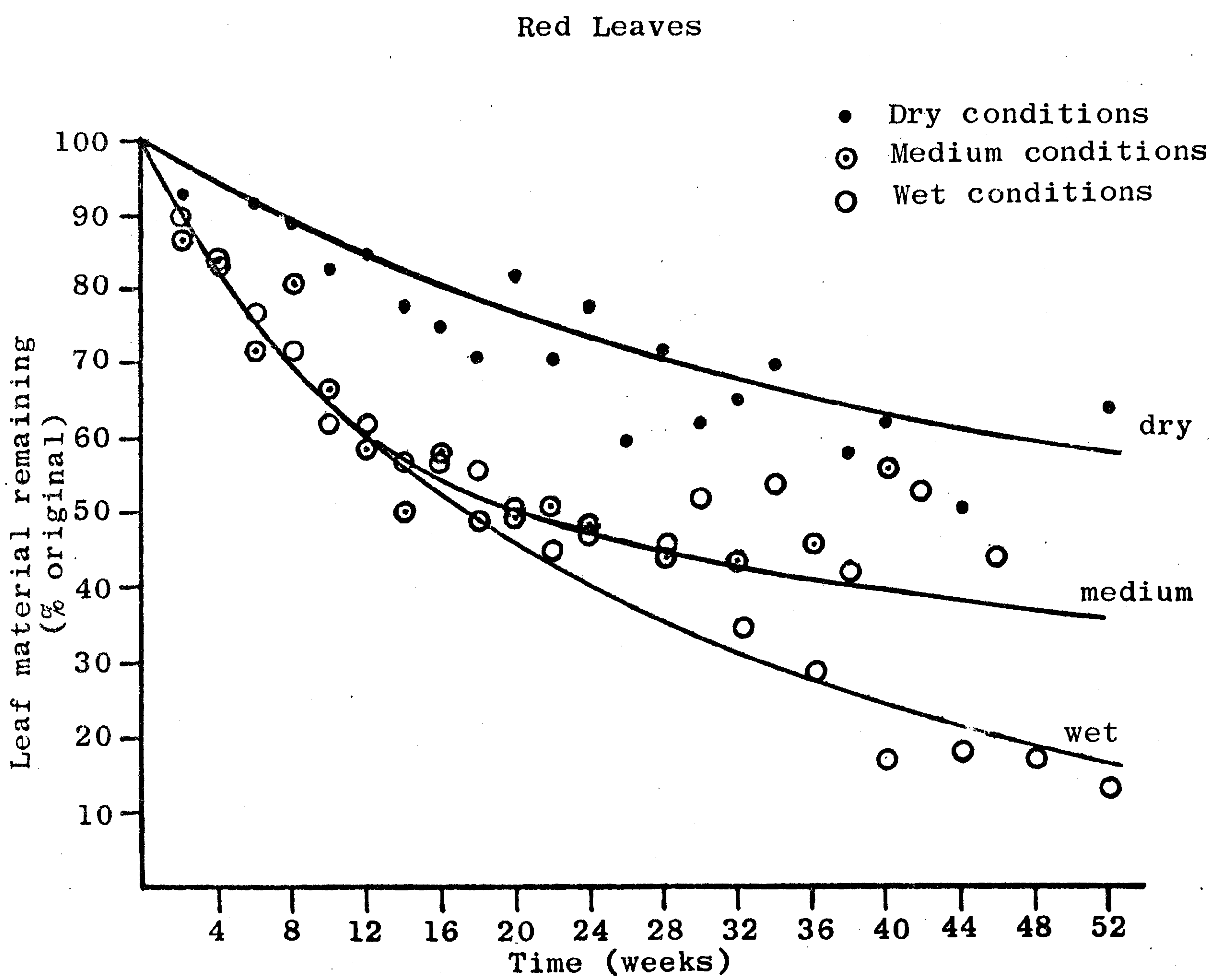


Figure 18 Leaf Decay

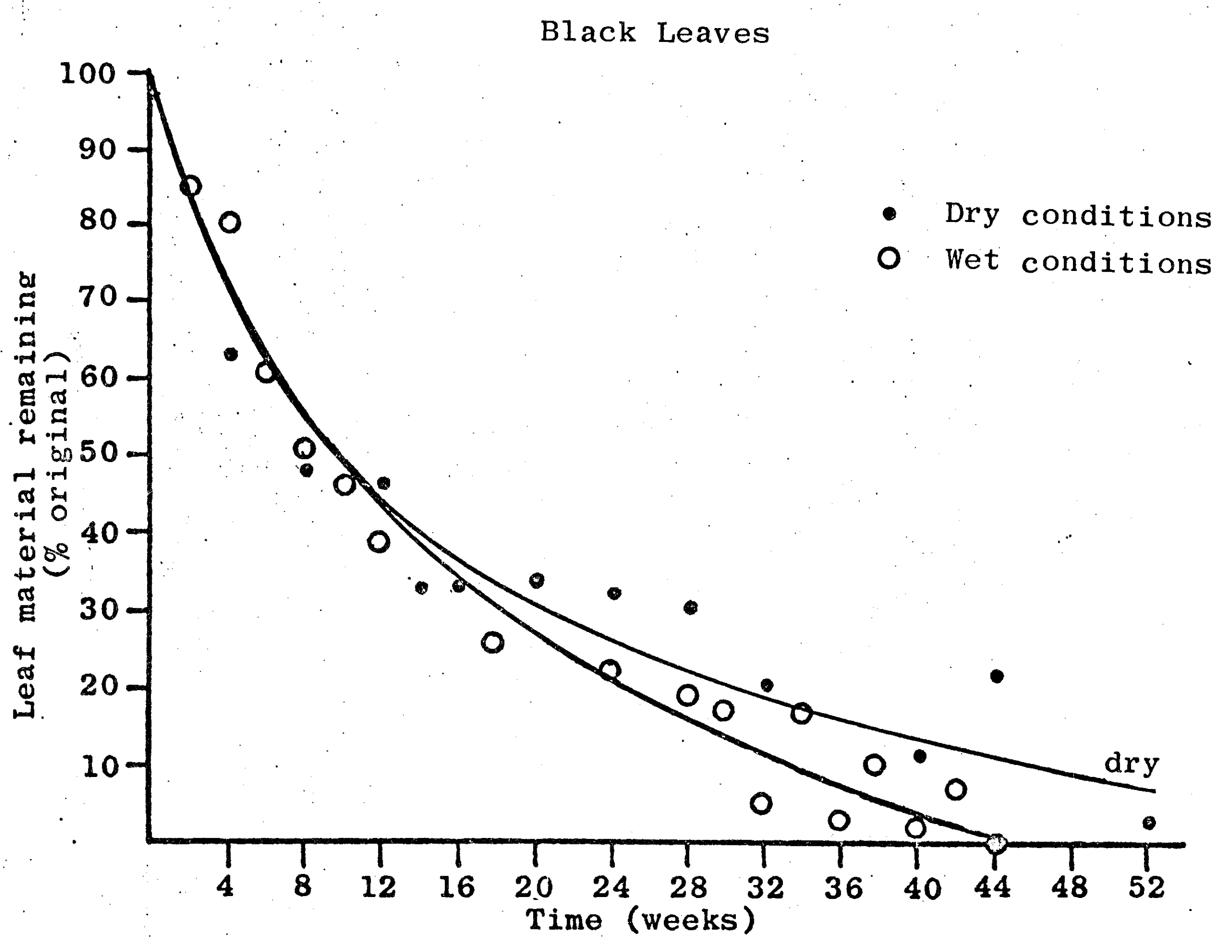


Figure 18 Leaf Decay (cont.)

