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The Ecology of Northern Florida Bay and Adjacent Estuaries

by

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THE MARINE LABORATORY

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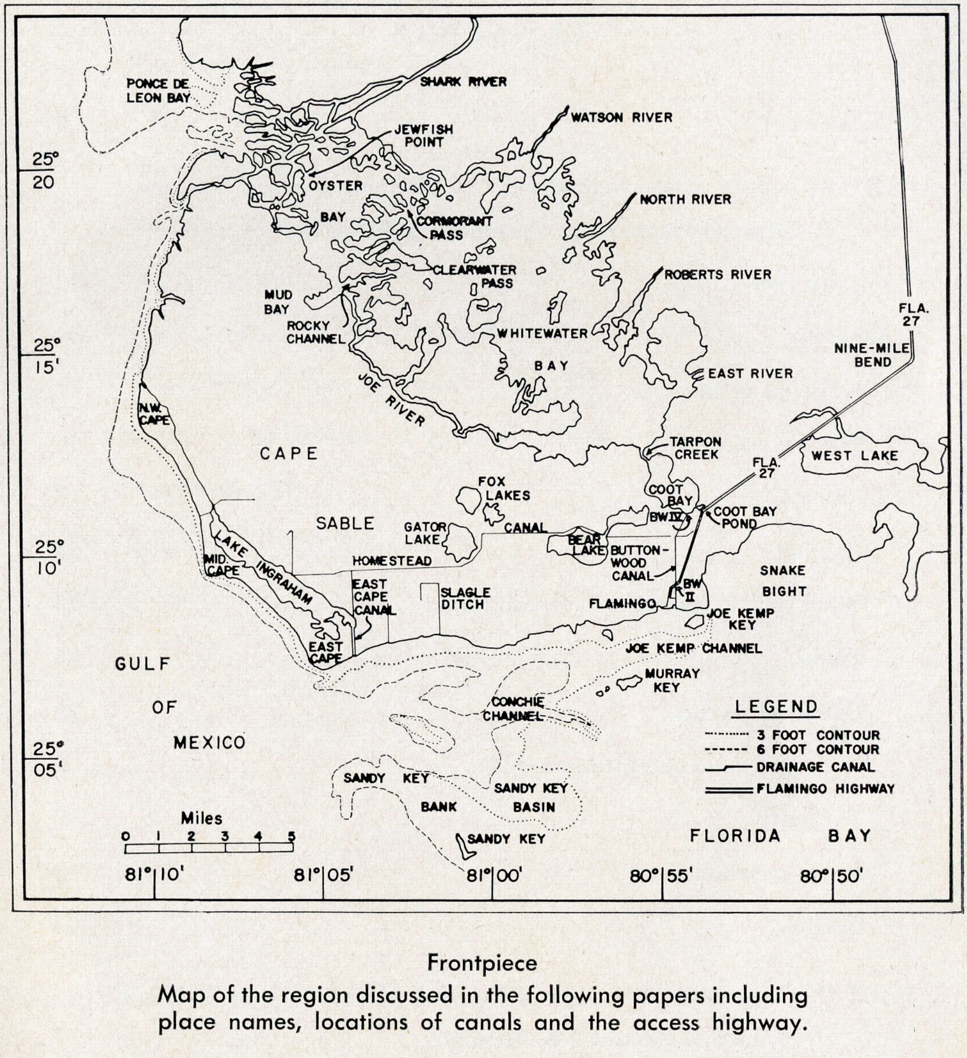
FOREWORD

THE STATE OF FLORIDA produces a greater variety of salt-water products, including game and food fish, than any other part of the country. The total commercial catch is over 200,000,000 pounds, with a value of more than $39,000,000 and more than 75,000 persons are solely dependent upon the industry for their daily bread. The auxiliary occupations such as boat-building and the numerous persons directly connected with the charter-boat fishery and sports fishing greatly exceed this total and bring the actual value of the sea fisheries to a figure which probably exceeds $200,000,000.

The State Board of Conservation is charged with the supervision, conservation and development of this important industry. In order to carry out these responsibilities it is necessary to engage in research whereby accurate information is gained upon which may be based sound methods of scientific management and control thereby contributing to maximum utilization of Florida's oldest industry.

Additional copies for fishermen, schools, wildlife clubs, civic groups and individuals may be obtained from the Director, State Board of Conservation, Tallahassee, Florida.

A list of publications in this series appears at the end of this book.



Frontpiece

Map of the region discussed in the following papers including place names, locations of canals and the access highway.

The Ecology of Northern Florida Bay and Adjacent Estuaries

CONTENTS

SUMMARY

An ecological study was conducted in the Cape Sable region of northern Florida Bay during the period July, 1957 through May, 1962. The region was selected for study because it seemed to be one of the few large areas of Florida that was nearly free from direct human environmental alteration. The need for the study stemmed from the problems of predicting the effects of environmental alteration on Florida coastal fisheries. Much must be learned about the ability of animals and plants to adjust to environmental changes under natural conditions before accurate estimates of effects of reclamation on the biota can be judged.

This paper discusses some aspects of the ecology that affect the natural biota of south Florida. The findings are summarized as follows:

1. The survey area lies at the focal point for runoff from the Everglades. The original watershed tributary to the study area covered some 9,000 square miles, extending from Orlando in central Florida to the Shark River and Gulf of Mexico. The effective watershed has been reduced by reclamation to about 3,000 square miles, i.e., the Everglades south of Lake Okeechobee.

2. Rainfall in the watershed south of Lake Okeechobee averages about 55 inches a year. Average annual rainfall at Cape Sable for the period of record was about 42 inches, with as little as 24 inches during the drought of 1961 and 26 inches in 1956.

3. The climate of south Florida, based on temperature and rainfall patterns, is characteristic of a "tropical savannah". Such regions have pronounced wet-dry seasons and not enough rain during the rainy season to compensate for the water loss through evaporation and transpiration which takes place in the dry season. The region thus has a water deficit which has been made up in the past by runoff from the region north of Lake Okeechobee.

4. The temperature of most of south Florida fluctuates less than 12F. between mean winter and summer air temperatures. A variation slightly greater, than this, of 14.5F, was observed at Cape Sable during the period of observation. The yearly mean air temperature during the period of record at Cape Sable was 74.7F. During the winter months of November through February the observed average variation between daily high and low temperatures was 39.6F. During the months of summer, June through September, the average variation between daily high and low temperature was 23.0F. The average daily variation in air temperature for 68 consecutive months at Cape Sable was 17.4F, with a maximum of 39F and minimum of 3F. Generally, years of heavy rainfall are characterized by lower than average temperatures, probably due in part to heavy cloud cover.

5. At the end of the normal rainy season, June through November, there is marked decrease in air and water temperature. Just prior to that time organic decomposition reaches a peak, causing a corresponding low dissolved oxygen content in the swamps and lagoons. This oxygen deficiency drives fish and invertebrates from the affected areas. This has been called the "bad water" period by commercial fishermen who often made good catches at that time. These oxygen deficiencies generally last about one month.

6. Winds of the Cape Sable region blow mainly from the east and southeast in summer and from the north-to-northwest in winter, with some influence being exerted by the easterly trade winds of winter which moderate the effects of polar air masses. Winds are the major factor in water circu-

lation in Florida Bay. Tides generated by winds often exceed those due to lunar influence. Wind-generated turbulence is the major cause of the normally high rates of calcium carbonate mud turbidities in Florida Bay. Winds blowing across Florida Bay aid in evaporation. This has been shown to average more than .3 of an inch per day in evaporating pans during the period March through July, 1961. Lunar tides in the estuarine portions of the study area and the nearby Gulf of Mexico are the mixed semidaily type. Tide curves in Coot and Whitewater Bay show the dominant influence of wind on water levels. Prior to opening of the Buttonwood Canal, south-to-southeast winds tended to drive water from Coot and Whitewater Bays through the Shark River. North and west winds piled water into the southeastern end of Whitewater Bay and into Coot Bay. Following completion of Buttonwood Canal, north-to-west winds continued to raise water levels in southeastern Whitewater Bay, as in the past, but the canal allowed Coot Bay to drain to Florida Bay thus decreasing the range of tide. Variation in range of lunar tides is greatest at the mouth of the Shark River, less at Cape Sable and dampens rapidly to the east until there is negligible daily variation in Snake Bight east of Flamingo.

7. The waters of the survey area generally show saturation of dissolved oxygen during the daylight hours and slightly below saturation at night. As expected, highest oxygen values occur in areas of greatest plant growth, with Florida Bay turtle grass beds and the algae beds of Whitewater Bay being most productive. Lowest oxygen concentrations were always found in Coot Bay and eastern Whitewater Bay during the late summer and fall when runoff was highest and when plant cover was least dense. During periods of peak runoff there is usually a gradient in dissolved oxygen corresponding to the salinity gradient in Whitewater Bay. Lowest values occur in the Whitewater Bay Station I area when salinity averages 15 ppt or less and increase to supersaturation in a westward direction toward Whitewater Station VII. Under such conditions, where the salinity gradient increases from 15 to 35 ppt between Whitewater Bay Stations I and VII, a difference of 40 per cent saturation usually is found during late afternoon. Total oxygen depletion was observed immediately following hurricane "Donna" of September, 1960, with conditions remaining between 80 and 37 per cent saturation in Coot and southeastern Whitewater Bay, into October. By December, 1960, all stations had returned to near 100 per cent saturation.

8. The annual range of pH observed was normally between 7.7 and 8.2, with low values of 7.5 occurring during periods of oxygen depletion. Leaching of humic acids from the mangrove swamps had little effect on pH of adjoining bays. Runoff from the swamps produced pH values .5 to .8 units lower than the nearby bay water. The muds in the upper two centimeters of the bottom had pH values of the overlying water. At times, the diurnal range of pH was as great as the annual range. The normal daily range of pH was between .2 and .4 units.

9. Turbidity in Coot and Whitewater Bays varied with runoff and salinity, with the greatest clarity always observed during periods of drought and the greatest turbidities occurring when tannins from the swamps, particulate organic matter from the larger rivers and marl muds from the bay bottoms were combined by wind mixing, in late fall. There was a clearly discernable turbidity gradient in Whitewater Bay that existed irrespective of the rainfall, with highest turbidities in the tidal portions of the Shark River and in the area of lowest salinity and greatest runoff in the southeastern end of Whitewater Bay. Water clarity increased rapidly toward central Whitewater

Bay and reached a maximum in the region named Clearwater Pass. Clearwater Pass is the normal dividing line between the estuarine and lagoon portions of Whitewater Bay, where the daily tidal scouring and water movement is slight, the bottom is stable, and there is protection from wind turbulence. Under those conditions several species of algae, notably *Udotea wilsoni* and *Acetabularia crenulata*, form a dense mat that further stabilizes the bottom.

10. Metabolic activities show that the productivity of Coot and Whitewater Bays compares favorably with similar bays along the northwest Gulf coast. Seasonal studies on gross metabolism in Coot Bay show a peak of metabolic activity in July and a low point in January.

11. Salinity values within the area fluctuate with runoff from the watershed. No clearly defined relationship can be observed between salinity and local precipitation. There is a close relationship between salinity values in the study area and runoff measured at the Tamiami Trail. A three month lag period seemed to exist between the passage of the peak flow southward from the Tamiami Trail to Whitewater Bay. There is a clearly defined salinity gradient across Whitewater and Coot Bays, with the lowest values always occurring at Whitewater Station V and increasing from there, both toward the Shark River and toward Coot Bay. Prior to the opening of the Buttonwood Canal between Florida Bay and Coot Bay the salinity gradient was considerably different, with lowest salinities occurring in Coot Bay and increasing toward the Shark River. Daily salinity variations due to tidal intrusion were wide in the Shark River, as high as 20 ppt and averaging about 10 ppt. Diurnal variation in salinity was negligible in Coot Bay except immediately adjacent to the mouth of Buttonwood Canal. Diurnal changes in salinity at Whitewater Bay I averaged 5 ppt, with the higher salinities occurring on the low end of the ebb tide period when the flow of slightly saltier water had passed through Tarpon Creek from Coot Bay. Diurnal salinity variations were normally barely detectable to absent at Whitewater Bay III, V, North River and East River. Daily variations in salinity in Florida Bay rarely exceeded 5 ppt.

12. The invertebrate fauna of Florida Bay east and south of Flamingo is largely derived from the Carolinian-Gulf of Mexico faunal provinces. An examination of 355 species of invertebrate animals found in Biscayne Bay and Florida Bay produced only 15 species that were common to both areas, or 4.2 per cent of the total number. The few Antillean forms that do occur in Florida Bay are found normally only along the edge of Florida Bay where it mixes with waters of the Straits of Florida and the Gulf of Mexico. Generally, the Antillean faunal elements are confined to waters having stable salinity and a high degree of clarity.

13. Biological sampling was undertaken mainly by small otter trawl and supplimented by night dipnetting with lights, hand collecting, van Veen bottom grab sampler and fish poison. Many of the common animals of the study area are extremely rare or absent in day-time collections yet may be collected in large numbers by night-light dipnetting. Pink shrimp, bay snapping shrimp, Key worm eels and spotted worm eels are good examples of larger animals that exhibit marked diurnal periodicity in activity.

14. The flora and fauna of the study area are regulated seasonally by temperature and salinity changes. However, the region has been divided into major habitats based on substratum characteristics as well. The inshore mark banks and supratidal marl prairies support an impoverished biota able to survive the extremes of heat, cold and desiccation that prevail in those areas. The majority of the animals are burrowing forms that live in the upper layers of

marl mud in the intertidal zone, under debris in the shore drift or construct deep burrows to water in the supratidal area. The turtle grass beds of the Florida Bay mud banks form the largest single community restricted to a more-or-less uniform substratum material. The level bottoms of marl mixed with varying amounts of organic material found in Coot-Whitewater and surrounding bays, ponds and swamp lakes form the second largest substratum category. The third largest area of more-or-less uniform substratum material is that found in the mangrove swamps north and east of Coot and Whitewater Bays. This has been called the salt-fresh-water transition zone. These bottoms are mainly of peaty material with small amounts of marl and are flooded periodically by rainfall, runoff, wind driven salt water and equinoxial high tides. Hard shell-sand and shell-gravel bottoms with occasional rock outcrops are found in the Conchie Channel to Cape Sable region. These are characterized by sparce plant growth, small numbers of invertebrates, some species of which may be exceedingly abundant, and by large numbers of fishes that move onto the turtle grass flats at night to feed but which return to the channels by day. The intertidal oyster reef and oyster clump community of the Shark River estuary is the next largest substratum category. Finally, the rocky channels of the Shark River estuary and other regions where tidal currents have scoured away the overlying soil, have been described.

15. Greatest numbers of species, both plant and animal, were found in the stable high salinity region between Sandy Key and East Cape Sable. Areas of very high and very low salinity showed marked reduction in numbers of species. If turbidity became heavy in either hypersaline or very low salinity waters the numbers of species were reduced even further.

16. Certain species of animals were commonly found only in particular situations, largely in association with distinctive plant groupings. The pinfish, *Lagodon rhomboides,* was the dominant fish in catches from the turtle grass flats. Immediately adjacent to these flats, in the channels having shell bottom deposits, the striped anchovy, *Anchoa hepsetus,* was most abundant in catches. In the oyster reef and clump environment the Florida blenny, *Chasmodes saburrae,* was dominant while the bay anchovy, *Anchoa mitchili,* thronged surrounding waters. The bay anchovy was the dominant species in the low to moderate salinity regions of Coot and Whitewater Bays. The mosquitofish, *Gambusia affinis,* dominated the mangrove swamps of the salt-fresh-water transition zone. In the *Chara hornemannii* beds, the clown goby, *Microgobius gulosus,* dominated catches in the dense weeds while the bay anchovy was the dominant species of open water over the *Chara.*

17. The plant and animal populations were always greatest when salinity values were between 30.0 and 45.0 ppt. The numbers of species, and numbers within species declined with declines in salinity. An offshore movement of animals from bays and the estuary, begun each year by falling salinity during the rainy season, was hastened by a somewhat abrupt decrease in temperature characteristically beginning in November and lasting through January. The widest variety of species in Florida Bay was usually found during November-December as migrant animals from further north along the Florida coast were joined by species from local inshore areas. The normal November decrease in average temperatures was usually preceded by an oxygen depletion period in the shallow swamp ponds and lakes. This "bad water period" concentrated small fish from the swamps along the bay margins where they were heavily preyed upon by birds and larger fishes.

18. Temperature fluctuations in southern Florida were seldom severe enough to cause mass mortality. There was, however, an annual offshore

movement of Coot and Whitewater Bay species in November, December and January. Many of the animals participating in this movement were mature individuals of euryhaline species such as the blue crab, *Callinectes sapidus*, and the striped mullet, *Mugil cephalus*, that are sea spawners in spite of wide temperature and salinity tolerances as adults. Other species, exemplified by the pink shrimp, *Penaeus duorarum*, use the bays as nursery grounds and leave these regions upon attainment of a certain size. Generally these begin leaving the estuaries prior to the onset of November cold weather but the offshore movement is accelerated by cold temperatures in shallow water. The offshore movements were most obvious in dry years when the bays fill with a variety of species and least obvious in years of heavy runoff that create low salinities in the back bays that exclude most marine species.

19. Mass mortality of fishes due to cold was observed during December, 1957 when water temperatures of 14-16C were recorded. A similar cold wave in February, 1958 caused no detectable kill and indicated a tendency to acclimatize on the part of the sensitive species.

20. Samples of sediments from Coot and Whitewater Bays indicated that three species of bivalve molluscs make up 70-80 per cent of the total calcareous relics. One of these, *Anomalocardia cunimeris*, was practically euryhaline; another, *Macoma mitchili*, was most abundant in low salinity, and the third, *Brachidontes exustus*, was dominant in moderate to high salinities (18-30 ppt). These data suggest wide fluctuations between nearly fresh-to near seawater conditions in Coot and Whitewater Bays in the recent past. Sediment studies also show organic content of muds to be highest in bay margins and off the mouths of the major rivers of the region. In the former case the organic material is derived from wind drifted aquatic plants and swamp detritus, largely red mangrove in origin. In the latter case the organics are largely of fresh-water origin and include large quantities of well preserved ramshorn snail, *Helisoma duryi seminole*, shells that exist alive only in the sawgrass environment of the fresh-water Everglades.

21. The Coot and Whitewater Bay areas as well as the mangrove forest adjacent to them on the north were probably fresh-to-brackish areas in pre-drainage times and having infrequent short periods of high salinity during droughts. The region was probably dominated by the calcareous alga, *Chara hornemannii*, and the widgeon grass, *Ruppia maritima*. The present West Lake Region is believed to be an approximation of pre-drainage conditions in Coot and Whitewater Bays. Under such low salinity conditions, it is probable that the fauna was much reduced, but there were probably heavy populations of killifishes, palaemonid prawns, juvenile ladyfish, gray snappers, pink shrimp and adult and juvenile blue crabs, striped mullet, tarpon, snook and sea catfish all of which were able to grow, largely free of predation and competition from the many species living in higher salinity just off shore.

22. These studies have made it possible to describe probable past alterations in the ecology of the study area and to predict changes in the plant and animal communities under differing temperature, rainfall and runoff conditions. As a result, recommendations can be made as to the quantities of water and the runoff pattern likely to result in the greatest gain to the plant and animal community. These findings can probably be applied to other south Florida estuaries and, with due consideration to differences in rainfall patterns and temperature variation, can be useful in predicting the effects of man-made changes in major estuarine systems of the southeastern United States and the Gulf of Mexico. Most of the significant changes in estuaries of this area are brought about by alteration in salinity and turbidity patterns. These changes

are hastened by such developments as island building, bulkheading, causeway construction and construction of unnatural tidal inlets.

23. Changes in the Everglades estuary were due principally to alterations in the watershed following the development of the Everglades for agriculture. In addition, local canal building has complicated the water exchange pattern, permitting high-salinity water to penetrate areas that were formerly fresh to brackish in nature.

24. Salinity is the major environmental factor in the area affecting the plant and animal communities. Salinities have changed, beginning about 1920, with a reduction in runoff to the Shark River from an estimated average annual flow of 2.3 million acre-feet to a measured average of 473,200 acre-feet. Coot Bay and Whitewater Bay salinities are now thought to be about twice as high as in the average years prior to 1920. The hydroperiod (i.e. the annual period during which runoff measurably dilutes seawater in the estuary) probably lasted 12 months of each year of average to above average rainfall prior to 1920. Since then this has been reduced to about 7 months. Further reduction of runoff from the Everglades, to the area within the Park, will probably shorten the hydroperiod to about 5 months. This will permit rapid salinity increase in Coot and Whitewater Bays, both by evaporation and by salt intrusion through tidal inlets from Florida Bay and the Gulf of Mexico.

25. Florida Bay has a limited watershed that acts as a moderating influence on the prevailing high salinities caused by evaporation. The salinity pattern of Florida Bay has probably not been altered in historic times. However, reduction of its small watershed, particularly the northern part near Homestead where annual rainfall is heaviest, could lead to permanent hypersalinity in Florida Bay. If salinity increases above 50.0-60.0 ppt it may be expected that many plants will not survive and many animals will be unable to reproduce successfully. If salinity rises above 60.0-70.0 ppt many species will die or be forced to leave the region. Hypersalinity in Florida Bay would be transmitted to Coot and Whitewater Bays by net gain of salt on each flood tide through Buttonwood Canal thereby making conditions unfavorable for many desirable animals and plants.

26. At present, Coot and Whitewater Bays have salinities ranging between 0-5.0 and 30-40.0 ppt, averaging about 18.0-25.0 ppt. Under these salinity conditions a greater variety of plant and animal life is present than in pre-1920 times. With a slight increase in average salinity the region would be subject to an invasion by most of the marine species now found off-shore. This would favor angling and sightseeing pursuits but would create a situation different than in pre-drainage times. We believe that salinities observed are probably most favorable for the perpetuation of the areas nursery grounds for shrimp, menhaden, crabs and other valuable species.

A return to conditions approximating those of the pre-drainage period would require a minimum average of 1.5 to 2.0 million acre-feet of runoff through the Shark River drainage annually. This should be spread over a full 12 month period.

27. In many southern estuaries low to moderate salinities should be maintained if possible and control should aim at supplying enough fresh water to result in annual salinities of about 18.0 to 30.0 ppt.

PART I

Aspects of the Hydrography of Northern Florida Bay and Adjacent Estuaries

by

Durbin C. Tabb and David L. Dubrow

INTRODUCTION

Parts I and II of this paper constitute the seventh in a series of papers on the ecology of northern Florida Bay and adjacent coastal estuaries, lagoons and mangrove swamps since the inception of the studies in July, 1957. Previous papers have dealt with descriptions of the flora and fauna (Thomas, 1961), (Manning, 1961 and 1961a) and (Tabb and Manning, 1961); the effects of hurricane Donna on the shallow-water biota of Florida Bay (Tabb and Jones, 1962) and the biology of pink shrimp (Tabb, Dubrow and Jones, 1962). In addition, three processed reports, two containing hydrographic data (Tabb, Dubrow and Manning, 1959) and (Tabb and Dubrow, 1962) and one containing pink shrimp biological data (Tabb and Dubrow, 1962) have been issued.

This paper presents results of hydrographic studies conducted in the Cape Sable region of Everglades National Park (Figure 1), during the period July, 1957, through May, 1962. It constitutes one aspect of an ecological investigation in a large south Florida estuarine area. This estuary was chosen for study because it is largely protected from human environmental alteration. The study was conducted to obtain a better understanding of plant and animal distribution under naturally fluctuating environmental factors, thereby assisting in the evaluation of effects of reclamation projects on the biota of similar regions along the Florida seacoast and elsewhere.

The need for such a study was brought about by concern over alterations in Florida's coastal waters as a result of reclamation and development activities, and the possible effect these would have on coastal fisheries.

Prior to the inception of this study in 1957 little work had been done in the northern shore areas of Florida Bay, although Ginsburg (1956) had described the hydrography and sediments of eastern and central Florida Bay, and Finucane and Dragovich (1959) had collected data on the hydrography of the western Florida Bay region and adjacent Gulf of Mexico during the 1955-57 drought period. A few references to crustaceans of the Florida Bay region were available (Rathbun, 1918, 1925, 1930, 1937), (Holthuis, 1951, 1952). Davis (1940) and Davis and Williams (1950) had done work on the mangrove swamps and plankton of the swamp ponds and lakes of south Florida

More recently Dragovich, *et al.* (1961) and Goodell and Gorsline (1961) published additional hydrographic data on the Florida Bay region, comparing it with Appalachicola Bay of northwest Florida.

The nearby Florida Keys and the complex of bays along shore to the north, including Biscayne Bay, have received considerable study. These studies have been summarized by Smith, *et al.* (1950), Joseph and Nichy (1955) and Voss and Voss (1955).

The study was supported by the Florida State Board of Conservation. In addition we are indebted to the Superintendent and staff of Everglades National Park for their courtesy and assistance in furthering the work by providing living quarters and dock facilities. We are appreciative of information on streamflow and evaporation given by Messrs. Klein and Hartwell of the Miami office of the U. S. Geological Survey.

Appreciation is also expressed to Dr. C. P. Idyll who directed the research and to Dr. E. S. Iversen, Dr. A. C. Jones and Dr. G. A. Rusnak of the Marine Laboratory staff for their advice and criticism throughout the course of the study.

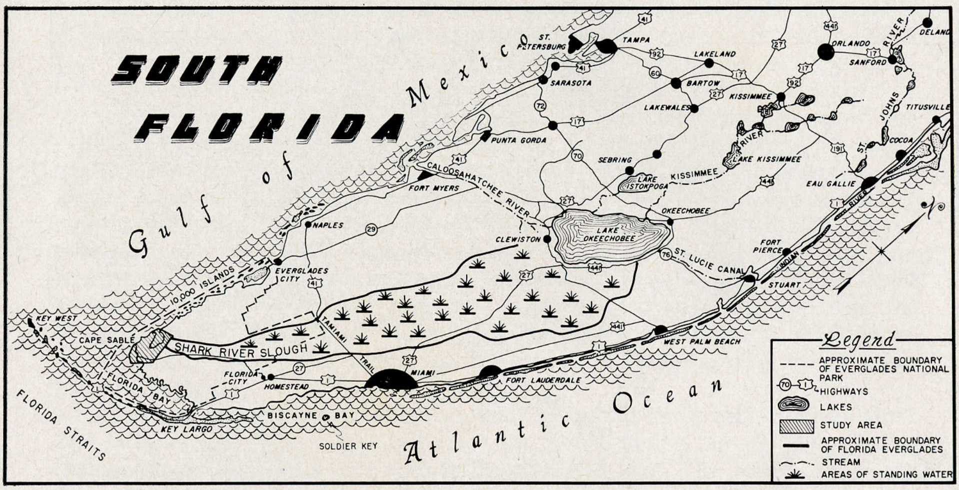


Figure 1. Diagramatic aerial oblique view of south Florida, showing the study area in relation to the Everglades-Kissimmee drainage basin, major highways, cities and the boundary of Everglades National Park.

METHODS

In July, 1957, forty sampling stations were established. These were chosen to give maximum coverage of the various water masses in the area. The original stations were located in relation to recognizable landmarks (usually islands or branches of well marked channels shown on U. S. Coast and Geodetic Survey Chart No. 598), or in the absence of landmarks, to navigation markers maintained by the National Park Service and the U. S. Coast and Geodetic Survey (Figure 2).

By 1959 sufficient information was available to reduce the number of regular stations to 24, with occasional samples being made at the others. Stations on transect from North River, across Clearwater Pass, and through Rocky Channel to Joe River were visited regularly beginning in mid-1959.

During the first two years of the study, observation periods averaged 5 days per month for hydrographic and 5 days for biological sampling. Hydrographic data collecting time was reduced to an average of 2 days per month during the remainder of the study, with supplemental observations being made during biological sampling.

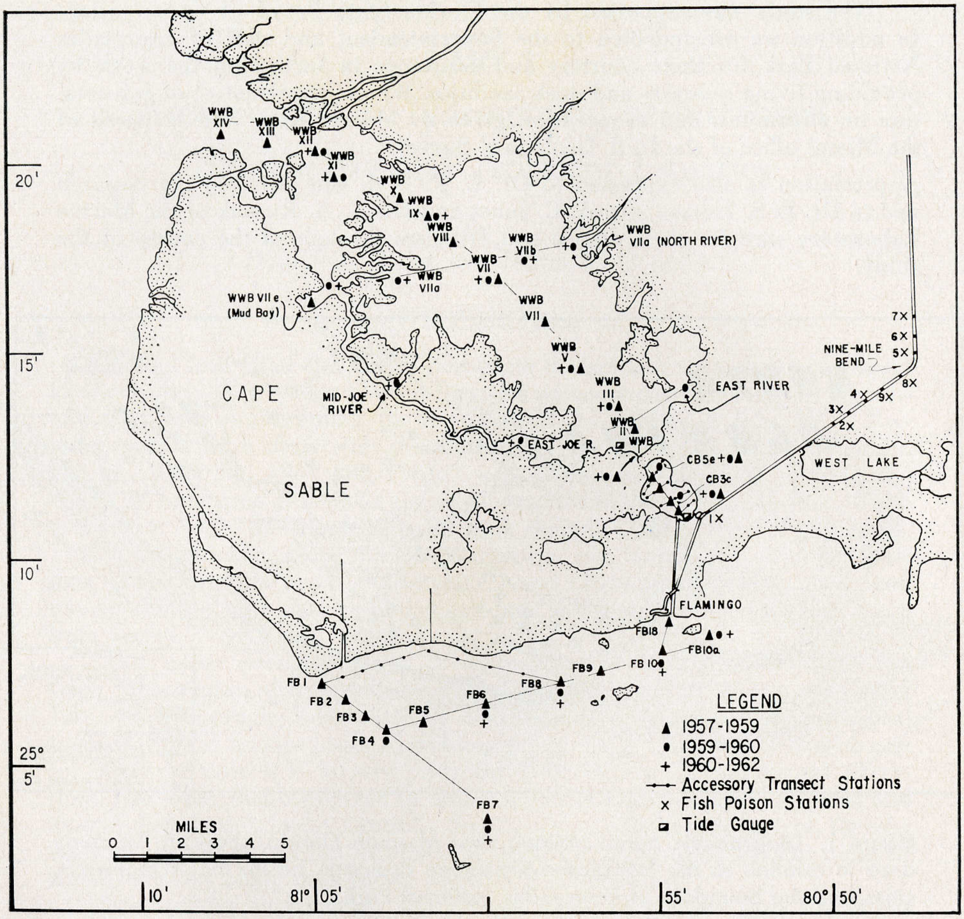


Figure 2. The Cape Sable region, showing location of hydrographic sampling stations.

Salinity was determined with standard seawater hydrometers, calibrated by the U. S. Bureau of Standards to 15C. Corrections for observed temperature were made by use of nomograms supplied by the manufacturer. [1] Temperatures were recorded to the nearest 0.1C. as registered on thermometers attached to the salinity determination kits.

Bottom water samples were obtained with a "Foerst" double-stoppered, messenger-operated sampler and a rubber-stoppered bottle which obtained samples within 8 to 10 inches of the bottom. Surface samples were taken by hand 6 inches below the surface.

Oxygen analyses were made by the Winkler method. The sodium azide modification was used when organic pollutants were suspected. Water samples for oxygen determination were kept in BOD bottles fitted with ground glass stoppers. Samples were fixed at the time of collecting, and titrated immediately upon return to the shore station at Coot Bay Pond or Flamingo.

[1]GM Manufacturing Company, 12 East 12 St., New York 3, N. Y.

The Beckmann "Model N" pH meter was used in hydrogen ion determinations.

Water clarity was measured by the use of paired "Weston" photocells, one mounted in a "Kahl" underwater housing, and the second in a waterproof box which served as the deck unit. Both photocells registered light intensity in microamperes, and light penetration data were recorded as per cent of deck reading. Water clarity readings were made only on sunny days between 1000 and 1500 hours.

DESCRIPTION OF THE AREA

Everglades National Park is situated at the extreme southern tip of Florida (Figure 1). Most of the Park area, whether in the fresh-water Everglades, or in the mangrove zone, is an aquatic region. Much of its unique flora and fauna is a direct result of large quantities of standing water. The mangrove forests within the Park boundaries are said to be among the largest in the world (Davis, 1946). The great size of the Park and the policies of the National Park Service insure that the effects of outside alterations are minimized. Flamingo, a former commercial fishing village, now the headquarters of the Cape Sable District within the Park, has been made accessible by construction of a paved road, an extension of Florida Highway 27. Major changes made within the Park boundaries consist of this highway, that acts as a partial barrier to water exchange, and the construction in 1957 of a canal between Flamingo and Coot Bay that permits small boat passage into the Whitewater Bay-Shark River region (See frontpiece). This canal, the Buttonwood Canal, opened Coot Bay to intrusions of high-salinity water from Florida Bay.

The waters of the area undergo wide fluctuations in salt content, since this is the focal point for runoff from the Shark River Slough and smaller streams that drain the Everglades to the east and west. The Shark River is a true estuary in that it lies at right angles to the coast, and has pronounced tidal mixing of fresh and sea-water.

Water depths are shallow throughout the area. Coot Bay averages about 3 feet, southeastern Whitewater Bay about 5 feet, and the Oyster Bay-Shark River estuarine complex about 6 feet. The greatest depth measured was 14 feet at low tide in the main channel of the Shark River where it enters Ponce de Leon Bay (Whitewater Bay Station XIV).

The region is underlaid by "Miami Oolite" limestone. Calcium carbonate marl and organic muds with locally produced shell gravel and shell sand inclusions cover the oolite throughout the open bay bottoms. The numerous islands are composed mainly of mangrove peat (Davis, 1946) and marl mud, and may be surrounded at low water line by narrow beaches composed of wind-sorted, locally produced shell gravel. In some areas, particularly in the Shark River, peat deposits up to 13.5 feet in thickness have been found (Spackman and Dolsen, 1961). Some of the thickest deposits of peat extend as much as a mile offshore and are now covered by the open water of the Gulf of Mexico. Spackman and Dolsen state that some of the deep peat layers now found offshore consist of remains of "*Chenopodium*," (pigweed) indicating fresh water conditions at the time of their formation.

The origin and size composition of calcium carbonate muds of East Florida Bay and the peculiar bank and basin bottom topography of the region as well as the general characteristics of the water circulation and hydrography have been described by Ginsburg (1956). The bank and basin regions of Florida Bay have an average depth of about 3 feet and extend west as far as Sandy Key off East Cape Sable. West of Sandy Key the depth increases to about 12 to 16 feet and the character of the bottom sediment changes from predominantly mud to coarse shell sand and whole shell, with much smaller fractions of marl. Where the waters of the Gulf of Mexico impinge upon the western edge of the Florida Bay banks, tidal scouring has created a series of channels. Two of these, Conchie and Joe Kemp Channels, extend along the shore from East Cape Sable to Joe Kemp Key off Flamingo. These channels have mixtures of clear Gulf water and highly turbid Florida Bay water, and contain a mixture of Florida Bay, Florida Keys and west Florida shelf flora and fauna that fluctuates in abundance with seasonal salinity, turbidity, and temperature.

Cape Sable, the dominant topographic feature of the region, is a barrier bar formed by on-shore wave action, long-shore current deposition and Florida Bay marl deposited during hurricanes. The formation and vegetation of Cape Sable has been described by Davis (1943) and Harper (1927).

The drainage basin

The drainage basin tributary to the Shark River and adjacent smaller streams extends to the headwaters of the Kissimmee River near Ocala in south-central Florida (Figure 1), and covers approximately 9,000 square miles. The area known as the Everglades covers about 3,000 square miles. It is an area of extremely low relief, the natural south shore of Lake Okeechobee being about 15 feet above sea level, the Tamiami Trail about 7 feet above, and the Nine-mile Bend area of the Park access highway about 1 foot above sea level. The low relief and the presence of natural depressions within the Everglades have permitted accumulation of fresh-water during the rainy seasons, with an attendent heavy growth of aquatic and wetland vegetation. The sawgrass, *Maricus jamaicensis,* is the dominant plant over much of the fresh-water Everglades, and this plant, plus lesser amounts of other semi-aquatics, has deposited great quantities of peat throughout the region (Davis, 1946).

The geological features of the drainage basin have been discussed by many authors (Matson and Clapp, 1909; Matson and Sanford, 1913; Cooke and Mossom, 1929; Cooke, 1945; Parker, 1942; Parker and Cooke, 1944; Parker, *et al.*, 1948; Hoy and Schroeder, 1952; Schroeder, *et al.*, 1958; and Klein and Sherwood, 1961). The hydrologic cycle in the watershed is complicated by the seasonality of rainfall, the porosity of the sub-surface rocks, and salt intrusion.

Climate

The climate of most of south Florida has been classified as a "tropical savannah" on the basis of temperature and rainfall (Hela, 1952). Such regions have relatively long dry seasons and not enough rain to compensate for water loss through evaporation and transpiration. Such areas experience a constant water deficit during dry seasons hence must depend on water from outside the region (in this case from the northern Everglades drainage) to make up the shortage. This peculiarity of the fresh-water supply is of primary importance in estuarine hydrography of the region, since loss of watershed or diversion of water within the watershed may bring about great alterations in coastal salinity patterns.

Most of southern Florida experiences less than 12F difference between the winter and summer mean air temperatures (Davis, 1943). From time to time there are extremes, particularly of cold, and these may have great effect on estuarine animals (Tabb, Dubrow and Jones, 1962). Mass mortalities of shallow-water animals of south Florida due to cold waves have been described (Storey, 1937). A discussion of the effects of low temperatures and other environmental extremes throughout the shallow-water regions of the world has been discussed by Brongeersma-Sanders (1957).

The available data on monthly average air temperatures from Cape Sable are shown in Table 1. Comparison of average temperatures for the three winter months (December through February) and the three summer months (June through August) show variation of 14.5 F, slightly greater than the 12 F shown by Davis.

Table 1. Mean annual and average monthly temperatures in °F for the period March, 1955, through April, 1962, at Flamingo, Florida. (Source: U. S. Dept. Commerce Weather Bureau Monthly Climatological Summaries).

Month	CALCULATION YEARS 1955	1956	1957	1958	1959	1960	1961	1962	Long-term monthly av. temp. °F
J	....	60.4	67.7	62.0	65.9	66.5	64.5	67.5	64.5
F	....	69.9	71.3	59.7	72.8	66.7	68.7	70.4	68.0
M	70.8	69.2	71.4	70.0	70.4	67.1	73.6	69.2	69.8
A	73.6	73.4	75.6	73.8	74.8	73.6	73.3	71.9	74.1
M	76.5	77.8	78.7	77.4	77.1	75.0	76.0	....	77.0
J	79.4	78.2	81.1	80.6	79.7	82.3	80.6	....	80.2
J	80.5	80.2	80.9	82.7	82.0	82.1	82.6	....	81.4
A	82.7	81.2	82.4	83.6	79.7	81.7	82.6	....	81.8
S	82.0	79.3	81.9	81.9	80.5	81.0*	80.5	....	81.1
O	76.7	78.8	76.0	76.6	80.3	81.0	77.3	....	77.6
N	71.8	70.0	74.7	75.8	74.2	75.0	72.7	....	73.5
D	68.5	67.3	66.0	69.1	66.5	65.4	68.9	....	67.4
Yearly mean	76.3	73.8	75.7	74.4	75.3	74.8	75.1	....	74.7
Yearly variation in °F	....	20.8	16.4	23.9	15.1	16.9	18.1	....	17.3

*Based on partial data, due to destruction of equipment by hurricane Donna, September 9-10, 1960.

Several authors have shown that the temperature of shallow bays, lagoons and estuaries of the Gulf of Mexico area closely parallels that of the air, due to thorough mixing and turnover by wind (Collier, 1938; Collier and Hedgpeth, 1950; Dawson, 1955). For this reason, the past temperature history of shallow estuarine areas may be obtained with reasonable accuracy by studies of weather records, when these are available. The maximum and minimum air temperatures, their monthly variation, greatest and least daily variation, and monthly average daily variation are shown for the period of record (March, 1955, through April, 1962) at Cape Sable (Table 2).

The average monthly variation between maximum and minimum air temperatures, average daily variation calculated for each month, and observed monthly deviation from the average daily variation are shown in Tables 3 and 4. Monthly maximum and minimum air temperatures may vary as much as 48 F in winter and as little as 16 F in summer. During the months of November through February, the average variation between maximum and

Table 2. Daily and monthly air temperatures in °F, showing extremes and averages for the period March, 1955, through December, 1960, at the Cape Sable District Ranger Station, Flamingo, Everglades National Park. (Source: U. S. Dept. Comm., Weather Bureau Climatological Observations).

Year	Month	Monthly maximum	Monthly minimum	Max.-Min. variation	Greatest daily variation	Least daily variation	Monthly average diurnal variation*
1955	M	87	44	43	31	11	21
	A	88	57	31	26	10	20
	M	89	59	30	28	13	20
	J	91	63	28	24	9	17
	J	92	71	21	19	12	15
	A	95	69	26	21	10	16
	S	92	70	22	19	10	16
	O	91	59	32	20	9	16
	N	86	50	36	30	13	21
	D	85	41	44	31	8	21
1956	J	81	37	44	39	10	24
	F	85	51	34	30	9	21
	M	86	43	43	32	12	22
	A	89	50	39	34	7	20
	M	89	62	27	26	8	19
	J	91	64	27	25	10	20
	J	93	68	25	23	16	20
	A	94	67	27	24	16	21
	S	92	66	26	23	10	17
	O	91	60	31	27	11	18
	N	89	41	48	31	15	26
	D	84	38	46	34	10	23
1957	J	86	40	46	37	14	25
	F	85	51	34	29	14	20
	M	88	45	43	29	3	18
	A	89	59	30	25	12	18
	M	90	67	23	19	10	16
	J	92	68	24	24	9	17
	J	93	71	22	19	10	16
	A	94	70	24	22	13	17
	S	93	71	22	20	10	15
	O	92	51	41	27	11	18
	N	88	55	33	25	9	17
	D	82	37	45	33	8	20
1958	J	79	38	41	29	4	17
	F	82	37	45	30	6	20
	M	85	41	44	29	7	16
	A	89	57	32	28	9	18
	M	89	55	34	30	9	18
	J	91	70	21	21	5	15
	J	92	71	21	18	11	15
	A	99	71	28	24	3	17
	S	90	74	16	....	....	....
	O	90	56	34	26	7	17
	N	86	58	28	19	9	15
	D	85	46	39	26	5	18

minimum readings was 39.6 F, and during the four warmest months, June through September, the variation was 23.0 F. The average daily variation in temperature at Flamingo, based on daily records for 68 consecutive months, was 17.4 F. The fluctuation around the monthly average daily variation is shown in Table 4.

Year	Month	Monthly maximum	Monthly minimum	Max.-Min. variation	Greatest daily variation	Least daily variation	Monthly average diurnal variation*
1959	J	82	39	43	33	6	17
	F	84	57	27	24	5	14
	M	84	44	40	30	8	17
	A	87	54	33	25	7	16
	M	89	58	31	....	....	....
	J	93	69	24	19	7	14
	J	90	70	20	18	9	14
	A	94	71	23	19	7	14
	S	91	71	20	18	10	15
	O	90	63	27	25	6	12
	N	88	40	48	26	7	15
	D	80	46	34	26	7	18
1960	J	82	34	48	34	7	18
	F	82	42	40	30	9	17
	M	82	43	39	31	6	18
	A	86	49	37	27	7	15
	M	87	57	30	26	7	17
	J	89	67	22	19	6	12
	J	91	71	20	18	7	14
	A	92	71	21	18	7	13
	S	90	70	20	16	8	12†
	O	90	71	19	19	10	14‡
	N	85	59	26	20	9	15
	D	83	40	43	27	6	17
1961	J	79	40	39	26	8	16
	F	83	47	36	24	6	14
	M	85	44	41	27	6	14
	A	86	52	34	24	5	15
	M	88	60	28	22	9	14
	J	90	67	23	18	8	13
	J	91	72	19	18	5	12
	A	91	72	19	18	7	14
	S	93	70	23	22	5	16
	O	90	57	33	21	6	16
	N	85	57	28	21	6	16
	D	83	38	45	33	4	15
1962	J	82	40	42	24	6	14
	F	82	49	33	26	5	15
	M	82	42	40	24	4	13
	A	85	52	33	29	6	16
	M	92	58	34	25	8	18

*Based on daily variation summary divided by total days per month
†Based on first eight days of the month prior to hurricane Donna
‡Based on last 19 days of the month following re-installation of instruments destroyed by hurricane Donna, September 9-10, 1960.

The rainy years of 1958 through 1960 were characterized by 30 day average daily variation values less than the long-term averages (Table 4). The cooler air of the period apparently gave rise to greater convectional activity as a result of differential heating of air masses, which in turn resulted in higher rates of precipitation. In south Florida thundershower activity is responsible for much of the precipitation. Many areas of Florida receive an average of 80 to 100 thunderstorms annually (Fla. Water Res. Study Comm., 1956, p. 19).