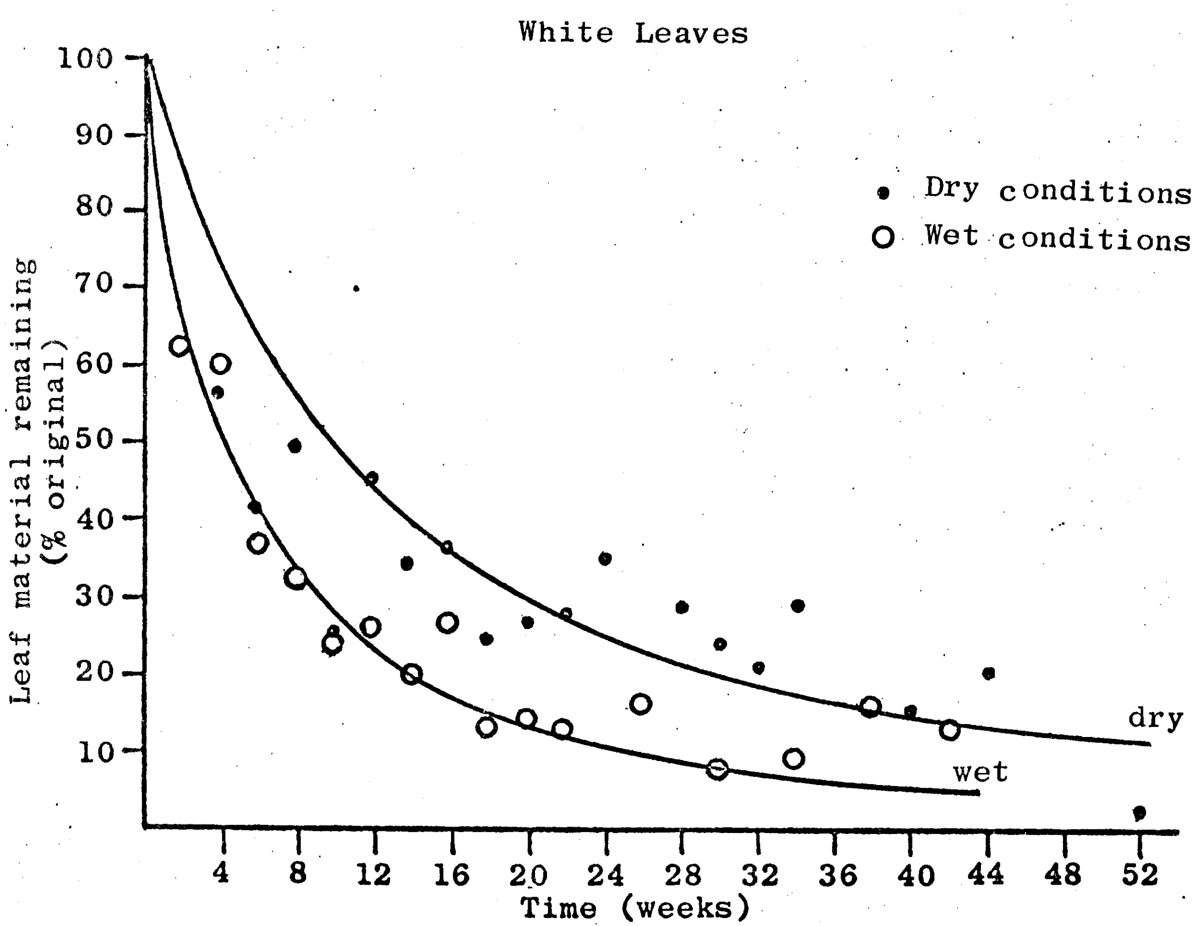


Figure 18 Leaf Decay (cont.)

required more than a year for Red leaves in a wet location. White mangrove leaves required about a year for complete reduction to detritus in a wet location; Black leaves required less than a year. Preliminary experiments with decay of radiocarbon-labeled leaves showed that measuring their production of carbon dioxide could not provide an index of value of a specific location to the Bay's ecosystem .

The observed decay rates of mangrove leaves are more rapid than sawgrass, cordgrass, or spike rush leaves, but slower than turtlegrass. (Figure 19). All of these plant materials have been identified as having important roles in detritus cycles (34, 51).

The components of mangrove forest litter decay, are carried by the tide to other locations, or accumulate in place. Red mangrove peat is for the most part made up of fibrous roots and root bark, with only a small fraction of material that appears to be leaf or branch wood residues. This suggests that the mangrove forests of the past have had most of their above ground litter decay (under the aerobic conditions at the soil surface) or be washed away by the tide within a year. The dead mangrove root material in the anaerobic soil does not decay nearly as rapidly, in fact, as peat, resists decay for geological periods.

Most pieces of wood and bark are dead and have begun to decay before they fall from the tree. Obviously the large branches and tree trunks that fall occasionally take more than a year to decay and become fragmented into detritus-sized particles.

Propagules [illegible] d mangrove survive for several months under water or [illegible] wet litter, but they die rapidly if

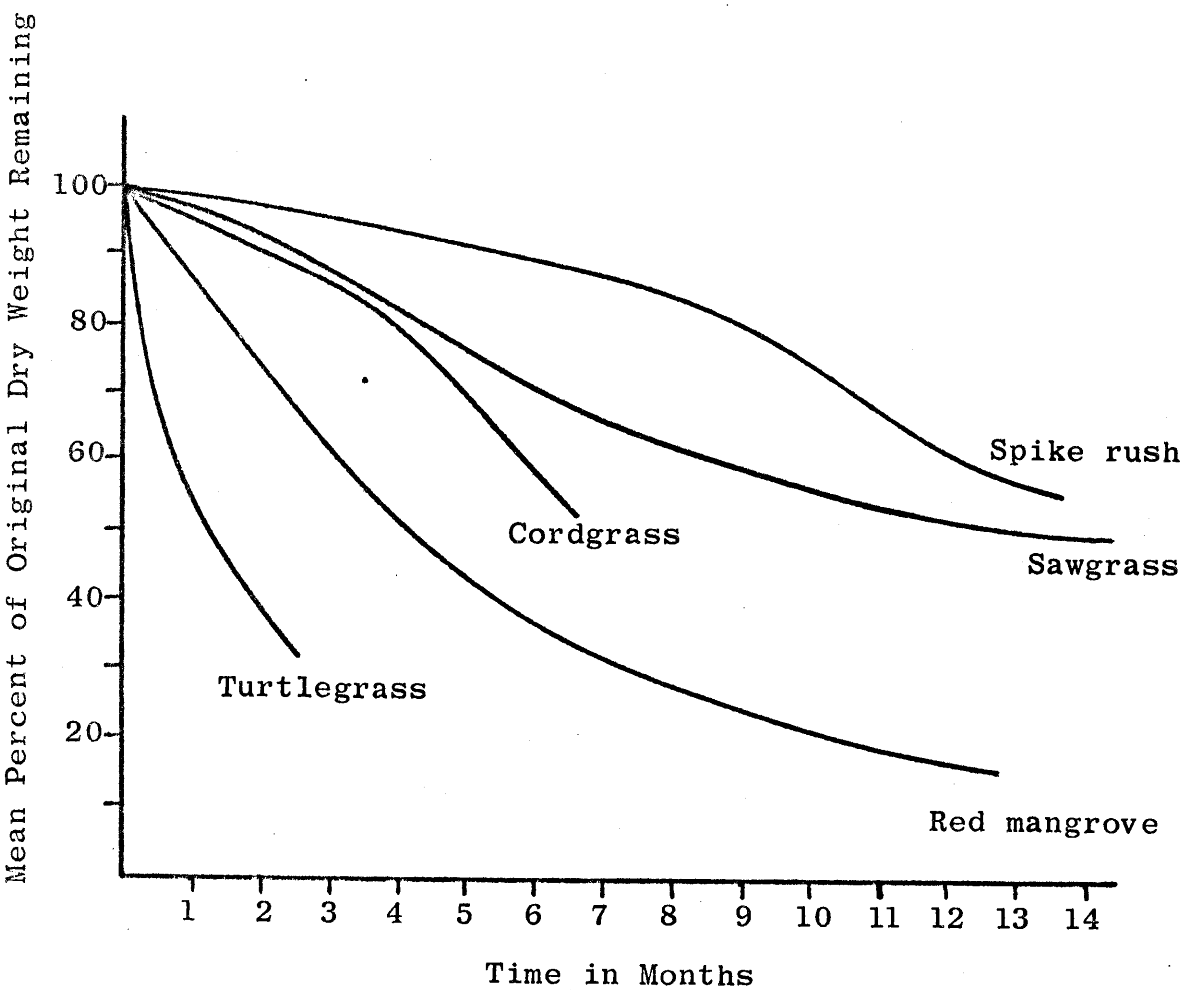


Figure 19 Leaf Decay in Several Plants that are Involved in Detritus Cycles (from this Report and (34) and (51))

exposed to the open sun. Batches of propagules in leaf decay bags suffered little loss in dry weight during the first six to eight months. Experience in the field indicates that at the time the new crop of propagules matures there are still a few survivors of the previous year in the flotsam windrows under the mangrove canopy. On the average propagules probably have decayed by about a year after they fall.

The Detritus Cycle

The general outlines of a mangrove swamp detritus cycle were indicated in the Introduction.

A simplified mangrove detritus food chain, from Odum (18), is shown in Figure 20 . (Arrow directions in this Figure translate to "serve as food for" or "is eaten by".) When mangrove leaves (or flowers or twigs, etc.) fall from the tree, algae grow on them and bacteria and fungi begin to digest them and an array of invertebrates bite them into bits. Protozoa and minute invertebrate animals (metazoa) feed on the algae, bacteria, fungi and protozoa. Larger invertebrates and small fish eat the protozoa and small metazoa. The plant feeders, the "herbivores", and indiscriminate feeders, the "omnivores", are in turn eaten by "primary carnivores", and these become food for "middle carnivores", and form the food of the "high carnivores". Recycling of wastes, which is an important element of the detrital food web, has not been shown. Most aspects of food chains are more complex than indicated. Typical organisms in each group are (18):

Herbivores:	copepods (small invertebrate animals)
	mysids " " "
	amphipods " " "
	sheepshead minnow
	insects, oysters, sailfin molly