Table 3.

A. Average monthly variation between maximum and minimum temperatures (°F) for period March, 1955, through December, 1960, at Flamingo, Everglades National Park. (Source: U. S. Dept. of Commerce, Weather Bureau Monthly Climatological Summaries).

Month	J	F	M	A	M	J	J	A	S	O	N	D
Variation	44.4	36.0	42.0	33.7	29.2	24.3	21.5	24.8	21.0	30.7	36.5	41.8

B. Average daily variation in air temperature, to be expected each month based on temperature data for the period March, 1955, through December, 1960.

Month	J	F	M	A	M	J	J	A	S	O	N	D
°F	20.2	18.4	18.7	17.9	18.0	15.8	15.7	16.3	15.0	15.8	18.2	19.5

A period of sudden decrease in air temperature, and a corresponding water temperature decrease, is usually observed in September, October, or November (Table 1). This accompanies changing meterological conditions at the end of the hurricane season. The period of lower temperatures is accompanied by low salinity values during rainy years, due to peak runoff from the mainland. At such times maximum flushing of decomposition products from the mangrove swamps result in reduced dissolved oxygen content of the bay water. Commercial fishermen called this the "bad water period" and occasionally made good catches of fish moving out of affected areas at this time. The periods of oxygen deficiency are generally short, seldom lasting more than a month, after which the animals move back into the bays.

Table 4. Monthly deviation from the average daily variation in temperature (shown in Table 3, panel B) for each month of the period March, 1955, through April, 1962, at Flamingo, Everglades National Park.

	MONTHS											
Year	J	F	M	A	M	J	J	A	S	O	N	D
1955	....	....	+2.3	+2.2	+2.0	+1.2	−0.7	−0.3	+1.0	+0.2	+2.8	+1.5
1956	+3.8	+2.6	+3.3	+2.2	+1.0	+4.2	+4.3	+4.7	+2.0	+2.2	+7.8	+3.5
1957	+4.8	+1.6	−0.7	+0.2	−2.0	+1.2	+0.3	+0.7	0.0	+2.2	+1.2	+0.5
1958	−3.2	+1.6	−2.7	+0.2	0.0	−0.8	−0.7	+0.7	0.0	+1.2	−3.2	−1.5
1959	−3.2	−4.4	−1.7	−1.8	....	−1.8	−1.7	−2.3	0.0	−3.8	−3.2	−1.5
1960	−2.2	−1.4	−0.7	−2.8	−1.0	−3.8	−1.7	−3.3	−3.0	−1.8	−3.2	−2.5
1961	−4.7	−4.2	−4.9	−2.5	−4.0	−3.2	−3.3	−2.3	−1.0	+0.1	−2.6	−4.1
1962	−6.2	−3.4	−5.7	−1.9	....	....	....	....	....	....	....	....

Rainfall

The annual rainfall of Florida localities south of Lake Okeechobee averages about 55 inches a year, with the heaviest amounts falling along the southeastern coastal ridge between Florida City in the south and West Palm Beach in the north. The Cape Sable region generally receives the least rainfall of the mainland stations. Long-term rainfall records for 9 stations tributary to Florida Bay are shown in Table 5, along with available rainfall data from Flamingo for the period 1955 through April, 1962.

Severe drought conditions and conditions of unusually high rainfall have been described (Davis, 1943; Perry, 1958). The average annual rainfall at Cape Sable during the period 1955 through 1961 was about 50 inches per year. As little as 24 inches fell in 1961 and 26 inches in 1956. During the hurricane year of 1960, about 83 inches was recorded at Flamingo. The years 1958 through 1960 were wetter than normal (Table 6). Approximately 20 inches of the above-average rainfall for 1960 came as a result of hurricane Donna (Tabb and Jones, 1962) and tropical disturbance Florence, both of

Table 5. Annual maximum, minimum and mean rainfall data from nine locations in the Florida Bay Drainage Basin (Fla. St. Bd. Conserv., 1954) compared with Cape Sable District data compiled from U. S. Weather Bureau Monthly Climatological Summaries.

RAINFALL STATION	PERIOD OF OBSERVATION	PRECIPITATION IN INCHES Maximum	Minimum	Mean
Florida City Lat. 25°24'N-Long.80°30'W	1946-1952	60.21 (1948)	41.59 (1951)	51.79
Homestead Experiment Station Number 1 Lat. 25°30'N-Long.80°30'W	1910-1952	94.07 (1947)	40.42 (1938)	62.75
Homestead Experiment Station Number 2 Lat. 25°30'N-Long.80°30'W	1940-1952	91.20 (1947)	44.10 (1951)	59.98
Homestead Section 1 Lat. 25°29'N-Long.80°29'W	1946-1952	93.71 (1947)	46.79 (1951)	62.23
Homestead Section 13 Lat. 25°28'N-Long.80°29'W	1945-1952	90.98 (1947)	42.36 (1951)	61.40
Homestead Section 16 Lat. 25°28'N-Long.80°32'W	1946-1952	76.48 (1947)	38.28 (1951)	55.37
Redlands Number 1 Lat. 25°35'N-Long.80°30'W	1946-1952	77.09 (1947)	46.30 (1952)	61.27
Redlands Number 3 Lat. 25°32'N-Long.80°31'W	1948-1952	59.38 (1949)	47.47 (1951)	52.83
Redlands Number 4 Lat. 25°30'N-Long.80°32'W	1949-1952	54.80 (1952)	45.51 (1951)	51.33
Flamingo (Cape Sable District) Everglades National Park Lat. 25°11'N-Long.80°54'W	1955-1962	82.83 (1960)	24.36 (1961)	50.03

Table 6. Monthly rainfall in inches for the years 1955 through April, 1962, used in calculation of mean monthly and annual precipitation rates for the Cape Sable District, Everglades National Park. (Source: U. S. Dept. of Commerce, Weather Bureau Monthly Climatological Data sheets).

	PERIOD OF OBSERVATION								
Month	1955	1956	1957	1958	1959	1960	1961	1962	Avg.
J	——	.62	.13	5.72	.62	.50	.93	3.71	1.74
F	——	1.22	3.73	1.55	2.07	2.95	1.27	.87	1.95
M	.34	.01	2.37	8.05	3.23	.67	.58	1.24	2.06
A	1.95	1.15	1.39	.82	.41	3.44	.03	1.80	1.37
M	1.73	.97	7.44	10.10	6.86	13.62	7.28	——	6.85
J	14.03	3.22	3.28	15.49	8.87	5.54	1.96	——	7.48
J	5.53	3.67	9.36	4.90	7.79	7.52	1.46	——	5.74
A	3.08	4.61	8.39	5.56	6.00	9.52	2.84	——	5.71
S	6.39	6.49	6.76	3.78	10.09	30.00*	2.76	——	9.46
O	1.39	3.73	4.97	4.54	8.28	5.87	2.97	——	4.53
N	.80	.19	2.00	.88	4.29	2.89	2.07	——	1.87
D	1.13	.30	1.76	4.08	1.72	.31	.21	——	1.36
Total	36.37	26.18	51.58	65.47	60.23	82.83	24.36	——	41.77

*Gauge blown away by hurricane Donna, September 9-10, 1960. The total includes approximately 20 inches of rain estimated to have fallen during the hurricane and during tropical disturbance Florence of the same month.

which occurred in September. During 1958 through 1960, south Florida rainfall was uniformly heavy, with 100 inch totals reported at several unofficial gauges in the Dade and Broward County areas. Perry (1948), on the basis of long-term weather records, predicts wet-dry cycles of approximately 24 years duration. He predicted that extremely high rainfall could be expected between 1948 and 1958, followed by extremely low rainfall between 1961 and 1967. At Flamingo, the wet period began in 1958 and lasted through 1960. There were two very dry periods at Flamingo during 1955-1956 and 1961-1962.

Wind and evaporation - transpiration

Summer winds in southern Florida blow primarily from the southeast. Winter winds are a combination of the easterly trades and north-to-northwest continental winds that originate in the polar fronts that cross the Gulf of Mexico and the Florida peninsula (Hela, 1952).

In Florida Bay and adjacent estuaries, winds cause rapid water temperature changes. Tides generated by winds often exceed those due to lunar influence (Figure 4). Wind is the major factor in the almost constant high turbidity so characteristic of northeastern Florida Bay, where the bay bottom consists of fine calcium carbonate marl mud. Winds play a major role in shaping the topography. The three capes of Cape Sable, for example, are an expression of wind-driven long-shore currents as well as of onshore wave action from the Gulf of Mexico.

Recent unpublished data on pan evaporation in the Florida Bay area, provided by the U. S. Geological Survey, show high evaporation rates (Table 7).

Table 7. Evaporation pan data and rainfall from Flamingo for the period March, through July, 1961.

	March	April	May	June	July
Evaporation rate (inches)	7.84	9.52	9.79	9.66	10.23
Rainfall (inches)	.58	.03	7.28	1.96	1.46
Monthly precipitation deficit	7.26	9.49	2.51	7.70	8.77
Daily average rate of evaporation (pan inches)	.25	.32	.35	.32	.34

In the watershed the evaporation process is coupled with that of transpiration, or loss of moisture by vegetation. Davis (1943) in discussing evapo-transpiration in sawgrass areas in the Everglades, said that water loss by this process amounted to 130 per cent of annual rainfall, or an average of about 67 inches per year. The Florida Water Resources Study Commission (1956) states that the potential loss of water by evapo-transpiration in the Miami area is about 14 per cent greater than annual rainfall.

Tides

Information concerning the tides of the Coot Bay-Whitewater Bay area was provided by the National Park Service which maintained two "Gurley" tide gauges with weekly recorders, one in southeast Coot Bay and one in southeast Whitewater Bay, for a period of about four years (Figure 2). Records are complete only for the years 1955 through 1957, but this period included the opening of the Buttonwood Canal and provides useful comparison of conditions before and after this.

The tides of the region are of the mixed semidaily type (Marmer, 1954). U. S. Coast and Geodetic Survey Chart No. 598 shows that tide range varies considerably along the Florida Bay-Gulf of Mexico shoreline. The normal range of tide at the mouth of the Shark River is 3.6 feet, 2.9 feet at East Cape Sable and 1.8 feet at Flamingo.

Prior to the dredging of the Buttonwood Canal in September, 1957, the tides of Coot Bay and Whitewater Bay had similar characteristics, since they had the same exchange with the Gulf of Mexico through the Shark River. Examples of typical tide tracings from the two gauges during the pre-canal period are shown (Figure 3). They differ in their peaks, with the broad curve for Coot Bay indicating slowed response on the changing tide due to the

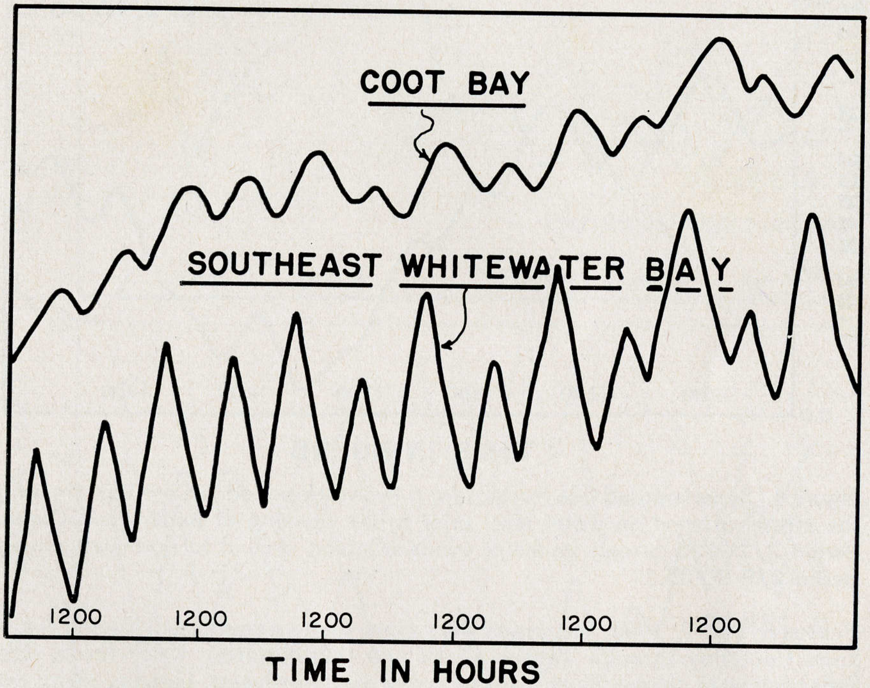


Figure 3. Typical tide gauge tracings at Coot Bay and eastern Whitewater Bay prior to the opening of Buttonwood Canal between Coot Bay and Florida Bay at Flamingo illustrating difference in height, and shape of peaks of Coot Bay tracings, due to constriction of flow through Tarpon Creek.

constriction of Tarpon Creek, the single outlet to Whitewater Bay. The inability of Tarpon Creek to handle much water also accounted for smaller tide variation in Coot Bay.

Prior to the opening of Buttonwood Canal, the average daily tide variation in Coot Bay was about 2.7 inches on the major tide and 0.89 inches during the minor tide. During the ten month period, January through October, 1955, tides during non-wind-influenced periods showed a range of 0.3 and 3.9 inches.

In southeastern Whitewater Bay during the period November, 1954, to October, 1955, there were only eight weeks when winds did not cause marked fluctuations in water levels. During that calm eight-week period the daily average range between the major high and low was 7.5 inches and 4.3 inches during the minor tides. The single greatest water movement during this period was 10.2 inches and the least water movement was 1.8 inches.

The effects of winds on Coot Bay water levels during the pre-canal period is shown in Figure 4. During the first week of the two week period illustrated,

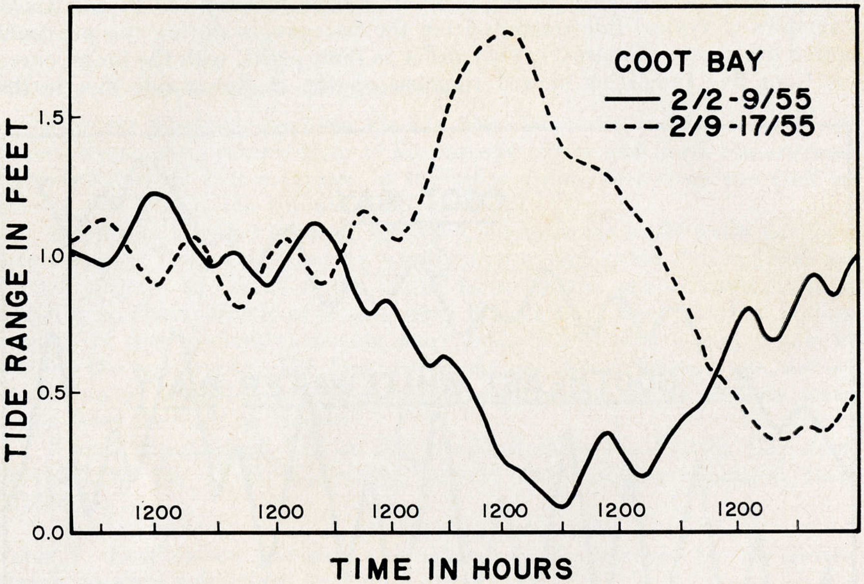


Figure 4. Superimposed tide tracings for a two week period in Coot Bay, showing the effects of wind on water level prior to the opening of Buttonwood Canal. Period 2/2-9/55, strong southeast winds swinging around to northwest during period 2/9-17/55.

February 2 to 9, 1955, the winds were from the east-southeast, forcing water from Coot Bay through Tarpon Creek and thus lowering water levels. The following week the winds had swung to the west-northwest, blowing along the long axis of Whitewater Bay, and forcing water into Coot Bay. Daily tidal fluctuations are nearly obliterated by such wind-induced water movements.

Until the canal was opened into Coot Bay in 1957, water levels in both Coot and Whitewater Bays were influenced by the same factors (*i.e.* seasonal pile-up of water at the peak of the runoff period, spring and neap tide levels and wind pile-up). The prevailing southeast winds of spring and summer tended to push water northwest along the long axis of the system and thence out the Shark River. Winter winds from the west-northwest had the reverse effect, causing a pileup of water in southeastern Whitewater Bay and in Coot Bay. Northwest winds of winter also caused some water movement into Bear, Mud and Fox Lakes south of Coot Bay, since the high water spilled over the low shore of Coot Bay through the mangroves. Water exchange between Coot Bay and these lakes reached its greatest volume during the period October through February.

After the opening of the Buttonwood Canal this pattern of water movement changed. Strong west to northwesterly winds that caused a pileup of water in southeastern Whitewater Bay now drive water out of Coot Bay through the canal, creating low water conditions in Coot Bay. The effects of wind on tide levels in eastern Whitewater and Coot Bays prior to the canal opening is shown and compared with conditions under similar winds after the canal was opened (Figure 5).

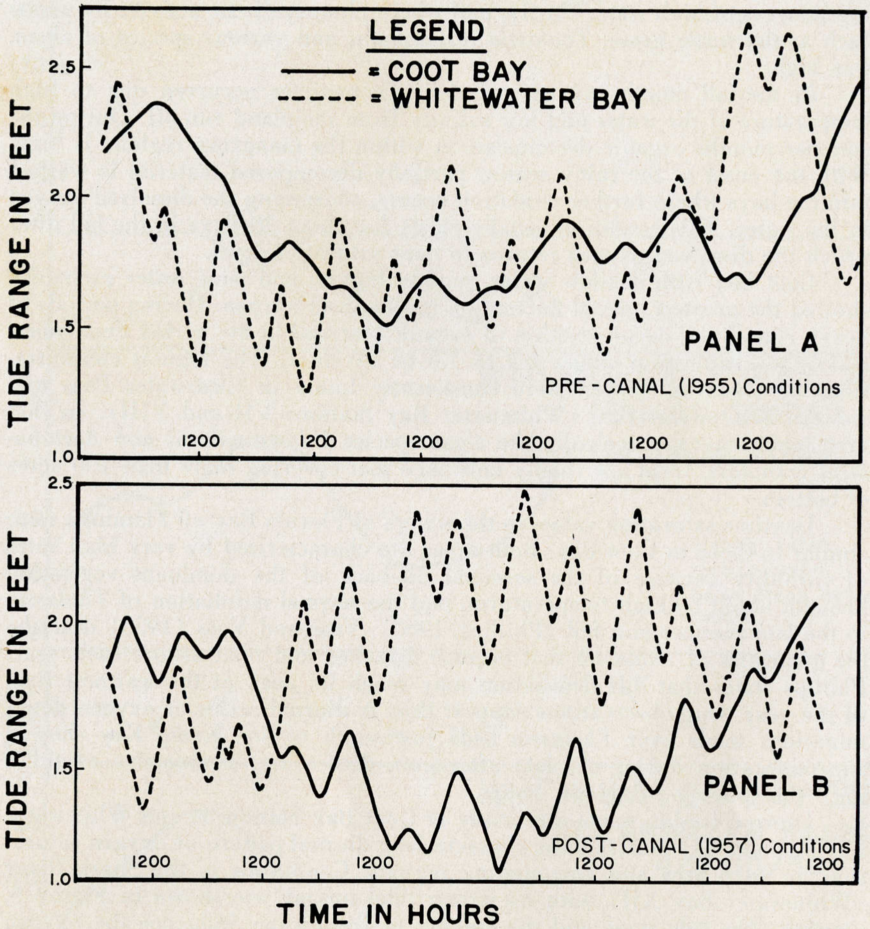


Figure 5. Tide tracings from southeastern Coot and Whitewater Bays. Panel A illustrates similarity of water levels under varying wind conditions prior to opening of Buttonwood Canal. Panel B shows that after the canal opening northwest winds that formerly raised levels in both areas, now lower Coot Bay by pushing water to Florida Bay through Buttonwood Canal.

Ginsburg (1956) states that lunar tides in Florida Bay east of Flamingo are weak to absent, and water circulation is almost exclusively caused by wind. Measurable tides are experienced only in a narrow band along the Florida Keys in eastern Florida Bay in the vicinity of the natural and man-made cuts through the Keys. It appears that the movement of daily tides is damped by friction of the rapidly shallowing bottom in the Flamingo area, and probably does not extend eastward much beyond Snake Bight.

Dissolved oxygen

Dissolved oxygen analyses showed that values were high during most of the year in all the bays, generally ranging between 3.0 and 4.0 ml/L, or 80 to 100 per cent saturation (Tabb, *et al.*, 1959; Tabb and Dubrow, 1962). Periods of supersaturation occurred when winds caused thorough mixing in areas of high water clarity, and where photosynthetic activity by plants such as the turtle grass, *Thalassia testudinum*, and various species of algae, was high.

In the fall months an oxygen deficit sometimes occurred due to high temperature of the water and low salinity from mainland run-off. During the summer months organic decomposition within the mangrove regions is high. With the onset of the rainy season partially decomposed material is washed into the bays where further oxidation occurs, consuming the dissolved oxygen in the water. This condition usually exists for about 30 days in the fall after which the dissolved oxygen returns to near saturation level.

Coot Bay with shallow water, muddy bottom and poor water exchange, showed the greatest annual fluctuation in dissolved oxygen. During periods of heavy runoff and decomposition of organic material in the period September-November, saturation values fell to 1.0 to 2.0 ml/L. The highest concentrations of dissolved oxygen were consistently found in Clearwater Pass and western Whitewater Bay (Whitewater Bay Stations VII and VIII). In that area, plant cover, principally the algae species *Udotea wilsoni* and *Acetabularia crenulata,* form a virtually unbroken mat covering more than 100 acres of bottom.

Daytime saturation values in the waters of Florida Bay off Flamingo were similar to those in Coot Bay. Both areas are characterized by very high rates of turbidity because of the seasonal die-back of the dominant vegetation brought about by high temperatures, and the normal defoliation of *Thalassia* in the late summer and fall (Phillips, 1960). Voss and Voss (1955) describe the quantities of *Thalassia* that become detached and float ashore each year. Phillips states that this defoliation may reach its peak at the warmest time of the year. Our observations support this. A diurnal series of oxygen determinations made over *Thalassia* beds just south of Joe Kemp Key showed supersaturation during the late afternoon, decreasing, irrespective of tides, until the following daylight hours.

Diurnal studies made seasonally at Coot Bay Station 3c and Whitewater Bay VII and XII illustrate the characteristic diurnal pattern of oxygen saturation for each area and surrounding regions. Conditions in the Shark River (Whitewater Bay XII) with its strong tidal mixing are shown in Figure 6, panel B. The tide stage and the amount of fresh-water influence the oxygen concentration in the Shark River. Coot Bay 3c and Whitewater Bay VII show strong relationships to photosynthetic activity and little of the tidal effect of the Shark River.