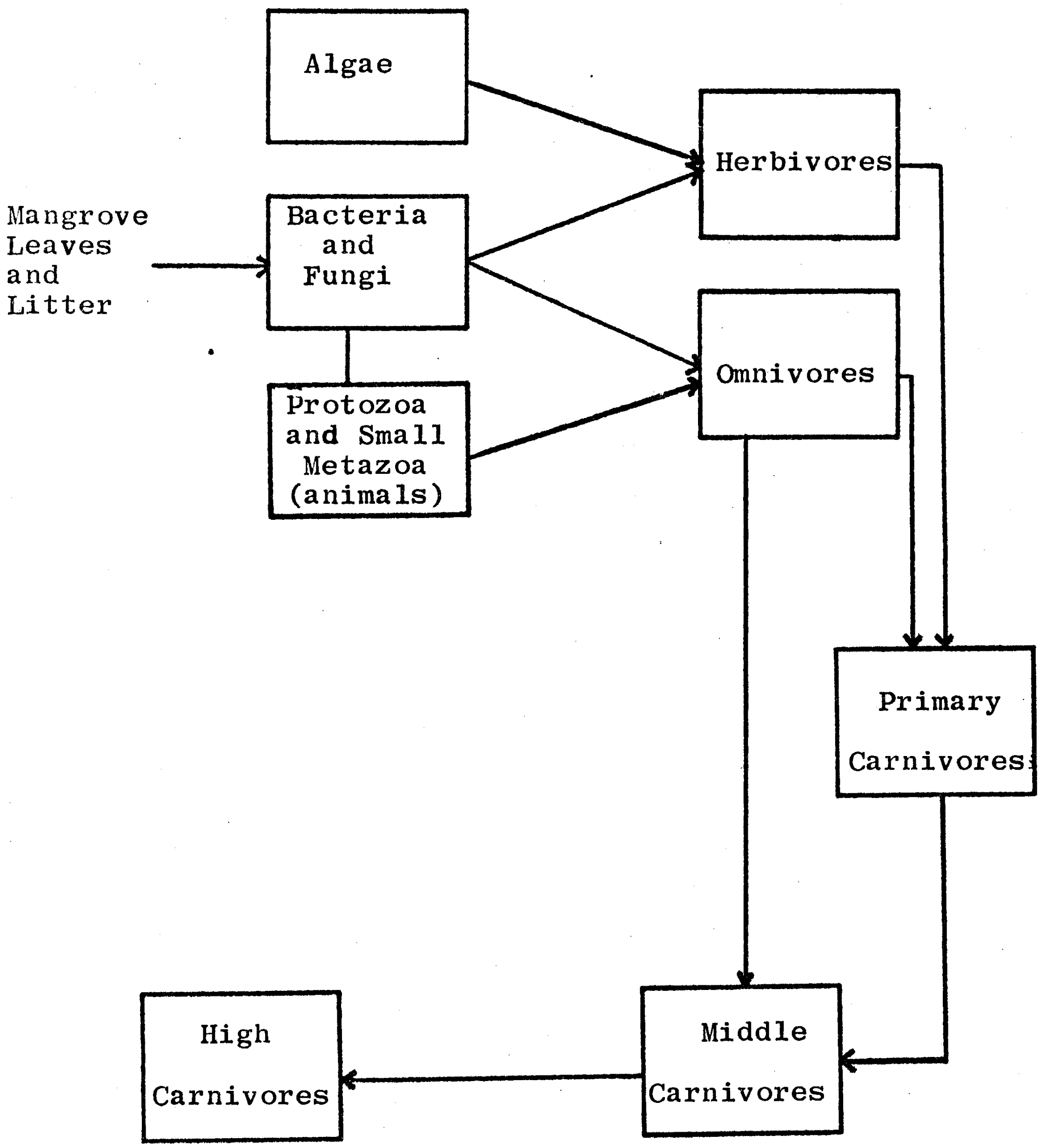


Figure 20 Simplified Mangrove Detritus Food Chain

Omnivores:	gold spotted killifish polychaete worms carideanand other shrimp
Primary carnivores:	mosquito fish pinfish least killifish
Middle carnivores:	blue crab spotted sunfish sea catfish bay anchovy
Higher carnivores:	alligator great blue heron bald eagle tarpon snook sea trout

Examples of the organisms involved in the early parts of the food web can be seen in Figure 21 , taken from Odum (18). There is available an 8 mm educational film loop that illustrates many of the organisms involved in the Florida mangrove detritus food web (35).

As mangrove litter is converted to detritus, there are soluble organic and inorganic materials produced which may be used directly by microorganisms or be absorbed on particles. In addition, the pieces or bits of plant material are eaten by herbivores or serve as substrates for the growth of bacteria, fungi, yeasts and other organisms. Microorganisms secrete a variety of organic compounds and when they die, give rise to even more compounds, some of which undoubtedly are growth factors for other microorganisms or invertebrates. There are a number of examples known where the growth of bacteria or other microorganisms is required before sterilized leaf material or purified cellulose pulp will support the growth of particular invertebrates (18).

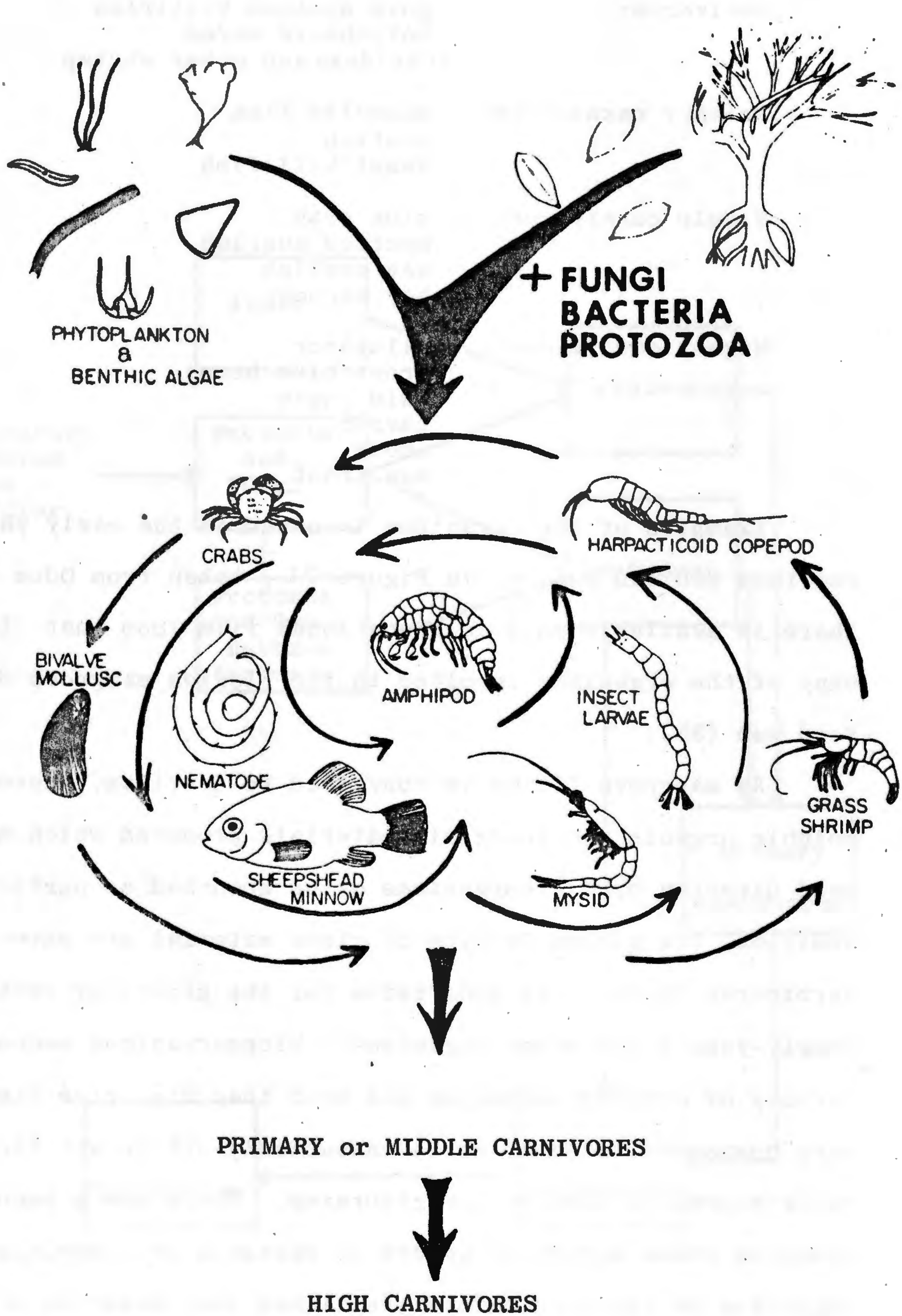


Figure 21 Detritus Consuming Omnivores (from Odum (18))

In addition to the synthesis of substances that serve as growth factors for other organisms, it was noted by Heald (17) and earlier investigators that the per cent protein in leaf material gradually increases during decay and detritus production because of the combination of carbohydrate loss and the incorporation of dissolved nitrogen from the medium into the fungi, yeasts, bacteria, etc. that are attached to the particles. This higher protein content makes decaying litter and detritus more nourishing than undecayed leaf material for an array of organisms that eat it. A part of the dissolved nitrogen that contributes to the protein enrichment of detritus comes from fixation of atmospheric nitrogen within the mangrove swamp. The role of this fraction is being actively investigated (53, 54).

It is interesting to note that artificial additions to the detritus cycle are practiced in Asian fish culture ponds. Macnae states that "Mangrove leaves and other chopped vegetation is scattered over the pond to sink and decay and add to the available nutritive material" in raising milk fish, Chanos chanos (3). This introduction of plant material is analogous to a recent University of Miami report of wheat bran being cultured as detrital material for feeding mariculture shrimp (36).

Although mangrove leaves etc. may require a year to be completely broken into detritus, there is no requirement that plant material be as small as detrital size to be washed out of the mangroves. In mangrove areas that are tidally flushed a part of the crop of fallen leaves and propagules etc. is carried away by the tides without complete conversion to detritus. This washing away of material is most likely for freshly fallen leaves, which ordinarily float for a few days. In areas of restricted tidal exchange, such as the paludal basins where the Black Marsh community is found, only a fraction of the litter is washed away by tides; the export may be detrital sized and soluble materials. Snedaker and Lugo have reported that approximately four times as much litter is found under mangroves in an area of poor tidal flushing as another site that was regularly inundated by the tides (27). Actually, anywhere that Black mangroves produce a large crop of pneumatophores, fallen litter tends to be trapped and therefore to decay in place.

Efficiency of the detritus cycle

The detritus cycle is often viewed as a system that utilizes the complex interrelationships of an estuary to convert photosynthetic products, for example mangrove trees and marsh grasses, into materials that are of potential use to mankind such as sport and gamefish, shrimp and crabs. This is, of course, an anthropomorphic view that ignores the natural patterns and significance of ecosystems.