In southeastern Whitewater Bay, oxygen values are lowest at Whitewater Bay I and increase toward the west, reaching peak values at Clearwater Pass. Low average salinities and heavy deposits of organic material in eastern Whitewater Bay caused this characteristic pattern. In addition, there are few plants in the eastern part of Whitewater Bay during periods of heavy runoff, when salinity falls below about 15 ppt. A difference of about 40 per cent saturation can usually be found between Whitewater Bay Stations I and VII during the afternoon hours. Probably the lower values found at Whitewater I are caused at least in part by addition of Coot Bay water through Tarpon Creek on the ebb tide. This water from Coot Bay normally produces an in-

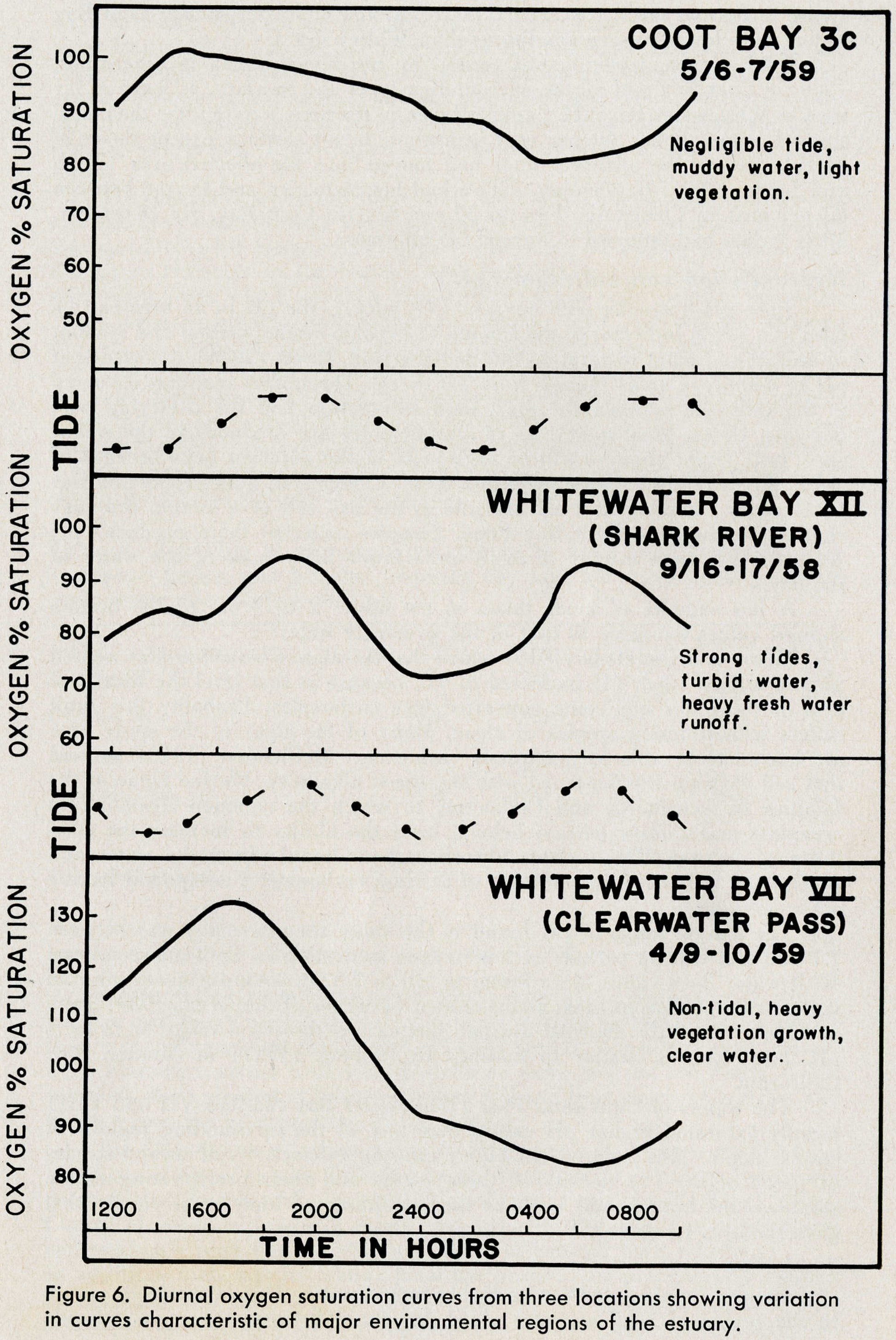


Figure 6. Diurnal oxygen saturation curves from three locations showing variation in curves characteristic of major environmental regions of the estuary.

crease in bottom salinity of from 3 to 5 ppt, and characteristically Coot Bay waters have lower oxygen conditions than Whitewater I.

Total oxygen depletion was caused by hurricane Donna in September, 1960, in Coot Bay and all the surrounding lakes and swamps, at least as far west as Whitewater Bay VII. Samples taken in the area 7 days after the storm showed values below 40 per cent saturation in all stations except those in Florida Bay where offshore water had moved into the affected area (Tabb and Jones, 1962). By October, values had begun to rise and ranged between 80 per cent in Clearwater Pass to 37 per cent in Coot Bay. By December, 1960, values had returned to normal for all areas.

Hydrogen ion concentration (pH)

Since pH fluctuates with oxygen - CO_2 supply, the pH in an area can be used as a rough indicator of the amount of organic decomposition and amount of animal and plant respiration that is occurring. Davis (1946) reported that pH in mangrove areas ranged from 5.0 to 7.2. The higher readings occurred at the interface between the marl mud substratum and the overlying peat deposits. Unless great quantities of organic acids are produced in the watershed, only slight changes will be noticeable in the adjacent bays because of the highly alkaline buffered condition there. Evidence of acid production was obtained by sampling at a culvert pool at the bay end of a swamp drainage channel leading into Coot Bay Pond. Samples collected there produced pH readings that were usually .5 to .8 units lower than those of the water of the bay.

A few samples of muds taken in the upper 2 to 3 cm of the bottom showed values the same as that of the overlying water.

Moore and Danglade (1915) stated that the alga, *Ulva enteroides*, ceased photosynthesis when pH increased to 9.0, because at that level the bicarbonates in the water are being converted into carbonates. Probably this limit differs with different species of algae. Many of the algae of the study area are known to be able to precipitate carbonates. McClendon (1918) showed that cell division was hastened with increased alkalinity. Marine algae of the families *Dasycladaceae* and *Codiaceae*, to which the common *Acetabularia crenulata* and *Udotea wilsoni* belong, have the ability to increase the alkalinity of an area. These plants absorb carbon dioxide from the water and precipitate carbonates in the form of calcium carbonate, a compound having a low solubility.

The annual range of pH found in the study zone normally was between 7.7 and 8.2. During periods of low oxygen saturation in Coot and southeast Whitewater Bays values were found to fall to 7.5. In some instances, diurnal variation in pH was as great as the annual variation (Tabb, *et al.*, 1959; Tabb and Dubrow, 1962). Normal diurnal fluctuations showed a range of .2 to .4 pH units. This is similar to findings by Moberg (1927) at Mission Bay, California.

The waters of Clearwater Pass (Whitewater Bay Stations VII and VIII) usually exhibited higher pH values than any of the surrounding regions of similar depth. This is due to the high photosynthetic activity of several species of green algae. The density of these plants and their precipitating action stabilizes the bottom and leads to the conditions of high water clarity that gave the area its name.

Turbidity

Florida Bay is noted for its highly turbid water. This is especially severe in the region of shallow water along the shore between the upper Florida

Keys and East Cape Sable. The heaviest turbidities are caused by the strong prevailing southeast winds, blowing across the full reach of the bay. Turbid conditions reach a peak concurrent with the period of defoliation of the turtle grass, *Thalassia testudinum,* in late summer (Phillips, 1960). In Florida Bay, turbidities are almost exclusively caused by fine particles of calcium carbonate marl in suspension. These impart a characteristic white to gray color to the water.

The brackish water of Coot and Whitewater Bays and surrounding swamps have turbidities of three different kinds. Tannins leaching from the swamps during the rainy season impart a dark tea color. Heavy runoff from the rivers tributary to the region carry loads of decomposed vegetation in particulate form, which impart a characteristic dingy black color to the water. When these two combine during the rainy season, light penetration is severely limited. In addition, during periods of strong winds, local marl deposits of the estuary are churned into suspension, imparting a gray to white color to the water. Combinations of all three occurred most often following long periods when the salinity varied between 0.0 and 15.0 ppt. At this time (August through October) most of the plant cover had disappeared and runoff was at a peak. The differences in light penetration during dry and wet seasons are shown for several stations in the estuary (Table 8).

Table 8. Turbidity at representative stations in Coot and Whitewater Bay (surface-6 inches, and bottom), showing dry and wet season changes. Data given as per cent of deck reading.

Station	Depth	Year	Month	Surface	Bottom
Coot Bay 2	4 ft.	1958	April	90.5	66.0
			August	88.1	49.5
Coot Bay 4	4 ft.	1960	April	95.7	73.9
			August	79.0	55.7
Coot Bay 5e	3 ft.	1960	April	95.5	73.5
			August	90.4	44.2
Whitewater Bay VII	5 ft.	1960	April	92.4	70.6
			May	90.0	75.2
			June	89.5	42.5
			August	84.2	36.8
Rocky Channel at Joe River	6 ft.	1960	April	84.8	55.4
			May	72.2	43.3
			June	88.7	35.8
			August	78.9	15.8

Although there may be turbid water throughout the region due to stormy weather and heavy runoff, there is a well established pattern of water clarity that remained consistent throughout the study period. Considering the transect from Flamingo, across Coot and Whitewater Bays and out the Shark River, water clarity is greatest at Whitewater Bay VII and least clear at Coot Bay and Shark River, the tidal portions of the estuary.

The high degree of water clarity in Whitewater Bay was a result of the occurence of algae, notably *Udotea wilsoni, Acetabularia crenulata, Batophora oerstedi,* and species of *Caulerpa* and *Gracilaria* (Tabb and Manning, 1961). Clarity of water improves in direct proportion to the spread of these plants and reaches a peak during periods of drought-induced high salinity.
In addition, high salinity waters have the property of precipitating organic material in a flocculent layer on the bottom. "Floc" deposits may reach considerable thickness in quiet bays having been observed as deep as 8 inches in

southeastern Whitewater Bay. This property of high salinity water to precipitate organics when combined with low sediment loads during dry seasons, quickly brought about clear water conditions. During drought periods when salinity rose to 30.0 to 40.0 ppt across Coot and Whitewater Bays, the bottom became clearly visible throughout the region.

Gross metabolism

Odum (1957) and Odum and Hoskin (1958) developed methods of studying gross metabolic activity within fresh and marine waters which allow large-scale comparisons to be made of total productivity of shallow waters. Their methods have been followed in the present study except that water samples were collected every two hours instead of every three hours.

Three stations, Coot Bay 3c, Coot Bay 5e and Whitewater Bay VII were used, since none of these areas were subjected to strong tidal intrusion that might bring in water from other areas with different oxygen characteristics. Vertical circulation was rapid and there was no vertical stratification. The

Table 9. Results of metabolism studies at three stations.

Station	Date	P	R	K	Temp. range in C°	Salin. range in ppt.	P/R
Coot Bay							
3c	July '58	7.50	14.10	1.59	29.8-31.8	13.2-14.7	.531
3c	Oct. '58	1.10	4.97	.96	23.0-26.5	15.6-18.1	.221
3c	Jan. '59	1.50	1.30	.18	16.0-19.0	18.9-23.0	1.150
3c	Apr. '59	2.44	4.68	.89	24.0-27.0	26.7-27.7	.521
Whitewater Bay VII	Apr. '59	8.22	7.03	.85	24.0-27.0	25.1-26.4	1.110
Coot Bay 5e	Jan. '59	.81	1.66	.44	15.0-18.0	18.1-20.5	.490

(P)—Photosynthesis; gm $O2/M^2$/day
(R)—Respiration; gm $O2/M^2$/day
(K)—Diffusion constant; gm $O2/M^2$/hour

values in gm. oxygen / M^2 / day for the three stations are given (Table 9). Diffusion constant is given in gm. / M^2 / hr. at 0 per cent saturation (K).

The values in Table 9 can be compared with those given by Odum and Hoskin (1958), and are reproduced in part in Table 10.

When the data on gross production (community metabolism and respiration) are compared with similar areas in Texas (Tables 9 and 10), it appears that the shallow bays in Everglades Park compare favorably in productivity, as indicated by average P/R ratio of .710 for Texas muddy bays, and .606 for Coot Bay. Perhaps the somewhat lower values for Coot and Whitewater Bays can be partly explained by the generally high turbidity in much of the area which limits the penetration of sunlight.

The high indicated productivity of Coot Bay during July is probably a result of maximum rate of growth of *Ruppia maritima,* the dominant plant at that time. In Whitewater Bay VII (Clearwater Pass) the indicated producer was the algae, *Udotea wilsoni* and a few associated *Gracilaria* species.

Several diurnal series of oxygen samples were collected and metabolism computations made that produced what seemed to be aberrant results. Local peculiarities of the water masses being tested may be responsible for these.

Tabb, *et al.*, (1959), and Tabb and Dubrow, (1962), contain the raw data from several 24 hour observations, not summarized here.

Table 10. Results of free water diurnal curve studies in shallow Texas bays having conditions similar to those in Coot and Whitewater Bays. (Reproduced in part from Odum and Hoskin, 1958.)

Systems with both plankton and bottom mud components	P	R	K	P/R
(Similar to Coot Bay)				
Cedar Bayou, July 22, 1957; salinity 24.6; 1.5 M deep	5.6	17.6	1.5	.318
Mesquite Bay, July 22, 1957; salinity 15.5; algal bottom, 1.2 M deep.	3.8	7.3	1.2	.520
Copano Bay, Aug. 18, 1957; salinity 11.8	2.1	6.2	0.7	.339
Copano Bay, Oct. 20, 1957	1.6	1.65	—	.970
Aransas Bay, Rockport Pier, May 19, 1957, 1 M deep, salinity 21.0	6.3	4.8	0.6	1.340
Aransas Bay, Rockport Pier, Oct. 20, 1957, 1.3 M deep, salinity 18.7	6.1	7.8	1.8	.781
Systems with dominant bottom plant and animal communities; plankton unimportant.	**P**	**R**	**K**	**P/R**
(Similar to Whitewater Bay VII)				
Laguna Madre, Texas, Mean, *Diplanthera*-ooze, 1957, annual curve.	4.3	5.6	0.2-1.4	.758
Redfish Bay, Port Aransas, Texas, *Thalassia* beds; Ransom Island, mean of 5 days in all seasons.	11.4	17.0	0.6-1.7	.670

Salinity

Salinity values within the study area undergo wide fluctuations in relation to rainfall and runoff. In most of Florida Bay east of Flamingo where tidal circulation is absent to negligible, evaporation is nearly as important in producing salinity variation as runoff. During the period of observation, salinity values were highest in Florida Bay, intermediate in most of Coot and Whitewater Bays, and lowest at and near the mouths of the rivers tributary to the region (Table 11).

Prior to the completion of Buttonwood Canal, the salinity gradient was established along the long axis of the Coot Bay-Whitewater Bay system, with lowest salinities in Coot and southeastern Whitewater Bays, and highest in the Shark River estuary. Since the opening of the canal the area has had a double gradient, draining and receiving saline water both from the Shark River and the Buttonwood Canal, so that lowest salinities are now found in central Whitewater Bay in the vicinity of Whitewater Bay Station V.

The hydrographic data collected during the nearly five years of the study are too extensive to be presented here and have been processed for distribution (Tabb, *et al.*, 1959; Tabb and Dubrow, 1962). Some of the data from stations representative of larger areas around them show the nature of fluctuations in salinity and the relationship of this to local rainfall (Figure 7).

The greatest variation in salinity conditions in the entire region was experienced by central and southeastern Whitewater Bay (Table 11). This was probably a result of the inability of the Shark River estuary to carry more than the runoff from its own channel during peaks of runoff. The severity of conditions in southeastern Whitewater Bay was further increased by the failure of the Shark River daily tides to intrude much beyond Clearwater Pass in the center and mid-Joe River along the southern margin. There also appears to be a natural drainage divide in the region of Clearwater Pass so that runoff from the Watson, North and Roberts Rivers runs in a southerly direction and thence out the Joe River-Little Shark River Channel. Apparently, this latter drainage is largely ineffective during years of heavy runoff in the Shark River, leading to accumulation of fresh-water.

Conditions typical of the estuarine portions of the study area are shown by Coot Bay Station 2 and Whitewater Bay Station XII (Figure 7). As expected, salinity values in the estuaries are much higher than in adjacent lagoons and are subject to short-term salinity fluctuations that quickly are erased by either the higher salt content of ocean water or, during periods of peak runoff, by river water. The offshore region of Florida Bay which we

Table 11. Long-term salinity characteristics of 10 stations along the salinity gradient during the period August, 1957, through May, 1962.

Station No.	No. monthly observations	Bottom salinity in ppt Lowest	Highest	Average	Long-term salinity as percentage seawater
Florida Bay 10	44	28.4	47.0	35.5	100.0%
Coot Bay 2	55	14.4	41.1	26.6	76.0%
Coot Bay 3c	65	8.0	41.1	25.3	72.2%
Coot Bay 5e	65	5.9	41.0	22.1	63.1%
Whitewater Bay I	55	4.0	40.0	18.7	53.4%
Whitewater Bay V	54	0.0	37.3	15.4	44.0%
Whitewater Bay VII	52	2.2	38.7	17.9	51.1%
North River VIIa	31	0.0	36.7	13.2	37.7%
East River	45	0.0	38.0	11.7	32.1%
Whitewater Bay XII	47	12.0	37.6	28.1	80.2%

studied is typified by Florida Bay Station X, located one mile south of Flamingo. The effects of heavy runoff during the rainy seasons was demonstrable there, but was of minor effect since waters of the nearby Gulf of Mexico intrude into the region as far east as Snake Bight.

Florida Bay waters ranged from slightly brackish to hypersaline conditions, but averaged close to 35.0 ppt. During the period of observation, salinity values ranged between 26.0 and 47.0 ppt. A high salinity of 70.0 ppt was observed by Finucane and Dragovich (1959) during the drought period of 1955-56. These authors found salinities above 40.0 ppt during 7 months of the year 1956 in the region from East Cape Sable to Joe Kemp Key. Additional salinity data from the East Cape Sable area has been reported by Goodell and Gorsline (1961).

There was an abrupt salinity gradient between East Cape Sable and Joe Kemp Key created by the rapidly diminishing tidal exchange (Table 12). During dry seasons, the highest values were normally found east of Florida Bay Station 10, in the area of high evaporation and minimum exchange with offshore waters. During wet years the reverse was true, with marine salinity

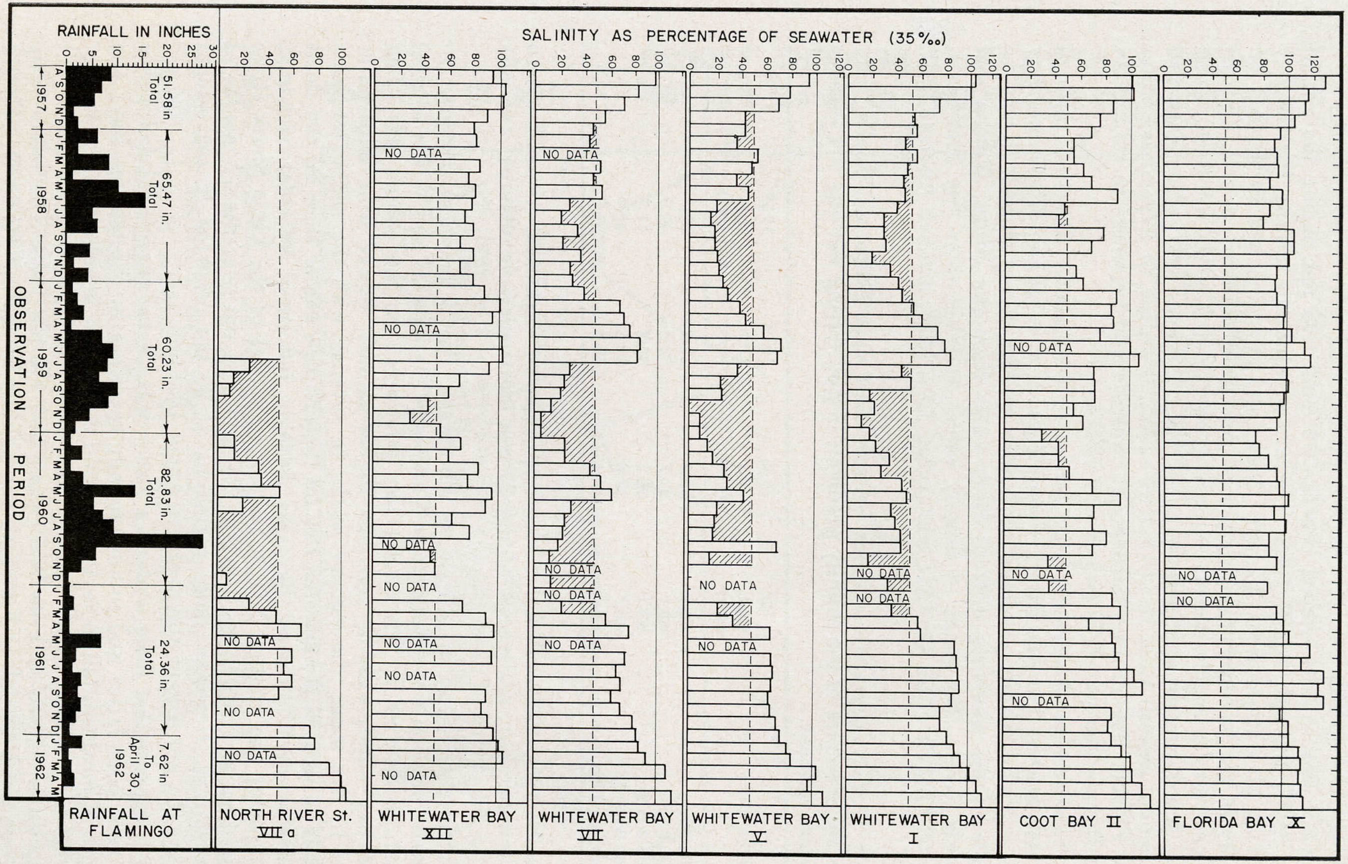


Figure 7. Monthly average salinity as percentage of seawater (35.0 ppt) at 7 representative stations along the salinity gradient and monthly rainfall at Cape Sable. Shaded portion indicates months when salinity fell below 17.5 ppt or 50 per cent of seawater.

being found west of Station 10. The sharp constriction of Joe Kemp Channel caused an abrupt increase in gradient during dry periods by slowing tidal intrusion and mixing.