The photosynthetic energy stored in plant litter may be used in a variety of ways. Two extremes are:

(a) A mangrove leaf may be eaten by an herbivorous mangrove crab and the crab eaten by a snook that is caught by a fisherman. This is obviously a very short food chain.

(b) A mangrove leaf may fall to the ground and bacteria grow on soluble organic substances dissolving from it. In the process these bacteria use energy from the reduced organic products of the plant's photosynthesis to make bacterial cells. The bacteria may be eaten by protozoa that oxidize bacterial cell materials to make protozoa. The protozoa may be eaten by metazoa that make their own cell material and are eaten in turn by a shrimp that is eaten by a minnow that is eaten by a larger fish that is eaten by a snook that is caught by a fisherman.

In these examples plant material becomes gamefish with an efficiency of maybe 1% in one case and less than 1/10,000 of 1% in the other.

The overall export of detrital material from a mangrove forest was estimated as approximately one half by Heald (17). In a study of a salt marsh community Teal has estimated the detritus export as 45%, and found that 47% of the consumption of net photosynthetic product is utilized by bacteria (16). He reported that 7% of the net production was used by primary consumers and 0.6% by secondary consumers.

Mineral Nutrients and Mangroves

In carrying out photosynthesis mangroves use carbon dioxide which is always available; however, like other plants they also require a supply of the inorganic or mineral nutrients Nitrogen, Phosphorus and Potassium as well as lesser amounts of an array of elements like Calcium, Magnesium, Iron, Sulfur, Manganese, Boron, Molybedenum, Copper and Cobalt. Except for minute amounts from dust and the Nitrogen that is brought in by rain, these elements must be obtained from (a) the soil or substrate; (b) debris washed in from the Ocean or Bay;

(c) the litter from the forest itself; (d) the tidal waters; or (e) runoff from the upland. Some background on these nutrient sources is:

(a) Soil or substrate Many of the soils of the mangrove areas along Biscayne Bay typically belong to the high calcium carbonate Perrine Marl series. Layers of mangrove peat are sometimes found as near the shoreline at Gables by the Sea, where it is more than 6 feet thick. Shell and calcareous sand and algal fragments are mixed in the marl and peat. Occasionally silica sand is found along the shore and mixed in the peat.

The more alkaline marl soils with low organic content very clearly tend to have low levels of soluble phosphate, as was noted earlier. A similar correlation is found in Llewellyn's data on mangrove soils of Everglades National Park (37). See Figure 22 for data from Llewellyn and this study. The low soluble phosphate in such high pH soils is predictable from the very limited solubility of Calcium phosphate in the range of pH 7.5-8.5 (38). Other elements such as Iron and Manganese may also be poorly available in the high pH marl soils.

The marl soils upland of the mangroves require high levels of fertilization and addition of minor elements such as Manganese for crop production (23). Even mangrove peat may be a poor supplement to marl soil. Davis reported that the levels of at least four trace elements, Copper, Manganese, Zinc and Boron are so low in peats that these elements must generally be added in order to raise crops on peat soils (39).

(b) Debris washed ashore. Large amounts of dead sea grasses and red, green and brown algae are cast ashore and collect

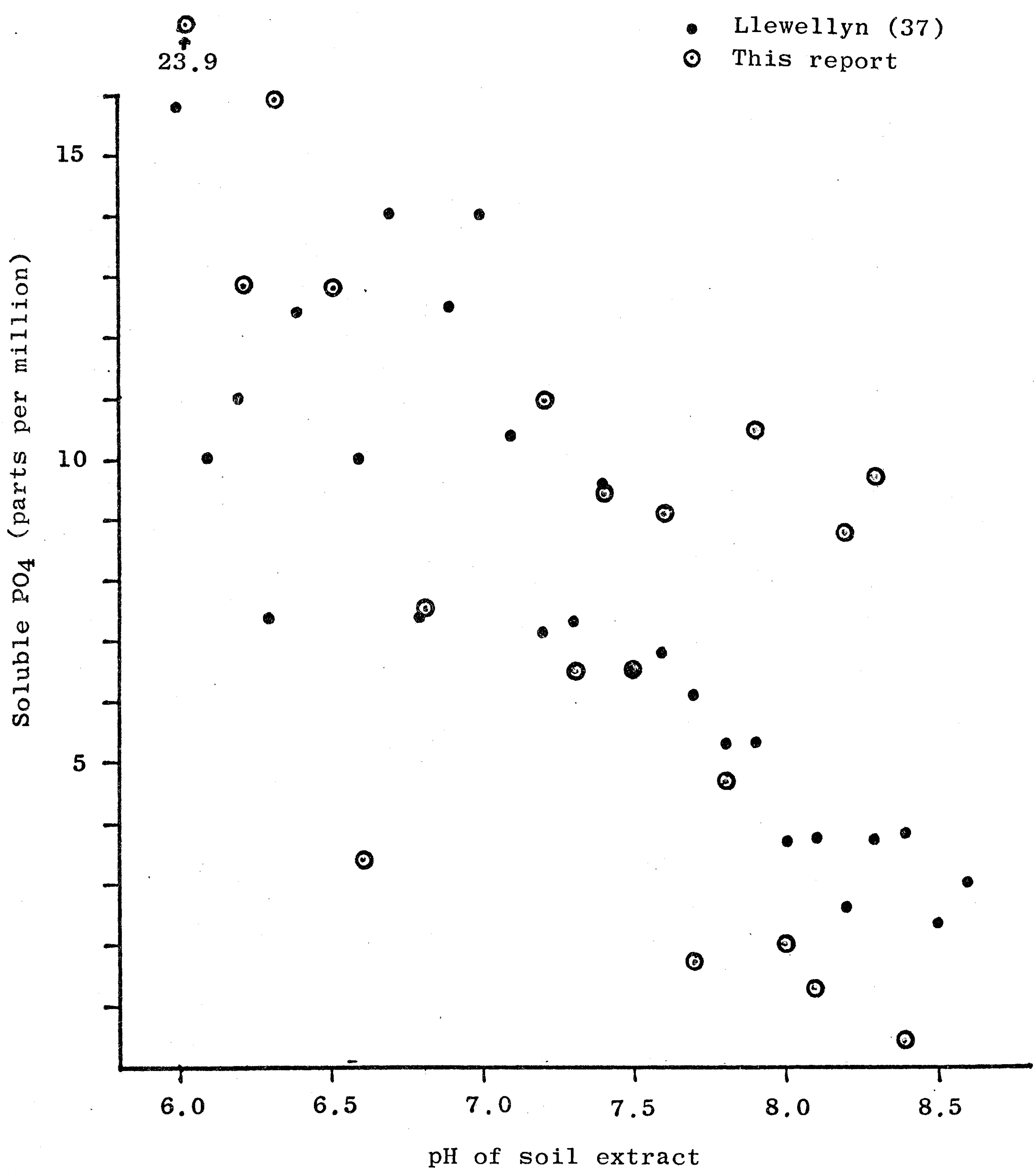


Figure 22 Relationship of Soluble Phosphate and pH of Soil Extract (All Determinations Averaged by 0.1 pH Units)

among the prop roots and pneumatophores of mangroves. The greater part of such flotsam is trapped among the mangroves near the shore. This material may well make an important contribution to the growth and vigor of the Coastal Band community since it is widely recognized as a source of mineral nutrients. In several parts of the world the rack of marine grasses and algae along the shore is gathered and rotted for use as fertilizer.

(c) Litter from the mangroves.Plant materials such as leaves, bark, roots and wood contain the mineral or inorganic elements Phosphorous, Iron, Copper, Nitrogen, Potassium, Magnesium, etc. as well as carbohydrates, cellulose, oils, etc. Inorganic elements are often supplied in fertilizers. Mangroves must ordinarily obtain some of their requirements by recycling the mineral nutrients dissolved from decaying mangrove litter.

In a tropical rain forest it has been shown that mineral elements such as Phosphorous from decaying litter are a very important part of the inorganic nutrient supply. These minerals are quickly and almost quantitatively reabsorbed by the trees through the network of shallow roots (58). When the trees in such areas are removed to clear the land for agriculture, the mineral nutrients are leached from the soil rather than recycled by plants and the productivity of such cropland often falls drastically within a few years (40).The root mass in a mature mangrove forest is very dense,and thus probably well adapted to recycling nutrients.

One of the effects of tides is their role in washing away leaves, propagules and detritus that contain mineral nutrients. Although there is evidence that some inorganic materials rapidly leach from leaves suspended in water (41), there is still a considerable loss of residual mineral nutrients where particulate organic materials are exported.

Tidal amplitude and soil elevation are both important in determining export of leaves and particulate matter. One extreme of litter export is the Sparse Scrub community in the southern part of the county where the soil surface approximates mean low water (MLW) and where, because there is water covering the soil most of the time, almost all of the litter is washed away. The other extreme is the Black Marsh community located in basins where it appears that little particulate matter is exported by the tides.

(d) Tidal waters. Incoming tidal waters carry dissolved mineral nutrients from the Bay. Lower Biscayne Bay is low in Phosphate (1/5 to 1/10) compared to ordinary Gulf of Mexico water (42, 43). Walsh found that sediment from a Hawaiian mangrove swamp removed more than 90% of the nitrate (NO_3) and phosphate (PO_4) from solution (44). Hesse has shown that mangrove soils in West Africa rapidly bind inorganic phosphate (45). It seems likely that shallow Biscayne Bay water which has been circulated long distances over mangrove roots, pneumatophores, mangrove soils and litter will be low in the mineral nutrients that the mangrove and their associated microorganisms take up.