Coot Bay salinity ranged between 5.9 and 40.5 ppt during the period July, 1957, through April, 1962. The average bottom salinity for the bay based on all stations was 23.7 ppt. Daily tidal intrusion had little effect on salinity of the bay except during periods of strong southerly winds. Diurnal changes were normally detectable only at the Coot Bay end of Buttonwood Canal, but during drought periods, as in 1961-62, the salinity wedge penetrated throughout eastern Coot Bay. The twice-daily intrusion of hypersaline water from Florida Bay during the drought caused rapid increases in salinity of Coot Bay and eastern Whitewater Bay (Figure 7).

Southeastern Whitewater Bay drains in a southerly direction through channels leading into Joe River (Frontpiece). In this region, Whitewater Bay Station V consistantly produced the lowest salinity values since it lies in the middle of the southerly drift of fresh water from the North, Watson and Roberts Rivers. The range of salinity values at Whitewater Bay Stations I, III and East River for the four year period July, 1957, through August, 1961,

Table 12. Hydrographic stations between East Cape Sable and Snake Bight showing examples of the salinity gradient, in ppt, during wet and dry seasons (surface values).

Station	1957 Sept. (dry)	1958 July (wet)	1959 Oct. (wet)	1959 Jun. (dry)	1959 Dec. (wet)
Florida Bay 4	43.1	36.2	32.2	38.7	26.1
Florida Bay 6	43.1	30.7	38.3	40.9	27.1
Florida Bay 8	43.1	30.1	36.2	41.9	26.7
Florida Bay 10	44.7	27.8	35.6	42.4	26.1
Florida Bay 10A	46.0	26.1	19.6	44.0	23.8

were 9.5-27.7, 10.1-22.5 and 5.0-20.0 ppt. respectively. Most of southeastern Whitewater Bay underwent about 20 ppt fluctuation in salinity annually during the period of observation.

Diurnal change in salinity at Whitewater Bay I averaged 5.0 ppt. No diurnal variation was detectable at Whitewater Stations III and V. The diurnal variation observed at Whitewater Bay I occurred on the ebbing tide when Coot Bay water, with its generally higher salinity, flowed into Whitewater Bay. In this sense, the estuary works in reverse, with the saline intrusion coming in eastern Whitewater Bay on the ebb tide rather than on the flood tide. Western Whitewater Bay was strongly influenced by tidal exchange. Whitewater Bay Station XII in the main channel of the Little Shark River showed salinity variations between 12.0 and 37.6 ppt over the 47 months of observations. However, daily variations of 20 ppt occurred in the estuary during the wet season and averaged about 10.0 ppt.

It appears that there is about a 2 month lag between peak rainfall within the park boundaries and minimum salinity values in Whitewater Bay. The failure of local rainfall to register a rapid depression in salinity suggests that normal local rainfall is not an important factor in regulating the salinity of large water masses such as Whitewater and Florida Bays. The relationship between local rainfall at Flamingo and salinity is shown (Figure 7). Runoff from the watershed north of the Tamiami Trail appears to be of major importance in controlling long-term salinities and in prolonging the periods of low salt content in the area of highest evaporation.

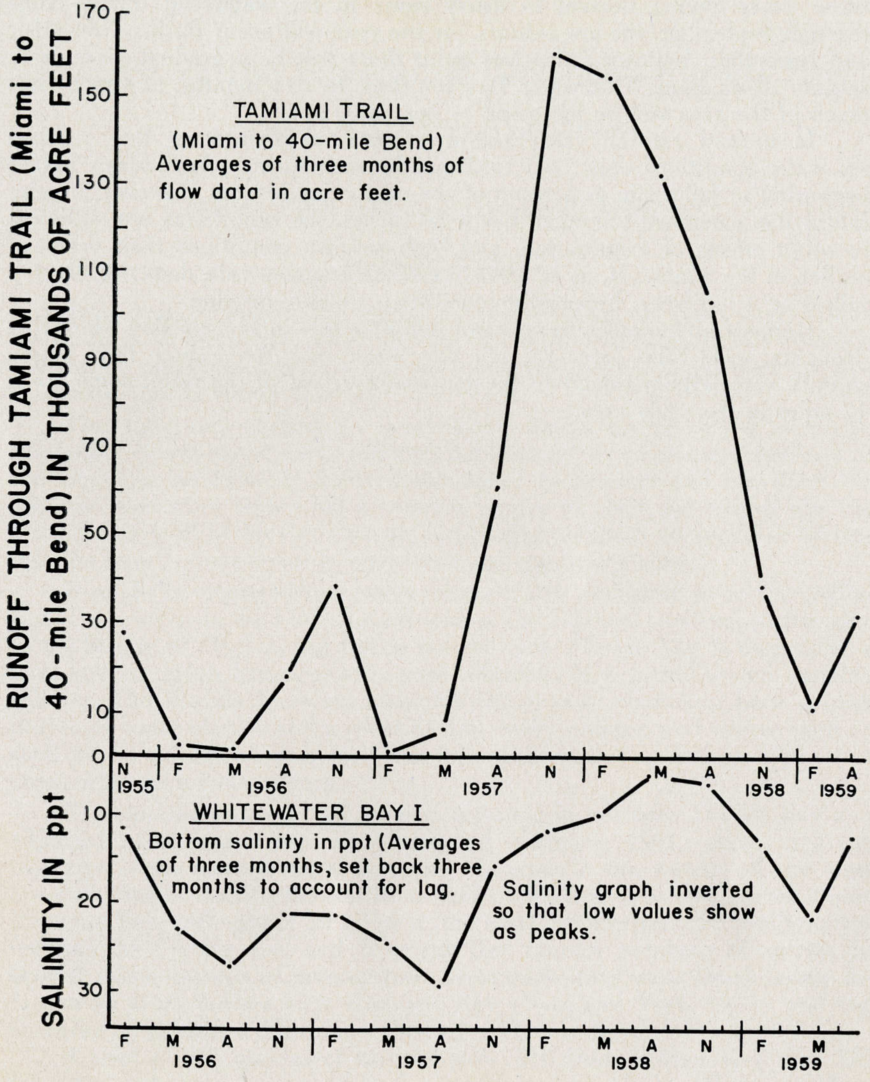


Figure 8. Runoff from the Everglades drainage basin measured in acre feet at the Tamiami Trail (points on the curve equal averages of three months flow along the 40 mile section of road where measurements are taken), compared with salinity values in southeastern Whitewater Bay (curve inverted to show low salinity values as peaks corresponding with peaks of runoff). Points on the salinity curve are also averages of three months of data.

The relationship between salinity in Whitewater Bay and runoff from the watershed, measured along the eastern 40 miles of the Tamiami Trail at a series of culverts, is shown (Figure 8). There is a close relationship if the salinity curve is moved back three months. Thus there is apparently a three month lag between the time that peak flow crosses the Tamiami Trail and the period of lowest salinity in Whitewater Bay. This suggests that at least during those years having normal to heavy rains in the watershed during June through September, the low salinity for the year will occur during November and December. Following this low point there will be a gradual increase in salinity throughout Whitewater Bay for three to five months, at which time much of the area will be increased to near 35.0 ppt.

In normal rainfall years salinity values in Whitewater Bay reached sea water conditions only for 1 to 2 months each spring (April-May) before beginning to fall again as a result of the next rainy season. However, if rainfall in the watershed fell much below 50 inches, the runoff was not sufficient to offset effects of evaporation, and high salinity conditions then occurred earlier in the winter. If, as in 1962, the normal spring rain does not develop following a dry year, hypersaline conditions quickly develop.

High salinity conditions are always most severe in Florida Bay. If, during droughts, wind tides force Florida Bay water into Whitewater Bay, hypersalinity can develop inland to the maximum extent of the tides, some 10 to 12 miles in the study area.

PART II

Aspects of the Biology of Northern Florida Bay and Adjacent Estuaries

by

Durbin C. Tabb and Raymond B. Manning

INTRODUCTION

This paper presents the results of observations on plant and animal distribution in relation to some aspects of the environment, chiefly salinity, substratum and temperature. Other environmental factors considered are dissolved oxygen, turbidity and pH.

The study area (Figure 1) is admirably suited for ecological investigations since it consists of many different habitats, all of which are reflections of the long-term relationship between mixing of fresh-water and sea water. In addition, the entire region has a common source of plant and animal life, the Florida Bay-Gulf of Mexico littoral, and these organisms encroach or retreat into the bays and estuaries as environmental conditions change.

It might be expected that many of the plants and animals of the region would also occur in the Florida Keys and on the adjacent shelf out to the edge of the Straits of Florida, but this is not the case. Florida Bay is essentially a level bottom region having muddy sand substrate, high turbidity and variable salinity. The Florida Keys are essentially marine in character, have a high degree of water clarity, and a great deal of rocky outcrop and coarse sand or shell gravel substratum material. The flora and fauna populations of the two areas differ as a consequence.

Examination of the list of animals collected in northern Florida Bay and adjacent estuaries and lagoons (Tabb and Manning, 1961) shows that the majority of the species there are more common in the waters off the west coast of Florida and in the northern Gulf of Mexico then they are in lower Biscayne Bay, only about 50 miles to the east. To illustrate the dissimilarity between the Florida Bay and Biscayne Bay faunas, numbers of species in several major groups of invertebrates from each area were listed, using information from Soldier Key, Biscayne Bay (Voss and Voss, 1955) and the checklist of Tabb and Manning (1961) for Florida Bay.

A total of 355 species of invertebrates, 116 from Soldier Key and 239 from the study area, were used in the comparison (Table 1). Of this number, 15 species, or 4.2 per cent of the total, were found in both areas. Both lists are certainly incomplete, but the proportion of common species among the total occurring is probably in the right order of magnitude.

The invertebrate fauna of the Florida Keys and adjacent shallow waters to the east is largely derived from the Antillean faunal province. On the other hand, the invertebrates of Florida Bay and adjacent estuaries and lagoons are closely allied to and in many instances, duplicated by species found further north to Texas on the Gulf Coast and North Carolina on the southeast coast. Lists of invertebrates useful in examining this problem are those by Wass (1955) and Holthuis (1951, 1952) from northwest Florida; Parker (1959,

1960) and Gunter (1950) from the Texas coast and Hay and Shore (1918) at Beaufort, North Carolina. These papers indicate that the invertebrate fauna of Florida Bay is largely composed of temperate climate species typical of

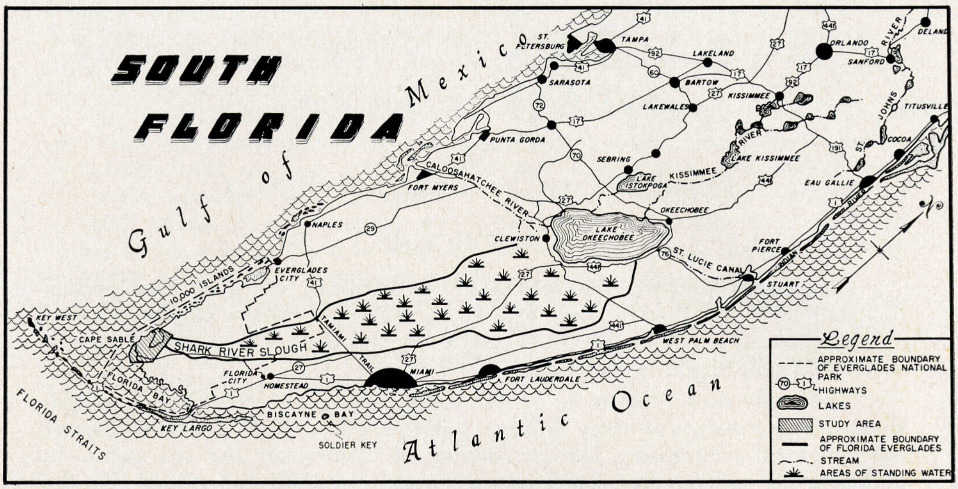


Figure 1. Aerial oblique representation of southern Florida showing the relation of the study area to the Everglades, the Gulf of Mexico and the Florida Keys.

Table 1. Numbers of invertebrates of various major groups listed from Soldier Key and Florida Bay, showing the number of species in each category and numbers of species shared by both areas.

Organisms	Soldier Key	Florida Bay	No. species shared by both areas
Sponges	10	13	1
Seafans and seawhips	7	3	—
Polychaete worms	12	7	—
Starfish	3	3	1
Brittlestars	7	9	—
Sea cucumbers	2	1	1
Chitons	2	2	—
Gastropods	35	68	7
Bivalves	13	59	1
Cephalopods	3	1	1
Barnacles	3	3	—
Shrimp and prawns*	2	33	2
Hermit and porcellanid crabs*	2	10	1
Grapsoid crabs (running crabs)	2	7	—
Spider and masking crabs	4	6	—
Swimming and mud crabs	8	12	—
Mantis shrimp	1	2	—
TOTAL	116	239	15

*Not thoroughly sampled at Soldier Key.

the Carolinian and Northern Gulf of Mexico faunal provinces although there were elements of the Antillean fauna in the area.

This makes it possible to apply some of the ecological information from the present study to most of the shallow estuaries, bays and lagoons of the Gulf of Mexico and southeastern United States.

METHODS

Collections of animals and plants were made in as many different environmental situations as possible, including the borders of the xerophytic marl prairies of Cape Sable. Collecting gears were adapted to the environment and included van Veen bottom grab, small-mesh beach seines, pushnets, fish poisons, night-light dipnetting, small-mesh channel nets, and otter trawls. Hand collecting was used in certain intertidal areas.

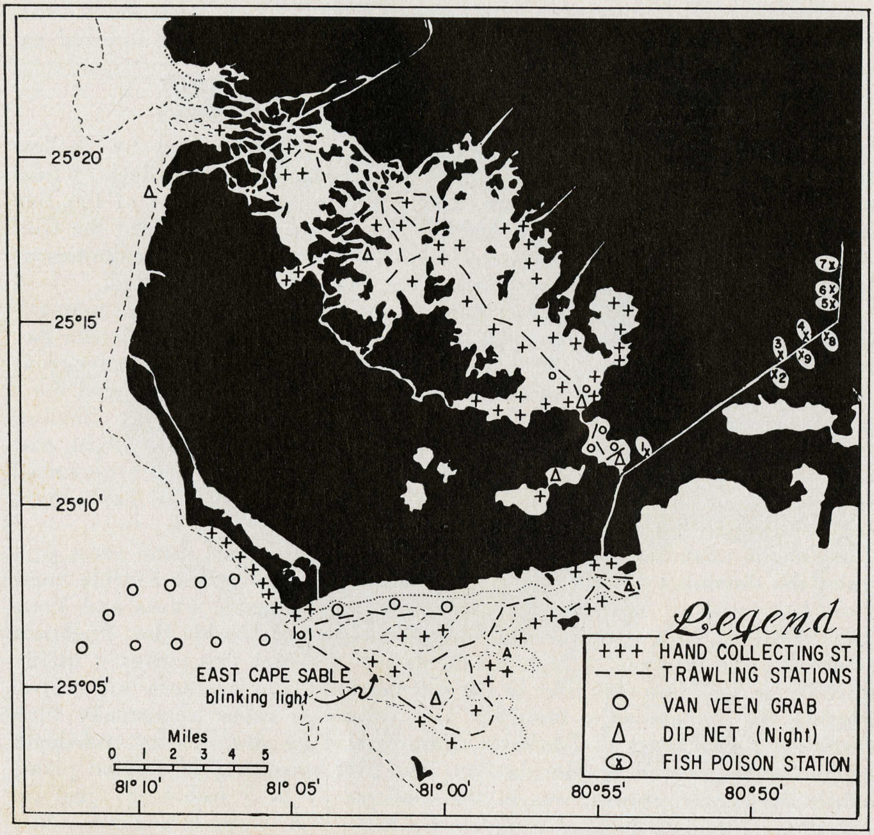


Figure 2. Diagram of the study area with locations of the major collecting stations and gear or methods utilized.

The small otter trawls called "try nets," commonly sold by dealers in commercial shrimp fishing equipment were modified by the addition of a one-half inch stretched mesh liner and constituted the basic collecting tool. The trawl operated efficiently for only about five minutes in the heavily vegetated areas of the estuary and this became the standard time for hauling this gear. Under towing speeds of 3-4 mph such nets span approximately 2 meters.

Trawl catches were made over most of the level bottoms of the region, adjacent to the hydrographic sampling stations (Figure 2). (Hydrographic data are reported in Part I of this paper.)

Several species of common animals in the bays and estuaries would rarely be collected except by night-light and dipnet. These animals include the worm eels, *Ahlia egmontis* and *Myrophis punctatus*, searobins, *Prionotus scitulus* and *P. tribulus*. Many species including inshore polychaete worms and the pink shrimp, *Penaeus duorarum*, bury in the bottom by day and move about freely on the surface at night. Therefore, it is important that night-light collecting using channel nets and dipnets be used in studies on abundance and distribution of estuarine animals.

Samples were collected monthly from July, 1957 to September, 1961. Occasional samples were collected after the latter month when unusual environmental conditions occured.

FLORA AND FAUNA OF OFFSHORE REGIONS

The northern Florida Bay environment is characterized by shallow waters, high turbidity, and high salinity due to evaporation and lack of tidal circulation. This is especially true of the northeastern portions of the Bay between the upper Florida Keys and Flamingo, and less so toward the Gulf of Mexico, although Finucane and Dragovich (1959) recorded salinities as high as 70 ppt just off Flamingo during the 1955-56 drought period.

Several more or less distinct habitats depending on the gross composition of the substratum were evident in the small part of northern Florida Bay studied (Figure 3). Above the high tide level the marl prairie and mangrove forest extend northward from the shore of Florida Bay to the flooded mangrove and marsh areas lining the south shore of Whitewater Bay. Shallow marl flats, extending up to a mile offshore, are found from Snake Bight, east of Flamingo, to the sandy beaches of Cape Sable. These are most pronounced in Snake Bight and from there to Flamingo, where large spoil banks have been built up at the mouth of the Buttonwood Canal

On the offshore marl banks, *Thalassia testudinum*, the turtle grass provides the dominant cover. This grass is widespread along the Florida coast from just north of Miami to the northern Gulf of Mexico (Voss and Voss, 1955; Phillips, 1960) and is found throughout most of Florida Bay. *Thalassia* is able to live in areas of high sedimentation, a factor that makes it highly effective as a bottom stabilizer in the soft marl muds of northern and central Florida Bay, where wind scouring may otherwise cause abnormally high turbidities. Two types of *Thalassia* characterized by size, density and depth range, were observed in Florida Bay. The first consisting of stunted plants exhibiting sparse growth, was in the shallows (1 to 3 feet deep) just off Flamingo, where turbidities were always high, and where few plants other than *Thalassia* were found. The second kind of *Thalassia*, with taller plants and uniformly heavy density, was found in the relatively clear waters of Sandy Key Basin about six miles south of East Cape Sable. The probable reasons for the difference in *Thalassia* growth and the distribution of other marine plants in the two types of environment are discussed in the section on salinities. Sandy Key and areas south and east of there are essentially marine with stable high salinities and good water exchange with the open Gulf of Mexico. East of Flamingo, however, the salinity gradient fluctuates widely, from about 25 ppt to 45 ppt with each change from wet to dry season. In the latter area *Thalassia* and many algae, mostly *Caulerpa* and *Gracilaria* species, were found during September through December, 1957, at the end of a prolonged drought. With the marked reduction in average salinity beginning in the winter of 1957 and ending in 1960, the *Thalassia* underwent a decline in size and abundance and the algae almost completely disappeared.

They did not return in abundance until the drought of 1961-62, reaching peak growth and coverage in the spring of 1962. Thus it appears that long periods of near or slightly above normal salinities are a requirement for maximum growth of *Thalassia* and most of the green algae species.

In some places, notably off East Cape Sable, and in Conchie Channel running east and west for a short distance across Florida Bay (Figure 3) the grass flats are replaced by hard shell sand bottom, where species of green algae, *Caulerpa,* and sponges and bryozoans replace the grass as the dominant cover. Each of these environments supports its characteristic fauna and flora.

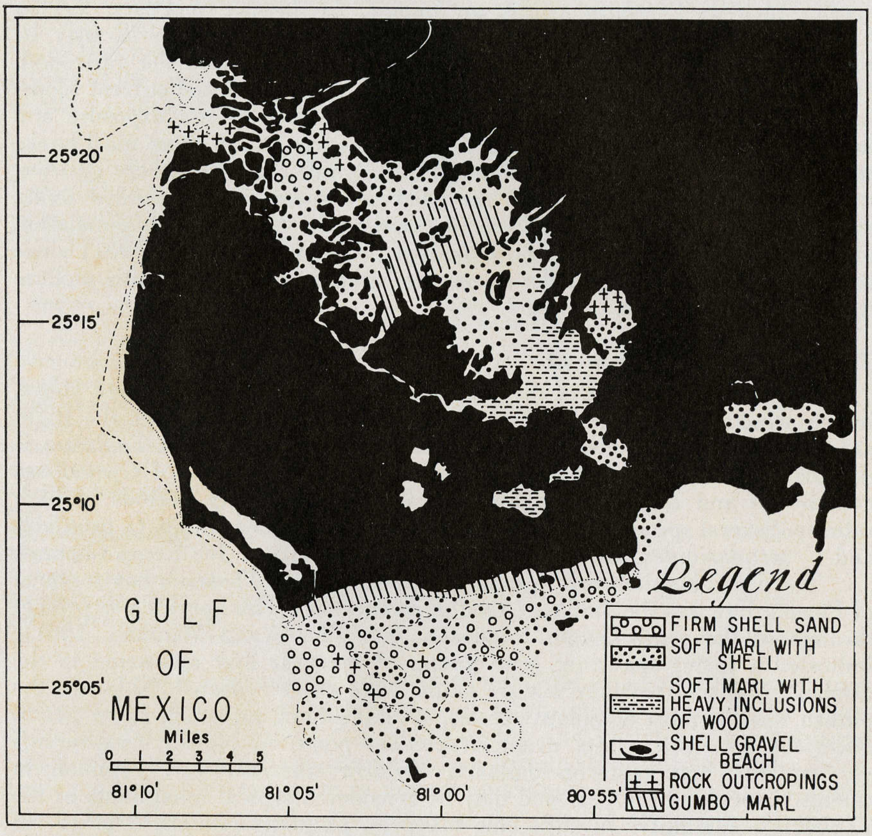


Figure 3. Diagram of the study area showing gross composition of major substratum types.