Because mangrove trees and sediment etc. extract inorganic nutrients from tidal waters, removal of nutrients must be much more complete where the flow of tide is minimal, as for example in the southern part of Biscayne Bay along Card and Barnes Sounds. Here the tidal amplitude is less than $\frac{1}{4}$ as great as along the shore of the middle part of the Bay and the land is relatively flat for a great distance from the shore. A line cut through the mangroves south of Mangrove Point shows a soil elevation rise of only 9 inches in one mile. Under these conditions tidal flow can be expected to carry minimal amounts of mineral nutrients to the mangroves at some distance upland from the shore.

(e) Runoff from the upland. It is difficult to assess the nutrient contribution of overland runoff to mangroves. Runoff that passes over marl soil, grasses and other plant material can be expected to suffer serious nutrient losses before reaching the mangrove areas from uplands. Indeed, studies of NO_3 and PO_4 absorption by plants and soils have recently given rise to the practice of retarding eutrophication in residential lakes by the use of grassed swales as nutrient scrubbers.

If there are grasses or marshes upland, very little by way of mineral nutrients may pass on to the mangroves because of nutrient recycling within the upland communities. It has recently been shown that a tidally washed salt marsh grass community retained 91-94% of the Nitrogen and Phosphate of secondary sewage sludge applied to it (46).

Mangroves are not unique in requiring nutrients. Alexander found that sawgrass in south Florida produced twice as many leaves in the first year when fertilized with milorganite (47). In mangrove replanting in the defoliated mangrove areas of the Saigon River delta, experiments of the author indicated that Rhizophora responded to fertilizer (48). This part of south Vietnam is an area where the "clear cutting" (achieved by the U.S. military forces with aerially applied herbicide) probably caused a loss of mineral nutrients.

Runoff from uplands in the form of river water that contains rich alluvium and dissolved nutrients is associated with very well developed mangrove forests in southeast Asia (3).

Locally a nutrient-rich runoff appears to have nourished the mangroves along the Oleta River in Dade County Aerial photographs of the Interama site taken in 1942 show poorly developed scattered mangroves As the urban population increased, the sewage nutrients discharged into the Oleta River increased and the mangroves prospered. Today the canopy cover is so complete that only the major creeks can be traced on an aerial photograph.

If nutrients from the overland flow of water along most of Dade County's mangroves were of great importance, and the mangroves are nutrient limited, the most upland of the broad expanse of dense Scrub red mangroves should grow better than those toward the shore, which is not the case. Therefore, along most of Biscayne Bay, runoff from the uplands does not appear to be an important source of nutrients for the mangroves.

Productivity of Biscayne Bay's Mangroves

The areas and mangrove litter production of the mangrove community types along the west side of Biscayne Bay and along the inside (western side) of the offshore islands from Coral Gables to the Monroe County line at U.S. Highway 1 are shown in Table 8 and summarized in Table 9. It can be seen that the Coastal Band community is the most productive of litter, although

Table 8 Area of Mangrove Communities Along Biscayne Bay*

Town-ship (S)	Range (E)	Sect.	Coastal Band	Dense Scrub	Sparse Scrub*	White Mixed	Black Marsh	Section Total
55	40	24	14.23	0.91	-	-	-	15.14
		25	31.14	16.29	-	-	-	47.43
		26	45.00	1.30	-	-	-	46.30
		35	17.47	-	-	-	-	17.47
55	41	19	91.22	177.31	-	-	-	268.53
		30	9.98	0.48	-	-	-	10.46
56	40	3	-	-	-	39.07	-	39.07
		10	-	-	-	94.83	-	94.83
		11	77.20	-	-	312.73	-	389.93
		14	96.00	193.26	-	-	-	289.26
		15	38.71	96.79	-	263.29	-	398.79
		22	48.39	262.48	-	110.10	-	420.97
		23	77.71	56.44	-	-	-	134.15
		27	99.04	14.65	-	-	-	113.69
		28	68.79	184.42	-	101.50	-	354.71
		33	41.16	291.78	-	121.70	-	454.64
57	40	4	50.52	282.47	-	22.37	-	355.36
		9	60.43	185.68	-	8.25	-	254.46
		16	45.47	229.07	-	11.19	-	285.73
		21	62.24	401.67	-	22.58	-	486.89
		27	9.31	31.06	24.52	-	-	64.89
		28	74.55	150.55	84.73	224.25	-	534.08
		29	8.55	-	-	-	-	8.55
		33	26.95	20.05	151.13	-	-	198.13
		34	6.36	16.77	94.87	-	-	118.00
58	40	3	13.83	32.40	64.29	-	-	110.52
		4	-	38.66	-	62.20	-	100.86
		9	-	35.53	-	-	-	35.53
		10	14.96	24.27	142.42	-	-	181.65
		14	102.77	36.43	30.36	-	-	169.56
		15	418.42	17.15	166.70	-	-	602.27
		16	-	18.98	-	-	-	18.98
		21	5.86	-	-	-	-	5.86
		22	129.57	41.50	387.86	-	-	558.91
		23	20.22	24.04	-	-	-	44.26
		27	17.93	15.03	69.65	6.89	-	109.50
		28	33.01	39.20	312.23	-	-	384.44
		29	21.16	-	410.16	-	-	431.32
		30	7.65	-	31.65	-	-	39.30
		31	30.25	-	332.44	-	-	362.69
		32	25.84	8.35	587.49	-	-	621.68
		33	72.68	96.27	211.06	-	-	380.01

Table 8 continued

Township	Range	Sect.	Coastal Band	Dense Scrub	Sparse Scrub*	White Mixed	Black Marsh	Section Total
58	39	20	39.14	-	-	-	-	39.14
		25	17.58	-	-	-	-	17.58
		26	3.11	-	-	-	-	3.11
		27	13.04	-	-	-	-	13.04
		28	33.59	-	-	-	-	33.59
		29	28.84	-	-	-	-	28.84
		32	22.95	-	-	-	-	22.95
		33	15.40	-	-	-	-	15.40
		34	25.43	-	-	-	-	25.43
		35	69.94	-	88.44	-	-	158.38
		36	35.41	-	241.07	-	-	276.48
59	39	1	140.09	-	502.04	-	-	642.13
		2	121.43	-	379.02	-	-	500.45
		3	23.93	-	439.71	-	-	463.64
		4	29.52	-	19.77	-	-	49.29
		5	9.52	-	-	-	-	9.52
		8	30.46	-	22.85	-	-	53.31
		9	117.53	52.11	284.13	-	-	453.77
		10	151.26	-	191.31	-	-	342.57
		11	126.19	28.83	362.39	-	-	517.41
		12	100.23	4.57	430.85	-	-	535.65
		13	43.44	27.27	144.16	-	-	214.87
		14	187.32	25.42	450.77	-	-	643.50
		15	221.10	157.46	258.79	-	-	637.36
		16	128.32	293.07	202.50	-	-	623.89
		17	2.70	-	23.51	-	-	26.21
		21	92.61	92.11	294.32	-	-	479.04
		22	219.15	7.48	399.90	-	-	626.53
		23	86.61	10.08	103.63	-	-	200.32
		26	70.49	26.31	17.15	-	-	113.95
		27	52.09	31.22	103.29	-	-	186.60
		28	87.70	27.56	180.33	-	-	295.59
		33	85.03	62.82	103.19	-	-	251.04
		34	1.40	-	-	-	-	1.40
		35	61.11	1.61	-	-	-	62.72
59	40	4	38.75	23.97	-	-	32.32	95.04
		5	33.13	19.10	55.56	-	-	107.79
		6	57.95	20.93	152.88	-	-	231.76
		7	26.67	19.10	22.96	-	-	68.73
		18	31.45	7.75	10.20	-	-	49.40
56	42	29	1.72	.55	-	-	-	2.27
		31	13.18	-	-	-	-	13.18
57	41	24	9.79	-	-	-	-	9.79
		25	6.28	-	-	-	-	6.28
		35	53.50	-	-	-	-	53.50

78 Table 8 continued

Township	Range	Sect.	Coastal Band	Dense Scrub	Sparse Scrub*	White Mixed	Black Marsh	Section Total
57	42	19	0.73	-	-	-	-	0.73
58	41	2	38.07	-	-	-	-	38.07
		9	25.27	-	-	-	-	25.27
		10	5.33	4.23	-	-	-	9.56
		11	18.03	-	-	-	-	18.03
		16	39.46	1.67	-	-	-	41.13
		20	10.87	10.42	-	-	-	21.29
		21	33.83	4.16	-	-	-	37.99
		28	42.15	-	-	-	-	42.15
		29	57.63	-	-	-	-	57.63
		32	0.27	-	-	-	-	0.27
		33	3.19	-	-	-	-	3.19

* Acres
** Total of types A, B and C

Table 9 Summary of Litter Production by Mangroves Along Biscayne Bay

	Community				
	Coastal Band	Dense Scrub	Sparse Scrub	White Mixed	Black Marsh
Area (acres)	5,415	4,022	8,586	1,401	32
Litter Production tons/year	21,173	8,044	5,473	2,620	40
% Distribution	56.7	21.5	14.7	7.0	0.1

not greatestin area. A breakdown of the total areas of the five community types by average species composition (Table 3) shows that the mangroves along the Bay are approximately 83% Reds, 13% Whites and 4% Blacks.