Inshore marl banks and supratidal marl prairies

Few invertebrate species can tolerate the range of environmental conditions found on the barren marl prairie that lies south of Whitewater Bay, and extends from Flamingo to Cape Sable. Two fiddler crabs, *Uca rapax* and *Uca pugilator,* and the pulmonate gastropod, *Melampus coffeus,* are the dominant species there. Along the exposed banks of the Buttonwood Canal between Flamingo and Coot Bay the fiddler crabs occur in localized areas, but where salinities are lower, along most of the northern two thirds of the canal, they are replaced by the isopod, *Ligia baudiniana.* Intertidally, at the edge of Florida Bay, the fiddler crabs are dominant, but other species, principally xanthid crabs such as *Eurytium limosum* and *Panopeus herbstii,* are common. Clumps of small mussels, *Brachidontes recurvus,* attach under any hard surface, and the mangrove crab, *Aratus pisonii,* and the porcellanid crab, *Petrolisthes armatus,* are found under rock and driftwood along the shore. The barnacle, *Balanus amphitrite niveus,* is also found commonly on solid wood or cement structures.

Immediately offshore the submerged to intertidal marl flats and spoil banks support a characteristic but reduced fauna. Here small burrowing species such as *Cyathura polita,* an isopod, the bivalve molluscs, *Tellina lineata, T. versicolor,* and the paper mussel, *Amygdalum papyria,* may be found, in addition to small fiddler crabs, *Uca speciosa,* and the gastropod, *Melongena corona.* These flats receive agitation from wind and current scouring during high tide periods, and are subject to intense sun exposure and heat during low tides. There is practically no vegetation on these marl banks with the exception of scattered plants of the chenille alga, *Batophora oestedii,* that finds attachment surface on the dead and sometimes on eroded living shells of the crown conch, *Melongena corona.* The crown conch population of the intertidal marl flats has been studied (Tabb and Manning, 1961) since there were three distinctly different morphological populations of this mollusc within the survey area.

Turtle grass environment

A general description of the *Thalassia* flat environment was given above, in the account of the Florida Bay environment. The Joe Kemp-Snake Bight area is located immediately south and east of Flamingo. There *Thalassia* is dominant at all times but the area may have small patches of *Cymodocea manatorum* and *Halophila engelmanni,* intermixed during periods of high salinity. Several species of the green alga *Caulerpa, C. crassifolia, C. prolifera,* and *C. sertularioides,* are common in the deeper parts of Joe Kemp Channel.

The most abundant fish in samples collected in the *Thalassia* environment of Florida Bay was the pinfish, *Lagodon rhomboides.* This species was present throughout the year. Length frequency data (Tabb and Manning, 1961), indicated a spring spawning, with young of the year first appearing in the catches in March. Sexually mature adults were never collected. Although the pinfish was the most abundant species, several others, including silver perch, *Bairdiella chrysura,* white grunt, *Haemulon plumieri,* pigfish, *Orthopristis chrysopterus,* and yellowfin mojarra, *Mojarra cinereus,* were common in catches throughout the year and may be considered typical inhabitants of the *Thalassia* community. Juvenile lane snappers, *Lutjanus synagis,* 2 to 15 cm in length, were abundant when salinities were higher than 30 ppt.

Caridean shrimp were always abundant in the samples from the *Thalassia* beds, although the *"Cyprinodontes-Palaemonetes"* community mentioned by Hedgpeth (1953) was not observed. In the Florida Bay turtle grass flats it is replaced by a similar assemblage dominated by the pinfish and three species of caridean shrimp, the palaemonids, *Periclimenes longicaudatus* and *P. americanus,* and a hippolytid,*Tozeuma carolinensis. Tozeuma* was abundant and apparently spawns throughout the year. Several other species of caridean shrimps, including *Thor floridanus, Hippolyte pleuracantha* and *Alpheus normanni,* as well as the juvenile stages of pink shrimp, *Penaeus duorarum,* are normal inhabitants of the turtle grass flats. Other common crustaceans are xanthid crabs, *Neopanope packardii, Pilumnus lacteus,* and juvenile stone crabs, *Menippe mercenaria.* Two spider crabs, *Libinia dubia* and *Metoporhaphis calcarata,* and the hermit crab, *Pagurus annulipes,* were occasionally collected. The hermit crabs were especially abundant in areas where gastropod molluscs of the genera *Modulus* and *Cerithium* were common, the dead shells of which provide the shelter for this small white hermit crab. Many molluscs are found under or on *Thalassia.* The ornate variety of *Chione cancellata,* with extensive leaf-like ribs, lives in the soft muds among the *Thalassia* rhizomes. *Cardita floridana* is the dominant attached bivalve, and two species of the genus *Anachis,* known to collectors as dove shells, are the dominant gastropods. These are *Anachis avara* and *A. obesa. Modulus modulus* is also a common species, at times occuring in dense colonies. The spotted slipper shell, *Crepidula convexa,* may become a fouling pest to other molluscs, restricting movement of the host mollusc, during periods of high salinity. The two common representatives of the genus *Cerithium* in the grass flats off Flamingo are the flyspecked cerith, *Cerithium muscarum,* and *C. eburneum.*

Table 2. Numbers of shrimp and fish captured in trawl samples from Joe Kemp Channel and Sandy Key Basin in Florida Bay, April, 1959, a period when salinity values were near that of normal seawater in both areas.

Species	Joe Kemp Channel Catch from 5 trawl hauls. Bottom salinity 36.5 ppt	Sandy Key Basin Catch from 4 trawl hauls. Bottom salinity 37.2 ppt
Crustaceans		
Periclimenes longicaudatus	36	25
Tozeuma carolinensis	20	22
Hippolyte pleauracantha	7	129
Leander paulensis	7	10
Thor floridanus	5	12
Latreutes fucorum	4	8
Fish		
Lagodon rhomboides	28	115
Gerres cinereus	11	3
Lutjanus synagris	9	6
Bairdiella chrysura	2	14
Orthopristis chrysopterus	3	11

All of these species are found in Sandy Key Basin where the habitat provided by *Thalassia* is supplemented by large clumps of bushy red algae, including *Dasya pedicellata, Laurencia poitei,* and *Acanthophora spicifera,* which afford shelter for abundant caridean shrimp. Most of the species listed from Joe Kemp Channel occur in greater abundance in the deep waters of the Sandy Key Basin area. An indication of the relative abundance of several species of caridean shrimp and fish from the two areas is shown in Table 2.

Among the carideans, *Hippolyte pleuracantha, Thor floridanus,* and *Latreutes fucorum* usually occur in greater numbers in Sandy Key Basin, probably because of the protection afforded by the bushy algae. Among the molluscs several species apparently prefer the clearer water; such species are the bay scallop, *Aequipecten irridians,* and the turban shell, *Turbo castaneus.* Isolated colonies made up almost exclusively of the latter species occur in the basin. Large numbers of scallops in spawning condition were collected in October, 1958. Many of these contained the "oyster" or "pea crab", *Pinnotheres maculatus.*

The pinfish was the dominant species in catches in Sandy Key Basin where they were slightly larger on the average than those of Joe Kemp Channel.

Several animals collected in Sandy Key Basin were caught only there and it is believed that they are restricted in their eastward distribution by the high turbidities and lower average salinities found in the Flamingo area during years of heavy runoff. Among these are the caridean shrimp, *Latreutes parvulus* and *Processa canaliculata,* the spider crab, *Podochela riisei,* the blue croaker, *Vacuoqua sialis,* the butter hamlet, *Hypoplectrus unicolor,* the jackknife fish, *Equetes lanceolatus,* the marbled blenny, *Paraclinus marmoratus,* and the seaweed blenny, *Blennius marmoreus.*

Hard shell sand bottom

There was a considerable reduction in the numbers of benthic species, both animal and plant, in the sand and rock outcrop areas of the tidal channels south and east of East Cape Sable. *Thalassia* was present, but in small quantities, and it was widely scattered. Sponges, bryozoans and brittlestars were the dominant organisms found in this habitat.

Conchie Channel is a deep tidal channel running parallel to the shore about two miles southwest of Flamingo. It drains basin areas to the east and south of Sandy Key. The bottom of the channel is hard packed shell, sand and gravel, with scattered outcrops of oolitic limestone (Figure 3). Although benthic animals living on this bottom are few, swimming forms, both fish and invertebrate, are numerous. Some of the common benthic animals found there were the drills, *Eupleura caudata,* turret shells, *Crassispira ebenina, C. ostrearum, Cerodrillia thea, C. perryae* and *Monilispira albinodonta.* Dove shells of the genera *Anachis* and *Columbella* were found along the fringes of the adjacent *Thalassia* flats. A robust, finely cancellate and sparsely scaled form of the bivalve, *Chione cancellata,* was apparently the most abundant large bivalve mollusc of the shell sand. Crustaceans were less abundant, particularly the carideans, but xanthid crabs, including *Pilumnus lacteus, Neopanope packardii,* and juvenile stone crabs, *Menippe mercenaria,* were very common in this area. The hermit crabs, *Pagurus pollicaris* and *Pagurus floridanus,* were uncommon and occurred only in the sandy bottoms of the channel. Since the channel is bounded by *Thalassia,* its fauna overlaps with that of the hard shell sand bottoms. As the channel approaches East Cape Sable, a sponge and brittlestar community completely replaced the *Thalassia* fringe fauna that mixed with the fauna of the channel further east.

Two species of brittlestars formed the dominant element of the bottom adjacent to East Cape Sable. *Ophiolepis elegans* was the most abundant; over 1,000 were taken in a single five minute trawl drag in March, 1959. *Ophioderma brevispinum* was also found in the same area but in lesser numbers. Table 3 gives numbers of animals per trawl drag for 11 separate drags, 5 during the spring peak of abundance and 6 during the fall period of least abundance, in the area between the East Cape navigation light and the shore at East Cape Sable (Figure 2).

Ophiolepis elegans was most abundant in deeper water south and east of Cape Sable on firm shell sand, while *Ophioderma brevispinum* was more abundant in softer and somewhat coarser shell sand and gravel just off the beach at East Cape Sable. Both species diminished rapidly in numbers in an easterly direction from East Cape Sable where soft mud intergrades with the preferred shell bottom.

Only a few other species of invertebrate animals were collected in the brittlestar beds. Among these were the triangle crab, *Heterocrypta granulata,* the rare anomuran, *Euceramus praelongus,* and several species of molluscs, including the gastropods, *Murex cellosus, M. florifer,* the cones, *Conus* *jaspideus* and *C. stearnsi,* and the bivalves, *Tellina similis, T. punicea, Semele proficua,* and *Tellidora christata.* The latter, a fragile species, was apparently most abundant where the mud and hard sand bottoms intergrade just east of East Cape. Sponges were abundant on the hard bottoms between East Cape Sable and Sandy Key, but few alcyonarians were found. One species, *Eugorgia* (formerly *Leptogorgia) virgulata* was taken twice in sponge collections. This species was cited by Bayer (1952) as a Florida disjunct species, occurring on the Florida west coast but not in east Florida, although its range is Gulf of Mexico to New York.

Table 3. Sizes and numbers of two species of brittlestars taken in otter trawl from the hard shell sand bottoms off East Cape Sable during November, 1958 and March 1959, periods of normal low and high population density. Trawling time 5 minutes per drag.

Drag No.	*Ophiolepis elegans*		*Ophioderma brevispinum*		Trawling location
	No.	Range of disc diameter mm	No.	Range of disc diameter mm	
			March, 1959		
1	146	4.3-12.6	39	5.0-11.7	Around blinker
2	1020	3.0-15.0	370	5.0-11.0	Blinker to East Cape Sable Beach
3	551	2.9-11.4	65	5.2-11.4	Southwest of East Cape Sable (200 yards)
4	169	3.7-9.9	19	6.0-9.4	Parallel to south face East Cape Sable
5	3	11.8-14.6	14	7.3-13.9	East to west off Slagle Ditch
			November, 1958		
1	66	4.7-10.6	46	4.8-10.4	Around blinker
2	33	5.2-13.5	24	6.8-12.8	Blinker to East Cape Sable Beach
3	10	5.7-11.7	2	9.2-10.8	Southwest of East Cape Sable (200 yards)
4	3	5.0-10.4	6	9.4-12.9	Parallel to south face East Cape Sable
5	0	——	2	9.8-11.5	East to west off Slagle Ditch
6	0	——	1	12.4	

The beach drift at East Cape Sable is evidently derived mainly from remains of the shelf fauna of the Gulf of Mexico beyond the depth ranges studied by us, and is virtually the same as that found on the west coast beaches of Marco and Sanibel Islands, Collier County, Florida. The major share of the beach drift material is apparently a result of mortality caused by prolonged westerly winds of winter that cause extensive kills on the coastal shelf of southwest Florida.

East of East Cape Sable, along the shore and parallel to it there is a shallow channel with soft mud buttom. This channel receives much of the turbid tidal drainage from Lake Ingraham and adjacent marl prairies through East Cape Canal. A localized high salinity community dominated by the branching bryozoan, *Stylopoma informata,* was found there. In this area of transition between the soft muds and hard sands further offshore animals characteristic to both areas are found, including small numbers of brittle-stars, *Ophioderma* and *Ophiolepis*. In addition the soft bottoms had numbers of starfish, *Echinaster sentus*, molluscs, *Chione cancellata* and *Calliostoma jujubinum*, the crustaceans, *Menippe mercenaria*, *Pagurus annulipes* and *P. pollicaris*, and blue crabs, *Callinectes sapidus*. Fishes were abundant in this area, including large red drum, *Sciaenops ocellata*, black drum, *Pogonias cromis*, tarpon, *Megalops atlantica*, and both species of marine catfish, *Bagre marinus* and *Galeichthys felis*. In addition, most of the Atlantic croakers, *Micropogon undulatus*, and kingfish, *Menticirrhus littoralis*, were taken in this rich feeding area. The most abundant fish in the catches from the Slagle Ditch — East Cape Canal region was the striped anchovy, *Anchoa hepsetus*. Pinfish, the most abundant species in the *Thalassia* flat areas, were seldom taken. The majority of brief squid, *Lolliguncula brevis*, were taken from the region just east of East Cape Sable.

BAY AND ESTUARINE ENVIRONMENTS

The inshore environment provided by Coot and Whitewater Bays was characterized by shallow waters, salinities normally below those found in Florida Bay (Figure 4) and a reduction in numbers of species when compared with Florida Bay. The bottom materials of the inshore bays vary, but is made up mainly of fine marl mud and shell sand, with locally heavy inclusions of massive peaty material and coarse wood fragments, particularly off the mouths of the rivers and along the mangrove shorelines. In the deep tidal channels of western Whitewater Bay tidal action has scoured the bottom to bedrock. Figure 3 suggests the complexity of the mangrove islands and the maze of channels that criss-cross the area. The only intertidal surfaces in this region are those of the mangrove prop roots. Several distinct biological assemblages may be found in the inshore area, but two of these, the benthic mud community and the mangrove community, are dominant.

Brackish-water assemblages

Submerged vegetation in the bays was, in general, less abundant than in nearby Florida Bay. Only two aquatic phanerogams, *Diplanthera wrightii* and *Ruppia maritima*, have been collected in the brackish bays. These were most abundant in Coot Bay and along the northeastern quadrant of Whitewater Bay. *Ruppia* grows most luxuriantly and flowers in the spring; *Diplanthera* replaced *Ruppia* in the winter dry season. In July, 1957, after a severe drought period, and prior to the opening of Buttonwood Canal with its attendant high turbidity, Coot Bay water was clear so that the bottom was easily visible. Salinities at that time were high (Figure 4) and *Diplanthera* was luxuriant and widely distributed. The area at that time contained an invertebrate fauna with many marine representatives (Table 4). After the opening of the Buttonwood Canal turbidity increased and salinity values decreased through 1958, 1959 and 1960. The low salinity resulted in a constant increase in abundance of *Ruppia* and an almost total decline of *Diplanthera*. By December, 1960, *Diplanthera* had all but disappeared from Coot and Whitewater Bays and the fauna associated with it had also gone. During such periods of low salinity, in the quieter northwest quadrants of Coot Bay and Whitewater Bay, the chara, *Chara hornemannii*, common to the fresh-water ponds of the saw-grass marshes of the Everglades, flourished in a dense mat to 2 feet thick. *Chara* was collected in all areas of northern

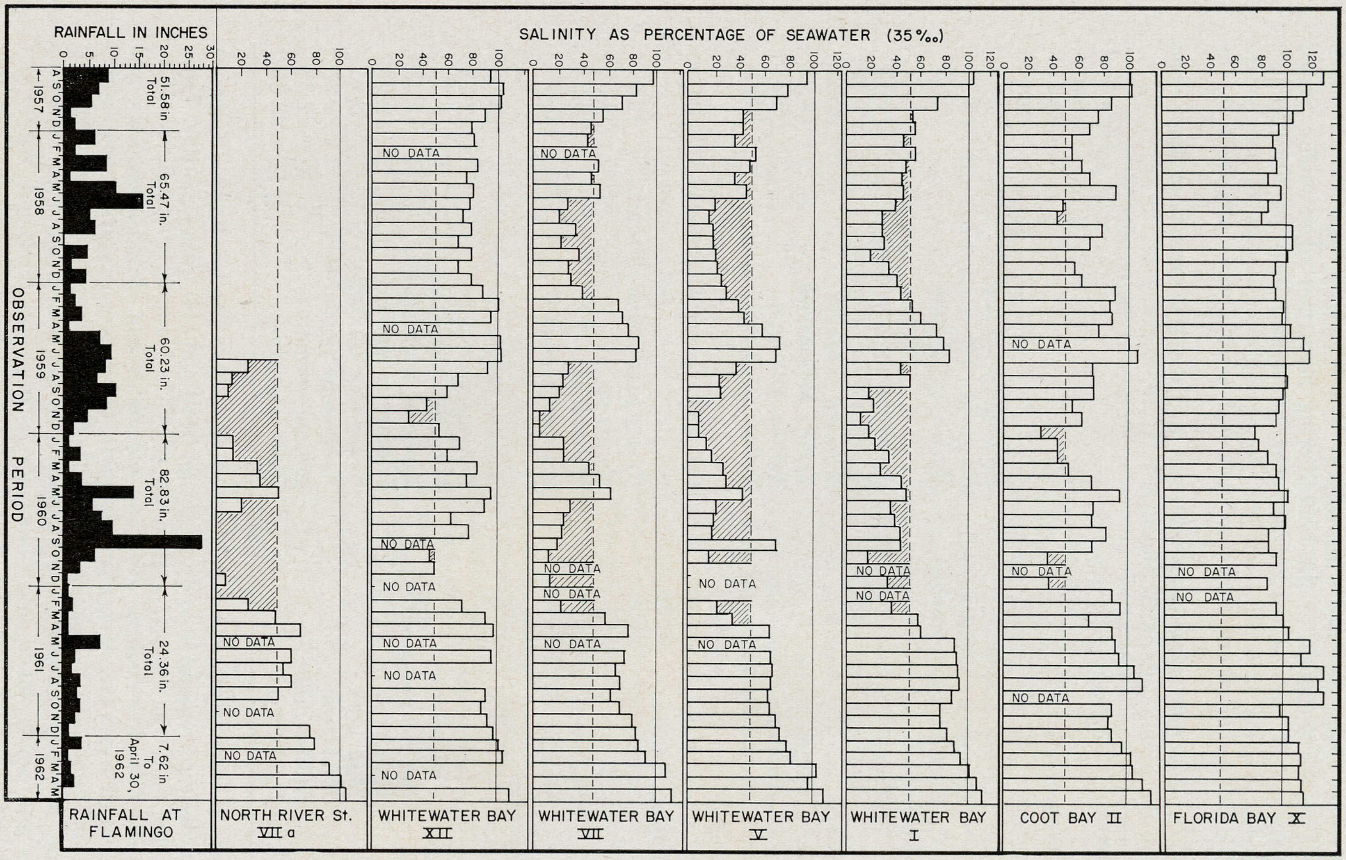


Figure 4. Monthly salinity values as a percentage of seawater (35.0 ppt) at 7 representative stations along the salinity gradient and rainfall at Cape Sable.

and eastern Whitewater Bay. Upon return of high salinity (30-38 ppt) in early 1962, *Chara* persisted when salinity had risen to 30 ppt.

With the exception of the mud-filtering black and silver mullet, *Mugil cephalus* and *M. curema*, the gray snapper, *Lutjanus griseus*, the filter feeding anchovy, *Anchoa mitchilli*, and the young of one species of menhaden, *Brevoortia smithi*, there were few fish that were always abundant in the

Table 4. Invertebrate animals collected in Coot Bay and Coot Bay Pond during the period July, 1957 through July, 1959.

		Observed salinity range in ppt
Molluscs:		
Gastropods		
Crown conch	*Melongena corona*	9-32
Common eastern nassa	*Nassarius vibex*	12-35
Elegant paper-bubble	*Haminoea elegans*	18-28
Pelecepods		
Pointed venus	*Anomalocardia cunimeris*	16-32
Morton's egg cockle	*Laevicardium mortoni*	28-32
________________	*Macoma mitchelli*	14-32
Tampa tellin	*Tellina tampaensis*	15-25
Alternate tellin	*Tellina alternata*	28-37
Promera tellin	*Tellina promera*	12-25
Brittlestar:		
________________	*Ophiophragmus filograneus*	8-24
Polychaete worms:		
________________	*Nereis pelagica occidentalis*	12-29
________________	*Nereis* sp.	30-38
Spaghetti worm	*Melinna* sp.	15-24
Golden comb worm	*Cistenides gouldii*	13-28
Crustaceans:		
________________	*Balanus amphitrite niveus*	25-36
Ivory barnacle	*Balanus eburneus*	12-32
Pink shrimp	*Penaeus duorarum*	6-35
Bay snapping shrimp	*Alpheus heterochaelis*	12-32
Blue crab	*Callinectes sapidus*	6-38
Mud crab	*Neopanope t. texana*	8-25
Mud crab	*Neopanope packardii*	28-38
Spider crab	*Libinia erinacea*	22-38
Spider crab	*Pitho anisodon*	22-35

muddy bottom, shallow bays. Most of the other species listed (Table 5) were observed moving in and out on the flood and ebb tides each day. These were the mojarra, *Gerres cinereus*, the goby, *Gobiosoma robustum*, toadfish, *Opsanus beta*, hog-chokers, *Trinectes maculatus* and *Achirus fasciatus*, and the spotted worm eel, *Myrophis punctatus*. Other species such as the spotted seatrout, *Cynoscion nebulosus*, the snook, *Centropomus undecimalis*, and the tarpon, *Megalops atlantica*, were common in the spring and winter. Swamp pools and ponds, lakes, and old canals surrounding Coot and Whitewater Bays, were nursery areas for young tarpon. Fishes collected in Coot Bay during the first two years of the survey, July, 1957, through July, 1960, are shown (Table 5).