Productivity of the Seagrasses of Biscayne Bay

The estimate of Jones that inshore areas of Biscayne Bay had a 25% cover of Turtlegrass (*Thalassia*) was used as the basis for calculations of the Bay's productivity. According to his data, actively photosynthesizing stands of turtlegrass produce a net of 9.8 tons of dry matter/acre/year (28). It is, of course, recognized that the use of this productivity factor is a rough approximation. Turtlegrass is by no means the only source of plant material in the Bay. Parts of Biscayne Bay support red algae (*Laurencia*, etc.), brown algae (*Sargassum* etc.), and green algae (*Ulva*, *Penicillus* etc.) as well as other seagrasses (*Diplanthera*, *Halophila*, *Syringodium*), all of which must contribute detritus to the system. The areas and productivity of the mangroves and turtlegrass are compared in Table 10. It is readily apparent that the total matter produced by the seagrasses (and larger algae) is several times greater than that from the mangroves of Biscayne Bay. This greater productivity of seagrasses (and algae) than the mangroves had been stated to be the case by several earlier investigators (for example Humm (cited by Odum (18)), and by Thorhaug et al. (49)).

Table 10 Contributions to the Detritus Cycle of Biscayne Bay*

Plant type	Area (acres)	(mi²)	Litter average (tons/acres/yr.)	Total Litter Production (thousands tons/yr.)
Mangroves	19,456	30	1.78	37
Seagrasses	105,657	165	2.35**	248

*Seagrasses in Bay between Coral Gables and County Line at U.S. 1, and mangroves along western shore of Biscayne Bay and inside (western) sides of islands

**Net litter for 9.8 tons/acre/yr. with 25% cover of bottom

EVALUATION AND MANAGEMENT OF MANGROVES

Evaluation of Mangrove Communities

All three mangrove species in south Florida produce litter that potentially enters into a detritus cycle. As shown by Odum, in studying mangroves that correspond approximately to the Coastal Band, complexity of the food web is both characteristic of the mangrove detritus cycle and an important feature of its value to the productivity of food and game fish etc. (18).

Mangrove communities show differences in the amount of litter they produce and in the form of on-site cycling. If we accept the amount of animal protein exported to the Bay as an index of the value of a mangrove community, we can see some broad differences in patterns. Dense Scrub produces less litter than Coastal Band, and therefore potentially less protein. Sparse Scrub mangroves have notably lower yield and appear to contribute a high ratio of "unprocessed" vegetative material (compared to animal protein) to the Bay than does the Coastal Band. A Black Marsh contributes less material to the Bay than a Coastal Band community. The upland White mangrove areas have moist, but not often wet, soils and a very poorly developed group of animals for detritus cycling compared to the complex web of the Coastal Band.

The ecosystem of the Bay is probably better served by the animal protein export of the Coastal Band community than by the plant material export of a Sparse Scrub or White Mixed community or than the soluble substance and detritus export of a Black Marsh. Indeed, the Sparse Scrub and White communities may be providing the Bay little more than dumping the equivalent amount of raked up ficus leaves or grass clippings into a waterway to be carried to the Bay with the tide. And, similarly, a Black Marsh may only be producing the equivalent of letting the "leachate" from a compost pile run into the Bay. An in depth evaluation of the contributions of the mangrove communities and their relationships to the marine resources of the Bay would require considerably more information than we have available today.

Management

Mangroves can be managed. In Malaysia the value of a mangrove swamp is viewed by the Forestry Department in terms of its yield of high quality wood for posts, firewood or charcoal. Rhizophora, the genus of Florida's Red mangrove, is a very desirable type in Malaysia, where government rules regulate cutting schedules and recommend ditching or channelizing to selectively encourage its growth (25). Rhizophora grows best in well drained soils and sites (3, 55). It has been noted in Florida along Biscayne Bay and at Marco Island that Red mangrove trees grow taller and closer together along tidal creeks than in nearby areas.

Scrub mangroves appear to suffer from poor soil drainage and/or nutrient limitation. It may be that channelization and fertilization could stimulate the growth and productivity of scrub mangroves. Whatever the cause of their stubby growth, it is likely that experiments on Dade County's mangroves would lead to management techniques for increasing the yield of plant material and improve the detritus cycle environment.

One form of management is the planting of mangroves where none are growing. Bowman reported in 1917 (56) that Red mangroves had been planted among the ballast stones used along the Florida Overseas Railway to help stabilize the causeway portions. Macnae described how in Asia mangroves are planted close together seaward of the shoreline to help trap silt and thus claim land from the sea for agriculture (3).

The author and coworkers have planted mangroves in South Vietnam (48), Everglades National Park, St. Lucie County, Charlotte County, at the Julia Tuttle Causeway, and other places along Biscayne Bay. The Dade County Department of Parks and Recreation has transplanted mangroves at the Key Biscayne Golf Course and Chapman Field Park and has worked with us in other plantings. The Miami Beach Parks Department has cooperated with us in mangrove planting within their city. A spoil island at Robertson Bay in Collier County has been planted with mangroves by researchers at the Marco Applied Marine Ecology Station. It is apparent that, with proper materials and appropriate sites, plantings can be successful. A number of factors such as elevation with respect to the tide, energy of the waves, and soil type are involved.

An attractive site for creation of a mangrove island is Pelican Island south of the Julia Tuttle Causeway in north Biscayne Bay. Because of the Aquatic Preserve status of Biscayne

Bay it does not seem likely that this area can be filled and developed as real estate, so that a carefully planned conversion into a mangrove swamp would help to compensate for past losses of mangroves in the Bay.

Health of Dade County's Mangroves

Dade County's mangroves have other enemies than real estate developers. Red mangroves along the Bay suffer from depradation by the marine isopod *Sphaeroma* and from tumors, and mangroves of all species suffer from lightning damage and storm erosion.

Sphaeroma is a small pillbug sized invertebrate that bores into the prop roots of Red mangroves at about the mean high tide line and kills their ends (57, 63). See Figure 23 for *Sphaeroma* and root damage. *Sphaeroma* occurs along the mainland of Florida on both coasts and is widespread since it occurs in Trinidad (58) and on both the Atlantic and Pacific coasts of Panama (59). *Sphaeroma* is common on the mainland shore of Biscayne Bay and much less so on the islands to the east. In some areas where the infestation is especially heavy, as along the Oleta River and Intracoastal Waterway at Interama, boring by *Sphaeroma* is responsible for many weakened Red mangroves falling over from boat wakes (60). *Sphaeroma* is most common where the mangrove oyster is found, which is in areas where the water is of lower salinity, and it is not found in the Florida Keys, where there is very little freshwater runoff. It is probable that *Sphaeroma* requires lowered salinity for its growth or reproduction. *Sphaeroma* has been boring holes in Red mangrove roots for many

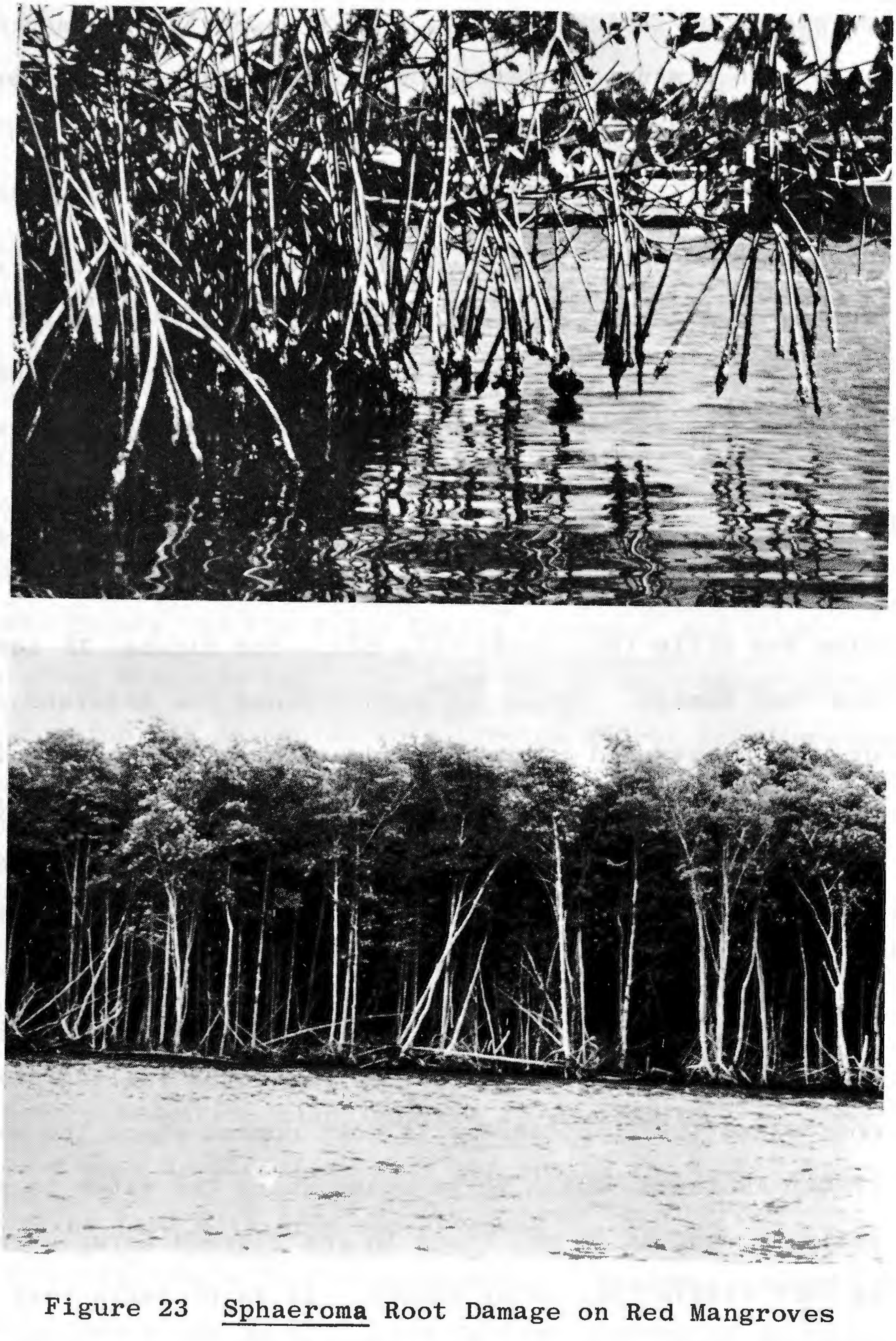


Figure 23 Sphaeroma Root Damage on Red Mangroves

years (26); however, as suggested by Rehm and Humm (57), it may be that mangrove damage is increasing in recent years.