Table 5. Fishes collected in Coot Bay and Coot Bay Pond during the period July, 1957 through July, 1959.

		Observed salinity range in ppt
Blacktip shark	*Carcharhinus limbatus*	18-35
Smalltooth sawfish	*Pristis pectinatus*	6-32
Southern stingray	*Dasyatis americana*	15-32
Florida gar	*Lepisosteus platyrhincus*	0-18
Ladyfish	*Elops saurus*	9-35
Tarpon	*Megalops atlantica*	0-35
Yellowfin shad	*Brevoortia smithi*	12-38
Scaled sardine	*Harengula pensacolae*	14-30
Bay anchovy	*Anchoa mitchilli*	9-30
Inshore Lizardfish	*Synodus foetans*	18-35
Gafftopsail catfish	*Bagre marinus*	24-35
Sea catfish	*Galeichthys felis*	12-35
Key worm eel	*Ahlia egmontis*	22-35
Speckled worm eel	*Myrophis punctatus*	17-37
Redfin needlefish	*Strongylura notata*	15-35
Halfbeak	*Hyporhamphus unifasciatus*	20-37
Sheepshead minnow	*Cyprinodon variegatus*	0-12
Flagfish	*Jordanella floridae*	0-9
Rainwater fish	*Lucania parva*	9-28
Mosquito fish	*Gambusia affinis*	0-30
Marsh Killifish	*Fundulus confluentus*	0-6
Sailfin molly	*Mollienesia latipinna*	0-33
Spotted seahorse	*Hippocampus erectus*	16-35
Pugnose pipefish	*Syngnathus dunckeri*	20-34
Gulf pipefish	*Syngnathus scovelli*	18-32
Snook	*Centropomus undecimalis*	0-35
Jewfish	*Epinephelus itajara*	25-37
Gray (Mangrove) snapper	*Lutjanus griseus*	0-37
Crevalle jack	*Caranx hippos*	9-35
Leather jacket	*Oligoplites saurus*	21-37
Yellowfin mojarra	*Gerres cinereus*	12-35
Silver perch	*Bairdiella chrysura*	9-35
Spotted seatrout	*Cynoscion nebulosus*	12-32
Black drum	*Pogonias cromis*	10-31
Red drum	*Sciaenops ocellata*	5-37
Pinfish	*Lagodon rhomboides*	8-35
Emerald goby	*Gobionellus smaragdus*	0-37
Code goby	*Gobiosoma robustum*	4-31
Clown goby	*Microgobius gulosus*	12-28
Bighead sea robin	*Prionotus tribulus*	18-32
Great barracuda	*Sphyraena barracuda*	25
Striped mullet	*Mugil cephalus*	0-37
Tidewater silverside	*Menidia beryllina*	17-26
Lined sole	*Achirus lineatus*	11-37
Hogchoker	*Trinectes maculatus*	14-35
Blackcheek tonguefish	*Symphurus plagiusa*	17-37

Table 5. (continued)

		Observed salinity range in ppt
Fringed filefish	*Monacanthus ciliatus*	(once at 18)
Southern puffer	*Sphaeroides nephelus*	12-35
Bandtail puffer	*Shaeroides spengleri*	14-20
Striped burrfish	*Chilomycterus schoepfii*	16-37
Gulf toadfish	*Opsanus beta*	6-37

The dominant large invertebrate in the muddy bays was the pink shrimp, *Penaeus duorarum*. Occasionally other crustaceans outnumbered shrimp but the pink shrimp apparently was able to tolerate most of the environmental extremes offered by the shallow, temperature-unstable, brackish-water environment. The snapping shrimp, *Alpheus heterochaelis*, and unidentified mysid shrimp were abundant during periods of salinity above 20-25 ppt. *Tozeuma carolinensis*, an abundant Florida Bay caridean shrimp, was seldom seen in Coot Bay. During periods when high salinity was accompanied by a high degree of water clarity, the wood boring isopod, *Sphaeroma destructor*, sometimes became extremely abundant. Blue crabs, *Callinectes sapidus*, were moderately abundant during summer and fall. They migrated offshore during October and November.

Several groups of benthic animals were found in Coot and eastern Whitewater Bays. In the past Coot Bay has had a heavy population of the ark shell, *Anomalocardia cunimeris*, the brittlestar, *Ophiophragmus filograneus*, (Thomas, 1961), the tube-worms, *Cistenides gouldii* and *Melinna sp.*, the xanthid crab, *Rhithropanopeus harrisii*, and the gastropods, *Nassarius vibex* and *Melongena corona*. Smaller numbers of the bivalves, *Macoma mitchelli* and *Tellina promera*, were persistent members of the benthic fauna able to tolerate the environmental extremes of the shallow bays. In mid-1957, when salinity values were high and the water clear as a result of a two-year drought, the butter and egg cockle, *Laevicardium mortoni*, was abundant in Coot and Whitewater Bay. These quickly disappeared with the decline in salinity during the summer of 1958. There is little doubt that many of the species collected in the benthic bay fauna early in 1957 and 1958 were marine species that had entered the bays during the preceding drought period, only to be driven out by the rapidly falling salinities beginning in January, 1958 and extending through December, 1960. Most of the species mentioned appear to have a short life span, in many instances probably about one year. An exception is the crown conch, *Melongena corona*. The *Anomalocardia-Macoma* associes is essentially a spring and summer dominant, while the *Ophiophragmus-Cistenides-Melinna* associes succeeds it in the fall and winter. Prior to the opening of the Buttonwood Canal into Coot Bay, larvae of the above species apparently were brought into eastern Whitewater and Coot Bays by tidal transport through Joe River, along the southern perimeter of Whitewater Bay. The brittlestar, *Ophiophragmus filograneus*, was found in greatest abundance in localized colonies along the shore of eastern Whitewater Bay between Tarpon Creek and East River, in soft mud, heavily charged with wood fragments (Figure 3). They were not collected in central Whitewater Bay. The discovery of this brittlestar in very low salinities was unusual (Thomas, 1961).

Normally there were only two species of algae, *Chara hornemannii*, and chenille alga, *Batophora oerstedi*, to be found in Coot Bay. The latter was ubiquitous, being found wherever there was suitable attachment surface of wood or stone. Whitewater Bay, however, with a wider range of salinities

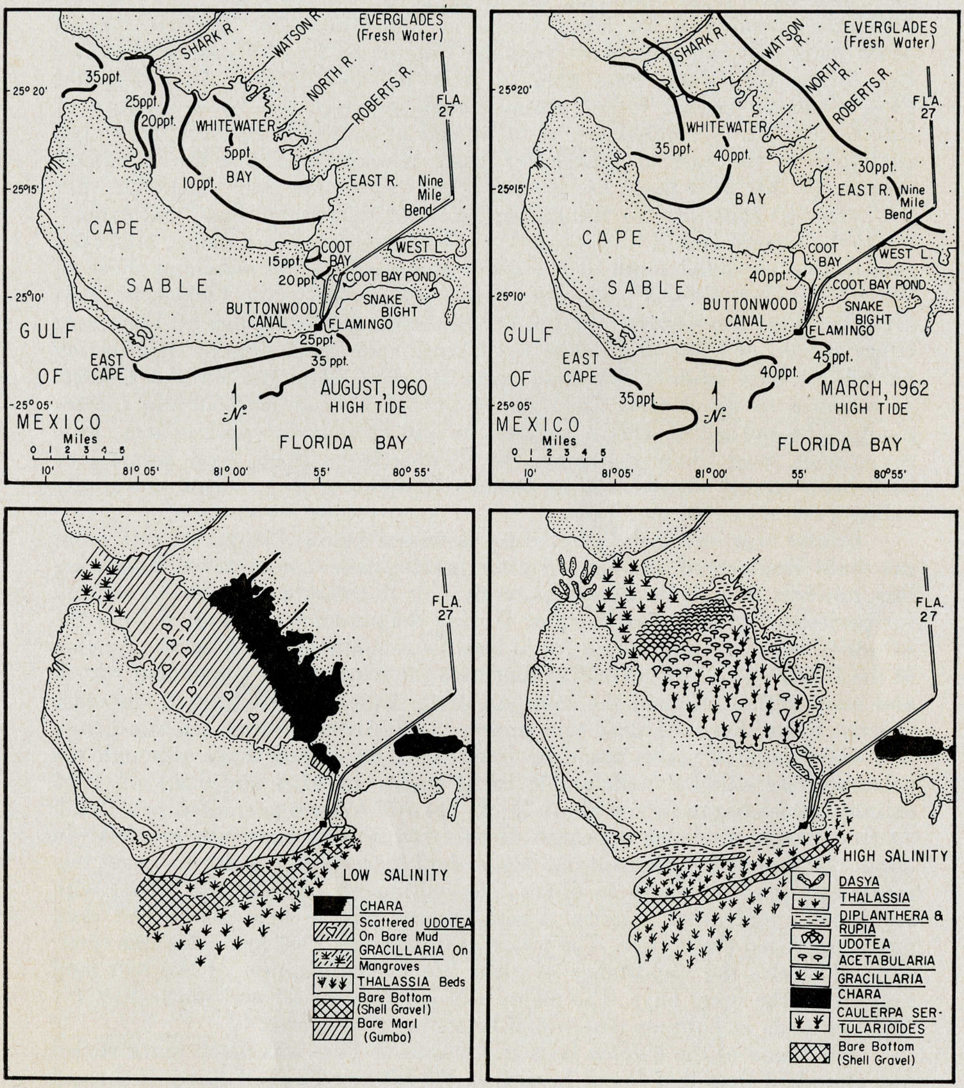


Figure 5. Generalized location of isohalines and plant distribution in relation to these during low and high salinity periods.

and types of substrate, exhibited an algal succession which was dependent on the seasonal salinity pattern. During the periods July, 1957, through November, 1959 and February, 1961 through May, 1962, the alga, *Batophora oerstedi*, was the dominant species in eastern Whitewater Bay along the shoreline and wherever there were exposed wood surfaces. It reproduces while the black mangrove occurs most abundantly and reaches its greatest size in the swamp centers. The white mangrove and the buttonwood *Conocarpus erecta* occupy generally drier ground than either of the two preceding species. The "prop" roots of the red mangrove extending into the water along the margins of the tidal creeks offer nearly the only attachment surface available to sessile animals in the intertidal zone. The prop-root fauna is generally small in numbers of species which often occur in large numbers.

The dominant animal in the intertidal area and below the low water mark of the Shark River estuary was the oyster, *Crassostrea virginica.* This reached its greatest density of settlement in an area just east of the Shark River in and around Oyster Bay. It diminished in numbers westward toward the mouth of the estuary in high salinities and eastward, in mid-Whitewater Bay, in the area of lowest salinity (0-15 ppt). It was also found in Joe River, a tidal channel running from Oyster Bay and the mouth of the Little Shark River to eastern Whitewater Bay (Figure 2, Part I). The oysters diminished rapidly in numbers along the Joe River channel as far as Mid-Joe River station although many oysters were again found in Tarpon Creek between Coot and Whitewater Bays.

There were almost no oysters in Coot Bay and virtually none along the northern shore of Whitewater Bay between the East River and Oyster Bay. Studies on settlement of larvae on wooden panels suggested that the larvae are transported from the Shark River area eastward as far as Whitewater Bay Station IX and along the Joe River channel to the Tarpon Creek area.

The mangrove forest of Everglades National Park suffered severe destruction during hurricane Donna of September 9-10, 1960 (Craighead, and Gilbert, 1962). The destruction of red mangroves was especially severe in the area from Flamingo to the western Park boundary. In the Shark River estuary the death of the mangrove and subsequent sloughing off of the bark of their aerial roots dropped the oyster clumps into the deep water of the estuarine channels where they died. The mangrove oyster community had not became fully re-established as late as March, 1962.

In eastern Whitewater Bay and Coot Bay where salinity values ranged between 10 and 30 ppt the oyster intermingled with the ivory barnacle, *Balanus eburneus.* In areas of minimum tidal influence, this barnacle was dominant.

Among the animals which were associes of the oyster in west Whitewater Bay was the xanthid crab, *Eurypanopeus depressus,* the porcellanid crab, *Petrolisthes armatus,* the ivory barnacle, *Balanus eburneus,* the polychaete, *Neanthes succinea,* and an unidentified calcareous tube-forming operculate serpulid worm. A swimming polychaete, *Nereis pelagica occidentalis,* was sometimes found abundantly in oyster clumps and was commonly observed at night, swimming at the surface in mangrove-lined channels. There was a characteristic algal flora of *Bostrychia-Catanella-Caloglossa* on the mangrove roots.

The intertidal flats of the mangrove islands supported a large population of fiddler crabs, including *Uca pugilator, U. speciosa* and *U. thayeri.* Burrows of the xanthid, *Eurytium limosum,* were common.

Three species of grapsoid crabs were abundant in the mangroves above high water. One of these, the mangrove crab, *Aratus pisonii,* was found throughout the study area and is well known from south Florida. The other two species, *Sesarma curacaoense* and *S. reticulatum,* were reported for the first time from south Florida by Tabb and Manning (1961). Their distribution within the area is not known although they are abundant in the Shark River estuary. *Sesarma reticulatum* has been characterized as a cold temperate species and has been cited as a south Florida disjunct (Hedgpeth, 1953). Its occurrence in south Florida is not surprising in view of the general lack of organized collecting from that area in the past.

The littorinid, *Littorina angulifera,* was the only gastropod mollusc abundant in the mangrove strand. They were commonest in the mature mangrove forests of the Shark River and decreased rapidly in size and abundance toward Coot Bay.

Oyster reef habitat

The southernmost living oyster reef in the U. S. is located in Oyster Bay of Everglades National Park. However, there are indications that the reef in Oyster Bay was once much larger than at present since the shallow shell banks on which the present population settles are nearly a mile long and about half as wide, although, the reefs are now small and temporary. The living portion of the reef is exposed by low spring and most neap tides. Three times the oysters on the reef crest have been killed by exposure to environmental extremes. During the cold waves of December, 1957, and February, 1958, the crown of the reef was completely killed. Recovery was rapid, however, and re-colonization by larvae from the protected sub-tidal portion of the Shark River population was complete by the following spring. The third kill took place during hurricane Donna, September 9-10, 1960, when the top of the reef was stripped bare of both living and dead shell. Abundant dead shell in the mud deposits of north and south Oyster Bay suggest the disturbing influence of past hurricanes on these reefs.

The oyster reef fauna was sparse, consisting of a massive form of *Melongena corona,* the crown conch, a few blennies, *Chasmodes saburae,* and the goby,*Gobiosoma robustum.*

The reef became heavily over-grown by the algae, *Gracilaria* sp., *Laurencia intricata* and *Acanthophora spicifera,* during the winter dry season when high salinities prevailed.

Rocky channels

Rocky channels are numerous in the Shark River estuary and adjacent tidal portions of Oyster and Whitewater Bays. Depths of the channels may exceed the average depth of the adjacent bays by 4 to 6 feet. Currents in the main channel of the Little Shark River were estimated at 4 mph, although usually they were slower.

Because of the swift currents in the channels, the bottoms are only sparsely covered by algae, although the rock outcrops provide good attachment surfaces. During periods of high salinity the marine red algae, *Dasya pedicellata* and *Gracilaria confervoides,* became dominants. Occasionally conditions became favorable, particularly in the mouth of the Shark River, for growth of the red algae, *Dasya* and *Agardhinula* sp., and in a few weeks these plants grew to lengths of 5 to 10 feet. The latter species may develop thalli in excess of four inches in width. *Ulva lactuca,* the sea lettuce, has been collected only in the edges of the main Shark River channel at Ponce de Leon Bay, where it grew attached to dead wood in the quieter water along shore. The green alga, *Caulerpa verticillata,* was the dominant species on all wood surfaces of the channel edges and formed large masses resembling horse tails, up to three feet long on a single mangrove root. *Laurencia poitei* and *Acanthophora spicifera,* two of the red algae of the channel areas, grew in greatest profusion in the tidal channels leading into Oyster Bay. All these species and a few others seem to be annuals. They flourished during the winter dry season and died as the salinity values fell at the onset of the rainy season. In Florida Bay a similar mortality occurred, but the effect was not so apparent because of the presence of many other species of plants that took their place.

When the algae were abundant they served as shelter for a large number of caridean shrimps, usually *Palaemonetes intermedius* and *Leander paulensis*, as well as small gobies, *Gobiosoma robustum*, and blennies, *Chasmodes saburae*. Many species of larger game fish, including snook, tarpon, ladyfish, red drum, gray snapper, spotted jewfish, spanish mackerel, spotted seatrout and crevalle jack were taken in the deeper channels and adjacent lagoon flats. Some 20 per cent of the angler catches of the above species landed at Flamingo are made in or adjacent to the deeper channels of the Shark River and the Oyster Bay-Whitewater Bay estuarine areas.

Salt-fresh transition zone

In the area north and east of Whitewater Bay there was an extensive transition zone between the marine, brackish and fresh-water aquatic organisms.

The alga, *Chara hornemannii*, is the dominant aquatic plant in this environment; it is replaced by the fresh-water flora of the Everglades in areas that experience no salt intrusion. Another alga, *Batophora oerstedi*, may be found in areas that experience salt intrusion, if there are rock surfaces on which it can grow. The *Chara* beds contained the "*Cyprinodont-Palaemonetes* communities" mentioned by Hedgpeth (1953). *Chara* beds of West Lake contained a mixture of *Palaemonetes intermedius*, *Palaemonetes paludosus* (usually found only in fresh-water), the goby, *Gobionellus smaragdus*, and dragonfly nymphs. Davis (1948) commented on the mixture of marine and fresh-water plankton in lakes adjacent to West Lake in the same region.

Small fishes, most of which belong to the salt-tolerant families *Poecilidae* and *Cyprinodontidae*, are abundant in the transition zone.

A series of poison collecting stations was set up in roadside culvert pools along the highway from Coot Bay Pond to the Nine-mile Bend area (Figure 2). These yielded mixed collections of fishes which are summarized in Table 7. Some of the specimens form a considerable extension of the range of the species.

Table 7. Fishes collected at roadside poison stations along the Flamingo highway between Coot Bay Pond and Nine-mile Bend, March 10-12, 1959. R and L indicate right and left side of the highway, going north. Water flow in this area is through the highway culverts, generally from east to west.

	STATION NUMBERS								
SPECIES	1(L)	2(R)	3(L)	4(L)	5(L)	6(L)	7(L)	8(R)	9(R)
SALINITY (ppt)	9.0	12.0	5.0	4.0	0.0	0.0	0.0	0.0	0.0
CYPRINODONTIDAE:									
Diamond killifish *Adinia xenica*	—	—	—	—	—	1	—	1	—
Sheepshead minnow *Cyprinodon variegatus*	—	—	—	—	—	23	1	—	—
Golden topminnow *Fundulus chrysotus*	—	9	—	—	—	8	1	1	5

Table 7. (continued)

SPECIES	1(L)	2(R)	3(L)	4(L)	5(L)	6(L)	7(L)	8(R)	9(R)
	STATION NUMBERS								
SALINITY (ppt)	9.0	12.0	5.0	4.0	0.0	0.0	0.0	0.0	0.0
Marsh killifish *Fundulus confluentus*	299	—	—	—	—	15	4	5	—
Gulf killifish *Fundulus grandis*	—	—	—	—	—	4	—	—	—
Seminole killifish *Fundulus seminolis*	—	—	—	—	—	—	—	—	3
Flagfish *Jordanella floridae*	—	1	—	1	6	141	29	6	—
Bluefin killifish *Lucania goodei*	—	4	—	6	—	—	—	6	—
Rainwater killifish *Lucania parva*	—	—	—	11	—	5	1	—	—
POECILIIDAE:									
Mosquitofish *Gambusia affinis*	—	29	12	50	1	190	32	167	12
Least killifish *Heterandria formosa*	—	8	15	40	—	—	1	16	1
Sailfin molly *Mollienesia latipinna*	388	34	1	60	5	391	203	198	12
ICTALURIDAE:									
Yellow bullhead *Ictalurus natalis*	—	4	17	2	—	67	10	—	58
Tadpole madtom *Noturus gyrinus*	—	—	20	2	—	3	—	—	14
CENTRARCHIDAE:									
Everglades pigmy sunfish *Elassoma evergladei*	—	—	2	13	—	—	1	—	3
Redbreast sunfish *Lepomis auritis*	—	—	—	—	—	—	—	—	12
Redear sunfish *Lepomis microlophus*	—	8	10	—	—	5	2	—	59
Spotted sunfish *Lepomis punctatus*	—	7	2	—	—	—	—	—	26
Largemouth bass *Mecropterus salmoides*	—	—	—	—	—	—	—	—	8
No. specimens per station:	687	104	79	185	12	853	285	400	213

HABITAT DOMINANTS

The dominant organisms of the various inshore and offshore habitats are summarized in tabular form (Table 8). By far the richest area in point of diversity of species and numbers of each was western Florida Bay, where the habitat is like that of the nearby open Gulf of Mexico and offers more or less constant environmental conditions through the year. West and central Whitewater Bay with heavy growth of *Udotea wilsoni,* had a fauna closely paralleling some elements of Florida Bay and the Gulf of Mexico, from which it no doubt derives its young following periods of low salinity. Coot and eastern Whitewater Bays provide habitats for benthic communities, especially *Anomalocardia, Macoma,* and tube-building polychaete worms. Numbers of these fluctuated with salinity values, being lowest when salinities fell below 25 ppt but persisting even when salinity averages 12-15 ppt. The benthic animals mentioned above were noticeably absent whenever plants became well established, hence can be characterized as mud dwellers. The mangrove fauna was characteristic and closely resembled that of a typical rocky shore fauna.

Table 8. Apparent dominance of macroscopic plants and animals under high and low salinity conditions in the major habitats studied.