The tumors of Red mangroves are very obvious as large cancerous growths on the trunks and branches of many of the trees along Biscayne Bay (see Figure 24). Often a tumor appears to have originated from wind damage. In some areas of heavy tumor incidence, each of the small holes in Red mangrove trunks made by sapsucking birds becomes the site of a tumor. It is clear from examining dead Red mangroves that many trees are weakened and killed each year by the growth of these tumors.

The pattern of tumors suggests that they originate from a combination of a pathogenic microorganism and physical injury. Although plant tumors are known to be caused by viruses or bacteria (72), the tumor of Red mangroves is caused by a fungus, Cylindrocarbon didymon (61). No tumors of Rhizophora have been seen by this investigator other than in Florida (i.e. not in South Vietnam, Central America, the South Pacific or the Caribbean), nor have tumors been mentioned in review articles on mangroves (3, 62).

Mangroves of Biscayne Bay are often struck by lightning, although it is difficult to evaluate the frequency compared to other non-mangrove areas. Seymour Goldweber of the Dade County Agricultural staff reports that lightning damage is common in tree crops of the county (73). A lightning strike hole in a Coastal Band mangrove community is shown in Figure 25. Other lightning strikes can be seen in Figure 13. Analysis of aerial photographs indicates that there are more than 160 "unhealed" strikes along the western shore of Biscayne Bay. The

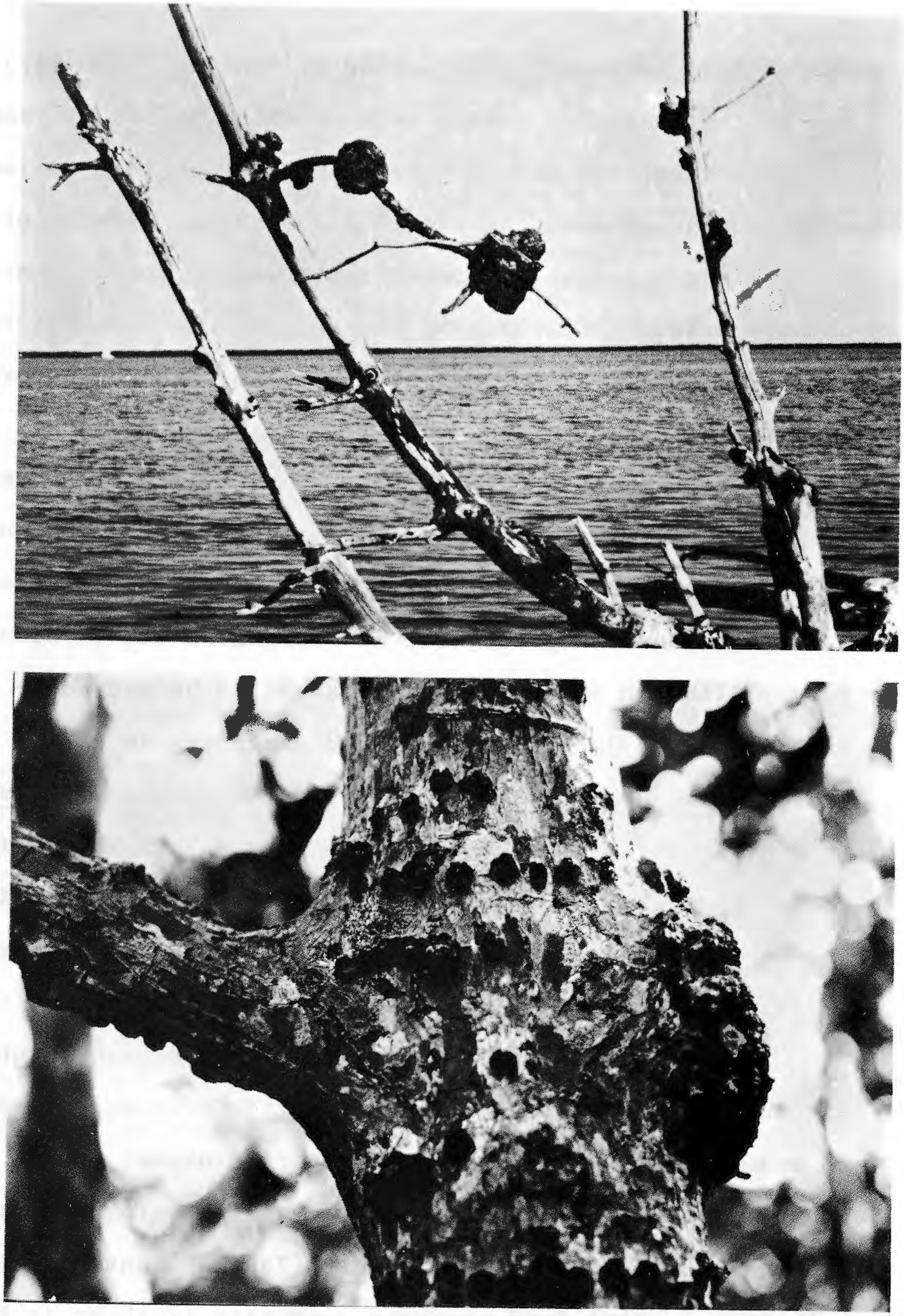


Figure 24 Tumors on Red Mangrove (above) and
Tumors Developing at Points of Sapsucker Holes (below)

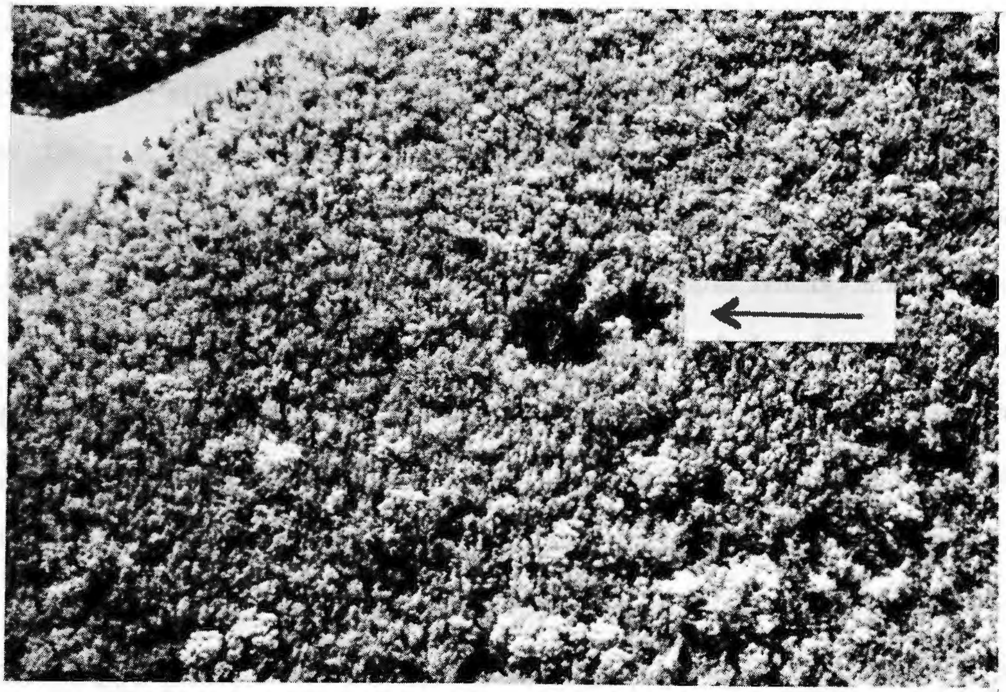


Figure 25 Lightning Damage in Coastal Band Mangroves

high incidence is not surprising since peninsular Florida is known to be an area with very high incidence of electrical storms. It is possible that the grounding of mangrove trees in saline water is involved. A strike area is typically 15-50 feet in diameter, and involves the killing of several trees. For a week the leaves of trees around the strike area are brown. Seedling trees quickly begin to fill the hole in the canopy left by the dead trees. It may be that Black mangroves in the Coastal Band are struck by lightning more often because of their greater height and higher salt content than nearby Red and White mangroves.

It has been stated that mangroves serve as a barrier to protect the land from hurricane tides. In the process of providing this protection, the mangroves of the Coastal Band suffer. As noted earlier, the mainland shoreline of Biscayne Bay shows signs of recent erosion, in places probably more than 200 feet since the 1920's. It has been suggested that a riprap of large boulders and fill be placed seaward of the Cocoplum property to protect its mangroves from further storm erosion (12, 13).

DISCUSSION AND CONCLUSIONS

The mangrove communities were classified on stereo color photography. With simplification to five community types there were, understandably, areas that were difficult to classify; however, the great majority of the mangrove acreage could be categorized readily. A set of 1 inch = 300 ft. aerial photo prints with community limits marked is being supplied to Dade County separately from this report for reference in land use planning etc.

The mature Coastal Band mangroves along Biscayne Bay produce more than half of the total litter material, although this community covers only 28% of the mangrove acreage. Inland from the Coastal Band is most often the Dense Scrub, which is responsible for about 22% of the mangrove litter production. Upland of the Dense Scrub in the southern part of the County is usually the Sparse Scrub, which is much less productive than the other communities, accounting for only about 15% of the total litter. The White and Mixed community is typically upland of the Dense Scrub and is more common north of Turkey Point; it accounts for 7% of the mangrove litter. The Black Marsh occupies an insignificant acreage in the total.

The relative value of mangrove areas can be assessed in terms of their production of litter. On this basis, the mature Coastal Band community is approximately 17 times as productive as is an equivalent area of extremely sparse Sparse Scrub. It is thus much more important to preserve the Coastal Band than Sparse Scrub.

The litter production values from this report can be used to estimate the litter production potential of the mangroves on a piece of property or compare two pieces of property. Appendix A is an aerial photograph (scale 1 inch = 300 ft.) and tracing of the mangrove communities just north of Black Point, in Section 14 or T 56 S, R 40 E. Only Coastal Band and Dense Scrub communities are found here. The acreages of the two community types are shown in Table 11 (data are from Table 8, page 76). Of the total area with mangroves in the section, 96 acres is Coastal Band and 193 acres is Dense Scrub. The total production of litter by the mangroves in this section is estimated to be 761 tons/yr. The estimation of mangrove litter production for an area of greater community diversity is shown in Table 12. Here there are four communities represented and a total of 534 acres that would be expected to produce 1073 tons of litter/yr.

The value of mangroves as producers of litter for the detritus cycle is a function of the amount of such litter and the efficiency with which it reaches the Bay.

Based on soil elevations where they are known, all of the Coastal Band and Dense Scrub are probably on soil that is below the MHW line; a part of the Sparse Scrub is above the MHW line, estimated to be about 1/5, based on plant associations in areas where there are elevations known; and about 2/3 of the White and Mixed community is probably

Table 11 Evaluation of Mangrove Litter Production in Section 14 T 56 S, R 40 E (just North of Black Point)

(just North of Black Point)

Community	Area (acres)	Average community litter production (tons/acre/yr)*	Total community litter production
Coastal Band	96	3.91	375
Dense Scrub	193	2.0	386
Sparse Scrub	-	-	-
White Mixed	-	-	-
Black Marsh	-	-	-
Total	289		761

*from Table 7, page 55

Table 12 Evaluation of Mangrove Litter Production in Section 28 of T 57 S, R 40 E (south of Homestead Bayfront Park)

Community	Area (acres)	Average community litter production (tons/acre/yr)*	Total community litter production
Coastal Band	74.6	3.91	297
Dense Scrub	151.	2.0	302
Sparse Scrub	84.7	.65**	55
White Mixed	224.	1.87	419
Black Marsh	-	-	-
Total	534	-	1073

*from Table 7, page 55

**This consisted of a mixture of types A, B and C. The value was selected as close to the average above the MHW line. It can be estimated from the data in this report that about 92% of the total mangrove litter production occurs below MHW. Such litter falls where tidal flushing can assure eventual contribution to the Bay.

Contributions of mangroves above the MHW line to the Bay are difficult to assess. In some areas above MHW the mangroves integrate with a variety of introduced and hammock species so that one needs to ask about the significance of litter from casuarina, salt bush, buttonwood, Florida holly, and sea daisy etc. as well as White mangroves to the estuary. Observation of such upland areas suggests that their litter tends to build up and decay in place near the site of origin.

The MHW line is not a sharp line below which detrital cycles contribute to the Bay's productivity and above which there is little input to the Bay; however, there is a tendency for this to be the case. Leaves decay more slowly at sites higher in the intertidal zone. Drier sites such as the upland White Mixed community have a paucity of the animals that are a part of the litter degradation system. Furthermore, studies of nutrient uptake by salt marsh and upland plant communities suggest that tight recycling of inorganic nutrients may be the rule and that overland runoff of inorganic nutirents probably has limited significance to the intertidal mangroves.

THE BULKHEAD LINE

Alternatives for Setting the Bulkhead Line

The bulkhead line is the line that defines the seaward limit to which an upland owner may fill his land. At some times in the past it has been necessary that riparian owners fill submerged lands in order to establish ownership. The bulkhead line has been the subject of a number of legislative acts and court decisions in Florida (64). Several bases have been used or suggested for establishing the bulkhead line, sometimes called the harbor line. These are:

Meander Line - was widely used in the past. It is a line, set by a government surveyor, that connects points along the shore, not as a boundary, but only as a convenience for locating the shoreline. Historically, misuse of the meander line sometimes has resulted in filling mangrove areas and parts of the Bay.

Vegetation Line - located at the bayward or seaward line of plants. If the bulkhead line were located at the vegetation line, the result would be that bulkheading would replace the present mangroves along most privately owned portions of the shoreline.

Mean Low Water Line - the Riparian Act of 1856 and subsequent court decisions under certain conditions gave riparian owners title extending to the Mean Low Water line (MLW) or to the offshore channel. This act was essentially repealed by the Public Lands Act of 1951, which gave the State title to submerged lands (65). Today there is no basis for consideration of the MLW line as a bulkhead line.

Mean High Water Line - the separation of sovereign and private lands by the line of "mean high water" or the "high tide line" comes from English law, where historically the line was interpreted as that of "ordinary" high tides. In 1935 a U.S. Court defined "mean high tide" as the average of all high tides through a complete tidal cycle of 18.6 years. Recently, O'Hargan, who reviewed bulkhead line history, has argued for the mean high water line as the appropriate demarcation of upland and sovereign lands (65).

A court decision in Dade County was made in 1971 requiring that the County Commission set the bulkhead line along Biscayne Bay at the Mean High Water line (MHW) or provide evidence for another location (66).

The "Florida Coastal Mapping Act of 1974" defines the "mean high water line" as: "the intersection of the tidal plane of mean high water with the shore" (67).

As was indicated in the introduction, the elevation of MHW varies at different points along the shore. According to the National Ocean Survey (NOS) "Biscayne Bay Tidal Survey 1973", elevations for MHW range from 1.61 ft. at the Miami Primary Tide Station to 0.86 ft. near the Card Sound Bridge (19). In some cases the MHW data have been corrected by more recent determinations. Thus, the elevation of MHW at the Cutler Drain area has been adjusted downward by the 1973 survey to 1.41 ft. from an earlier figure of 1.52 ft. (1).

Because of tidal differences along the shore, "the intersection of the tidal plane of mean high water with the shore" must refer to the MHW-shore intersection at the particular part of Biscayne Bay under consideration. The MHW line is therefore that line along the shore reached by the appropriate high tide on a day when the height of the high tide and the elevation of MHW for that part of the coast are the same. This intersection needs to be determined accurately. Along the gently sloping shores of Card Sound an inch difference in MHW elevation could mean a difference of almost 600 ft.

Mangrove Line - it has been suggested informally that the bulkhead line be established at the upland edge of the mangroves. Such a line would pose some formidable problems. Aerial photographs from the 1920's show that in some areas, as on the Cocoplum property, the mangroves did not extend as far inland as they do today. The indications are that hurricane high tides seeded upland areas. Hurricanes are regularly associated with high tides. Those from the 1926 hurricane reached 13.2 ft. at Dinner Key in Coconut Grove (69). The hurricane season is during the time of year that Florida's mangroves produce seeds, so most hurricanes have seeded uplands with mangroves. The reason mangroves, especially the White mangroves, extended their range into the marl flats after the mosquito ditches were dug, whereas they had not done so when seeded by earlier hurricanes, is that the mosquito ditches provided the means for the salt water of the monthly and equinoctial high tides to reach these areas. It is not that mangroves require salt water, but rather that the mosquito ditches provide periodic surface salt water that gives the mangroves a competitive advantage over the plants that were growing there.

The ground elevations of the present stands of White and Mixed mangroves on marl uplands average 1.75 ft. at Cocoplum and 1.78 ft. on the ITT property at Snapper Creek. MHW in these areas is about 1.43 to 1.45 ft. (19). Clearly, a bulkhead line placed at the farthest upland mangrove would be claiming land for the State which was cultivated fields until saltwater intrusion that followed drainage of the Everglades and the digging of the mosquito ditches made it too saline to farm. The mangrove line is located almost $\frac{1}{4}$ mile west of the salinity dike in Section 29 of T56S R40E.

Florida's Red and White mangroves will grow in fresh water and all three species will grow on dry land if competition from fast growing species is kept down, as by mowing of the surrounding grass (see Figures 2 and 3).

Role of Recent Legislation

Legislation passed in 1974 by the Dade County Commission establishing Biscayne Bay as an "Aquatic Park" (70) and the subsequent designation of Biscayne Bay as an "Aquatic Preserve" by the Florida Legislature (71), bear on the bulkhead line. The Florida Statute describes the Aquatic Preserve boundaries along the eastern and western shores of Biscayne Bay as the mean high water line. It also prohibits the Trustees of the Internal Improvement Trust Fund from approving the establishment of bulkhead lines unless such lines are located on the MHW line. Thus, any location of the bulkhead line seaward of the MHW line would now be moot.

Comments

From a biological point of view the location of a bulkhead line upland of MHW on the basis of mangrove distribution is fraught with difficulties. It is suggested that control of land development for preservation of natural resources above the MHW is more appropriately achieved by other means than the bulkhead line.

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APPENDIX A