PANEL A
HIGH SALINITY

Habitat Dominant	Florida Bay Channels (30-45 ppt)	Florida Bay Grassy Banks (30-45 ppt)	Coot Bay (18-35 ppt)	Southeast Whitewater Bay (18-35 ppt)	Western Whitewater Bay (18-35 ppt)
Plant	*Caulerpa crassifolia*	*Thalassia testudinum*	*Diplanthera wrightii* (winter) *Ruppia maritina* (summer)	*Caulerpa sertularioides*	*Udotea wilsoni*
Fish	*Anchoa hepsetus*	*Lagodon rhomboides*	*Anchoa mitchilli*	*Anchoa mitchilli*	*Anchoa mitchilli*
Crustacean	*Neopanope packardii*	*Periclimenes longicaudatus*	*Sphaeroma destructor* (motile) *Balanus eburneus* (sessile)	*Balanus eburneus*	*Balanus eburneus*
Mollusc bivalve	*Prunum anicinum*	*Cardita floridana*	*Anomalocardia cunimeris*	*Macoma mitchelli*	*Crassostrea virginica*
gastropod		*Cerithium eburneum*	*Nassarius vibex*	*Bulla occidentalis*	*Cerithium muscarum*
Echinoderm	*Ophiolepis elegans*	*Echinaster sentus*	*Ophiophragmus filograneus*	*Ophiophragmus filograneus*	*Echinaster spinulosus*

PANEL B
LOW SALINITY

Habitat Dominant	Florida Bay Channels (28-30 ppt)	Florida Bay Grassy banks (28-30 ppt)	Coot Bay (5-18 ppt)	Southeast Whitewater Bay (5-18 ppt)	Western Whitewater Bay (5-18 ppt)
Plant	*Caulerpa verticillata*	*Thalassia testudinum*	*Ruppia maritima* (spring - summer) *Chara hornemannii* (summer - fall)	*Batophora oerstedi*	*Udotea wilsoni*
Fish	*Bairdiella chrysura*	*Mugil cephalus*	*Anchoa mitchilli*	*Anchoa mitchilli*	*Anchoa mitchilli*
Crustacean	*Leander paulensis*	*Penaeus duorarum*	*Balanus eburneus* (sessile) *Penaeus duorarum* (motile)	*Balanus eburneus*	*Balanus eburneus*
Mollusc bivalve	*Tellina similis*	*Tellina promera*	*Anomalocardia cunimeris*	*Macoma mitchelli*	*Brachidontes exustus*
gastropod	*Nassarius vibex*	*Prunum apicinum*	*Nassarius vibex*	*Nassarius vibex*	*Nassarius vibex*
Echinoderm	None	None	None	None	None

SEASONAL CHANGES IN ANIMAL ABUNDANCE

There appeared to be a large influx of fishes and invertebrates into the Flamingo area late in the fall. Since this normally coincided with the lowest salinity in Coot and Whitewater Bays, the abundance of this influx was centered in Florida Bay. The apparent peak in numbers, of species not commonly taken at any other time of year, occurred in October through November and occasionally into January. Such an invasion was noted particularly in October, 1958, when trawl catches contained many species not seen before or since (Table 9). A similar movement was mentioned by Gunter (1945) in the northern Gulf of Mexico at the beginning of winter, but in that case the animals appeared to be moving seaward from the inner bays. In Florida Bay many of the animals were marine in origin and appeared to come into the area from the Gulf of Mexico littoral zone.

Table 9. Species that reached a peak in abundance in Florida Bay during late fall and early winter.

Invertebrates	
Squilla empusa	*Podochela riisei*
Squilla prasinolineata	*Calyptrea centralis*
Trachypeneus constrictus (juveniles)	*Crepidula plana*
Sicyonia typica (juveniles)	*Fasciolaria tulipa*
Alpheus normanni	*Bursatella leachi plei*
Scyllarus americanus	*Arcopsis adamsi*
Ebalia cariosa	*Musculus lateralis*
Portunus spinimanus	*Aequipecten irridians*
Menippe mercenaria (juveniles)	
Fish	
Anchoa hepsetus	*Leiostomus xanthurus*
Anisotremus virginicus	*Ogcocephalus radiatus*
Alutera schoepfii	*Ophisthonema oglinum*
Achirus lineatus	*Brevoortia sp.* (large)
Bairdiella chrysura (large)	*Prinotus scitulus*
Chloroscombrus chrysurus	*Prinotus tribulus*
Chilomycterus schoepfii	*Sciaenops ocellata* (large)
Chaetodipterus faber	*Selene vomer*
Diplectrum formosa	*Scomberomorus maculatus*
Etropus crossotus	*Sphaeroides harperi*
Haemulon sciurus	*Symphurus plagiusa*
Haemulon plumieri	*Vacuoqua sialis*
Lutjanus synagris	

Among the more common animals that showed seasonal peaks in abundance were pink shrimp, *Penaeus durarum*, described by Tabb, Dubrow, and Jones (1962). Spotted seatrout and mangrove snapper, tarpon, snook and red drum were present the year around but were concentrated mainly in the winter and spring.

EFFECT OF HYDROGRAPHY ON BIOTA

Salinity was found to have a marked effect on the biota. Within the ranges of salinity found in Everglades National Park, the lower the salinity the lower the number of species (Table 10) and the smaller the average size of the individuals. Among invertebrates, particularly molluscs, there may be marked stunting. This was noted by us for *Cerithium muscarum*, *Bulla*

Table 10. Species found in study area under various salinity concentrations.

Algae and phanerogams

1. Species not found in salinities below 28 ppt

Caulerpa crassifolia	*Chrysemenia uvaria*
Caulerpa cupressoides	*Laurencia poitei*
Dictyota cervicornis	*Halymenia floridana*
Sargassum filipendula	*Halophila engelmanni*
Euchema isiforme	*Thalassia testudinum*
Hypnea musciformis	*Syringodium filiforme*

2. Species normally found above 28 ppt, occasionally below

Caulerpa prolifera	*Acanthophora specifera*
Caulerpa sertularioides	*Dasya pedicellata*
Gracilaria confervoides	*Laurencia intricata*

3. Species usually found from 15-28 ppt, occasionally above

Acetabularia crenulata	*Caulerpa verticillata*
Udotea wilsoni	*Diplanthera wrightii*

4. Species normally found under 15 ppt

Batophora oerstedi	*Chara hornemannii*

Crustaceans

1. Species found only above 28 ppt

Cilicaea caudata	*Palaemon floridanus*
Squilla prasinolineata	*Panulirus argus* (juveniles only)
Sicyonia typica	*Scyllarus americanus*
Hippolysmata wurdemanni	*Euceramus praelongus*
Latreutes parvulus	*Petrolisthes galathinus*
Ogyrides yaquiensis	*Porcellanopsis soriata*
Pagurus longicarpus	*Portunus gibbesi*
Pagurus pollicaris	*Menippe mercenaria*
Pagurus impressus	*Pilumnus lacteus*
Paguristes tortugae	*Podochela riisei*
Petrochirus diogenes	*Heterocrypta granulata*
Persephona aquilonaris	*Anaplodactylus insignis*

2. Species found above 28 ppt, occasionally below

Balanus amphitrite niveus	*Pagurus annulipes*
Squilla empusa	*Ebalia cariosa*
Trachypeneus constrictus	*Portunus spinimanus*
Alpheus normanni	*Neopanope packardii*
Hippolyte pleuracantha	*Libinia dubia*
Latreutes fucorum	*Libinia erinacea*
Thor floridanus	*Metoporhaphis calcarata*
Tozeuma carolinensis	*Pelia mutica*
Leander paulensis	*Pitho anisodon*
Periclimenes longicaudatus	

3. Species usually found between 15-28 ppt, occasionally above

Balanus eburneus	*Periclimenes americanus*
Cleantis planicauda	*Neopanope texana texana*

4. Species usually found below 15-20 ppt

Palaemonetes intermedius	*Eurypanopeus depressus*
Rhithropanopeus harrisii	

Table 10. (Crustaceans, continued)

5. Species occurring in wide range of salinity (0-38 ppt), more abundant in lower range

Balanus eburneus	*Alpheus heterochaelis*
Penaeus duorarum	*Palaemonetes intermedius*

6. Species found in salinities of 5-38 ppt, no apparent preference

Petrolisthes armatus	*Callinectes sapidus*

7. Species found below 5.0 ppt

Procambarus alleni	*Palaemonetes paludosus*

Molluscs

1. Species found only above 28 ppt

Diodora dysoni	*Columbella rusticoides*
Calliostoma jujubinum	*Anachis avara*
Tegula fasciata	*Anachis obesa*
Turbo castaneus	*Anachis translirata*
Modulus modulus	*Busycon contrarium*
Cerithium floridanum	*Busycon spiratum*
Cerithium eburneum	*Nassarius ambiguus*
Cerithium algicola	*Fasciolaria tulipa*
Calyptraea centralis	*Fasciolaria hunteria*
Crepidula plana	*Pleuroploca gigantea*
Erato maugeriae	*Conus stearnsi*
Trivia candidula	*Conus jaspideus*
Polynices duplicatus	*Terebra dislocata*
Natica livida	*Crassispira ebenina*
Murex recurvirostris rubidus	*Crassispira ostrearum*
Murex pomum	*Cerodrillia perryae*
Murex florifer	*Cerodrillia thea*
Murex cellosus	*Monilispira albinodonta*
Eupleura caudata	
Columbella mercatoria	
Pleurobranchus atlanticus	
Chaetopleura apiculata	*Lucina amiantus*
Dentalium antillarum	*Codakia orbiculata*
Dentalium pilsbryi	*Trachycardium muricatum*
Arcopsis adamsi	*Trachycardium egmontianum*
Chione cancellata	*Tellina versicolor*
Cardita floridana	*Tellidora cristata*
Glycymeris pectinata	*Semele proficua*
Musculus lateralis	*Mactra fragilis*
Atrina rigida	*Corbula contracta*
Atrina serrata	*Corbula barrattiana*
Pecten ziczac	*Corbula swiftiana*
Aequipecten muscosus	

2. Species found above 28 ppt, occasionally below

Cantharus tinctus	*Nassarius vibex*
Melongena corona	*Aequipecten irridians*
Cerithium muscarum	*Bursatella leachi plei*
Bulla striata	*Brachidontes recurvus*
Cantharus multangula	*Tellina alternata*

Table 10. (Molluscs, continued)

3. Species usually found below 30 ppt, occasionally higher

Crassostrea virginica	*Macoma mitchelli*
Nassarius vibex	*Brachidontes exustus*
Haminoea elegans	*Laevicardium mortoni*

4. Species occurring in wide range of salinity (5-38 ppt), more abundant in lower range

Anomalocardia cunimeris	*Tellina promera*
Nassarius vibex	*Amygdalum papyria*
Prunum apicinum	*Polymesoda floridana*

5. Species found only below 5 ppt

Congeria leucophaeta	*Polymesoda caroliniana*

Table 11. Seasonal changes in salinity and relative abundance of algae in Whitewater Bay, 1957.

Station	Date	Salinity, ppt	Plant life in order of abundance
V	8/29/57	32	*Acetabularia* *Batophora* *Udotea* *Caulerpa*
	9/12/57	26-28	*Acetabularia* *Batophora*
	10/8/57	24	*Acetabularia* *Batophora* *Laurencia*
	11/19/57	15	*Batophora* *Chara* *Acetabularia*
VI	9/12/57	27-29	*Batophora* *Acetabularia*
	10/8/57	25	*Batophora* *Acetabularia*
	11/19/57	18	*Acetabularia* *Batophora*
VII	8/29/57	33	*Acetabularia* *Caulerpa* *Udotea*
	10/8/57	25	*Batophora* *Acetabularia* *Udotea*

Table 11. (continued)

Station	Date	Salinity, ppt	Plant life in order of abundance
	11/19/57	19	*Udotea*
	12/17/57	15-18	*Udotea*
VIII	8/29/57	32	*Udotea* *Caulerpa* (3 spp) *Acetabularia*
	9/12/57	28	*Udotea* *Caulerpa* (3 spp) *Acetabularia*
	9/26/57	28	*Udotea* *Batophora* *Acetabularia*
	10/8/57	26	*Udotea* *Laurencia* *Caulerpa*
	11/9/57	21	*Udotea*
	12/3/57	13	*Udotea*
	12/17/57	16	*Udotea*
IX	8/29/57	32	*Caulerpa* (2 spp) *Udotea* *Laurencia* *Gracilaria*
	9/12/57	25	*Caulerpa* *Batophora*
	9/26/57	29	*Batophora*
	10/8/57	24	*Batophora* *Udotea* *Caulerpa* (2 spp) *Acanthophora* *Laurentia*
	11/19/57	23	*Udotea* *Caulerpa* (2 spp) ----
	12/20/57	14-17	*Udotea* *Laurencia* *Batophora*

striata and *Crassostrea virginica*. However, small size of the fishes in an estuary may not be a result of stunting due to salinity but rather that the juveniles stages of animals can apparently tolerate lower salinities than the adults (Gunter, 1950).

Extremely high salinities were common in the shallow water of eastern Florida Bay, especially during the winter dry season and during drought periods (Finucane and Dragovich, 1959). Prolonged high salinities seem to have limited numbers of species in Florida Bay, but such high salinity periods have been too few and too short to determine this accurately.

Salinity control of the fauna and flora was particularly evident in parts of Whitewater Bay, where a salinity range of 0-35 ppt is a normal annual occurrence. The change in aquatic flora in eastern Whitewater Bay in the winter of 1957-58 is a good example of this control (Table 11). The Clearwater Pass area of western Whitewater Bay had a limited brackish-water assemblage of plants and animals during most of the year. In periods of high salinity, however, the biota typified by the molluscs may be more than doubled (Table 12).

Table 12. Molluscs normally found in Clearwater Pass, Whitewater Bay

Cerithidea costata	*Prunum apicinum*
Cerithium muscarum	*Brachidontes recurvus*
Nassarius vibex	*Brachidontes exustus*

Molluscs entering Clearwater Pass, Whitewater Bay during periods of high salinity (above 25 ppt)

Vermicularia sp.	*Cantharus tinctus*
Modulus modulus	*Aequipecten irridians*
Natica canrena	*Cardita floridana*
Urosalpinx tampaensis	*Laevicardium mortoni*
Eupleura caudata	*Bursatella leachi plei*

The meeting place of the fresh and salt water lay between Whitewater Bay hydrographic stations VII and IX (Figure 2 Part I). Collections of animals and plants show that centers of abundance of certain species shifted back and forth across this area as the salinity changed. The fauna of this area was directly related to the salt content.

Animals and plants seemed to exhibit clear-cut salinity preferences, despite a record of occurrence of a species below or above a given "normal" range. The salinity ranges of 248 species of animals and 25 species of plants have been summarized (Table 13).

Marine animals can tolerate higher salinities with a reduction in temperature. This is apparent when the salinity preferences of the fauna from Everglades National Park are compared with the salinity preferences of the same animals found by Simmons (1957) in Laguna Madre of Texas, where salinities are normally much higher. Nearly all the South Florida species listed as occurring in the Laguna Madre live in much higher salinities in the north Gulf of Mexico. It is interesting to see that some of the species apparently restricted to salinities below 28 ppt in Whitewater Bay tolerated and apparently preferred much higher salinities in the Laguna Madre. Some examples are eel grass, *Diplanthera wrightii*, the anomalous ark shell, *Anomalocardia cunimeris*, and the ivory barnacle, *Balanus eburneus*. All

Table 13. Number and percentage of species of aquatic plants and animals from the estuaries, bays and lagoons (including the inshore portion of Florida Bay) of Everglades National Park, by observed salinity ranges.

Organisms	Oligohaline species 0-5		Brackish species 5-25		Mesohaline species 15-30		Marine species 24-40		Euryhaline species 0-50		Total species
	No.	%	No.	%	No.	%	No.	%	No.	%	
Animal											
Fish	3	3.0	8	8.0	24	24.0	56	57.0	8	8.0	99
Crustaceans	2	3.4	3	5.1	8	13.5	43	72.9	3	5.1	59
Molluscs	1	1.5	4	6.0	16	23.9	41	61.2	5	7.5	67
Echinoderms	—	—	—	—	2	16.6	10	83.3	—	—	12
Polychaetes	—	—	3	27.3	3	27.3	5	45.5	—	—	11
Plant											
Seed plants	—	—	1	25.0	—	—	3	75.0	—	—	4
Algae	1	4.7	1	4.7	3	14.3	14	66.6	2	9.5	21

INFLUENCE OF TEMPERATURE, OXYGEN AND SALINITY VARIATIONS

Very low temperatures were encountered in the study area during the winter of 1957-58. The shallows cooled quickly during the prolonged cold waves of that year, and low water temperatures (14-16 C) killed many of the marine and brackish-water species, particularly those of the tropical representatives of the biota (cf. Gunter and Hildebrand, 1951; Storey, 1937). Table 14 lists the species killed during the cold wave of December, 1957.

Table 14. Species killed by the cold wave of December, 1957 in the order of abundance of dead observed.

Fish	*Birds*
Synodus foetans	Black skimmers, *Rynchops nigra*
Centropomus undecimalis	
Lutjanus synagris	
Cynoscion nebulosus	*Mammals*
Megalops atlantica	Manatee, *Trichechus manatus*
Haemulon sciurus	

are forms restricted largely to estuarine or brackish water foreshores of bays in south Florida, and are apparently restricted by salinities in excess of 28-35 ppt. Yet *Diplanthera* thrived in the Laguna Madre in 45 ppt salinity and was present at 60 ppt. *Anomalocardia* preferred a salinity of 45 ppt in the Laguna Madre, but was reduced in numbers in Coot Bay when salinity exceeded 32 ppt. *Balanus eburneus,* the ivory barnacle, was one of the most common animals in the brackish waters of the survey area (4-35 ppt), yet it preferred salinities of 25-75 ppt in the Laguna Madre. Some ivory barnacles entered the high salinity of Florida Bay, but evidently preferred water of lower salinity at least during part of their life cycle, as they were not found far from the mouths of estuaries. Their optimum salinity seemed to be from 15-30 ppt, where they exhibited the fastest growth coupled with greatest population density. Within the estuaries they appeared to be limited only by lack of attachment surfaces and salinity below 5-9 ppt.

In general, oxygen saturation levels in the study area remained above the critical level of 1-2 mg per liter mentioned by Emery and Stevenson (1957). However, after periods of heavy rainfall in late summer oxygen depleted runoff from the mangrove swamps entered the estuaries. On such occasions, large numbers of killifishes were driven to the bay margins where oxygen conditions were more favorable. At such times they were attacked by bay fishes and wading birds.

In shallow bodies of water, winds and currents, principally tidal, can have profound effect on the fauna. Prolonged westerly winds cause mortalities of marine animals, notably molluscs, as shown by masses of shells washed ashore on Cape Sable beaches following such storms. Strong easterly winds turn the inshore waters of Florida Bay into veritable "pea-soup" and if of more than two or three days in duration, can cause a marked reduction in fish until water conditions improve (Robins, 1957). Increased turbidities resulting from the opening of the Buttonwood Canal have caused marked alteration in abundance and distribution of benthic animals in Coot Bay.

BOTTOM SEDIMENTS

Samples of bottom sediments were analyzed to provide an estimate of the character of the bottom as a substratum for benthic organisms, and to give some indication of the nature of deposition of the various sediment size fractions in relation to currents, wind transport and fresh-water source.

Paired 50 gram samples (wet) were collected in the upper 10 cm of the substrate at Whitewater Bay Station V, Coot Bay Stations 5e, 4c and 3c, and on the intertidal gumbo marl flats at Flamingo.

Table 15. Particle size of sediments as percentage of total sample from representative stations in Coot, Whitewater and Florida Bays.

Particle size range mm	Coot Bay 3c	Coot Bay 4c	Coot Bay 5e	Whitewater Bay V	Flamingo, intertidal marl bank
> 2.00 mm	3.0	5.9	1.2	5.1	7.0
1.00-2.00 mm	1.0	9.1	1.6	4.4	10.0
0.50-1.00 mm	3.0	11.5	1.4	6.4	6.0
0.25-0.50 mm	4.0	12.6	1.8	11.2	6.0
0.125-0.25 mm	4.0	6.8	1.9	10.4	4.0
0.062-0.125 mm	5.0	4.7	1.5	3.8	7.0
< 0.062 mm	78.0	38.6	82.0	43.2	58.0
% organic material	2.0	10.0	8.6	15.2	2.0
Total wet wt. of sample in grams	50.9	50.0	51.0	50.0	49.9
Sediment type based on particle size	Sandy mud	Sandy mud	Silty mud	Sandy mud	Gravelly mud

The percentage composition of particles of various sizes is shown in Table 15. The species of animals forming skeletal remains in the sediments are listed as percentages of the total undigested weight within the sample (Table 16). Variation in percentage of each species for all three stations in Coot Bay is shown (Table 17). Calcium carbonate marl constituted a large percentage of total sediments at all stations, ranging between 68 to 75

Table 16. Percentage composition of recognizable calcareous animal remains from Coot Bay and Whitewater Bay sediment samples.

Particle size category		Coot Bay	Whitewater Bay
> 2.00 mm	Molluscs	93.0	100.0
	Tube worms	7.0	—
1.00-2.00 mm	Molluscs	96.5	98.0
	Ostracods	3.0	—
	Tube worms	.3	—
	Unidentified	.2	2.0
0.50-1.00 mm	Molluscs	87.0	89.0
	Ostracods	2.5	—
	Tube worms	5.0	—
	Foraminifera*	4.0	2.0
	Unidentified	1.5	10.0
0.250-0.50 mm	Foraminifera*	40.4	14.0
	Molluscs	47.0	70.0
	Ostracods	6.0	—
	Unidentified	7.0	16.0
0.125-0.250 mm	Foraminifera*	58.0	20.0
	Molluscs	9.0	69.0
	Ostracods	4.0	—
	Unidentified	29.0	11.0
0.062-0.125 mm	Foraminifera*	—	6.0
	Molluscs	—	48.0
	Unidentified	—	46.0

*Foraminiferans identified as *Streblus beccarii, Cassidulina* sp., and *Textularia* sp. Two additional species, *Elphidium discoidale* and *Archaias compressus*, were identified in sediments collected in Florida Bay at Flamingo.

Table 17. List of species and percentage range of each as whole shell and shell fragments found in sediment samples from three locations in Coot Bay as an indication of the probable past hydrographic conditions (Stations 3c, 4c and 5e).

Common name		Range of percentage of samples
Scorched mussel	*Brachidontes exustus*	33.1-34.0
Pointed Venus	*Anomalocardia cunimeris*	22.6-27.0
Mitchil's macoma	*Macoma mitchelli*	10.0-24.5
Tellin	*Tellina sp., probably tampaensis*	1.0- 7.5
Rice shell	*Retusa candei*	4.7-13.0
Variable bittium	*Bittium varium*	4.0- 4.6
Morton's egg cockle	*Laevicardium mortoni*	.6- 1.0
Striate bubble shell	*Bulla striata*	.3- 1.0
Fly-specked cerith (dwarfed form)	*Cerithium muscarum*	.3- 4.0

per cent silt and 25 to 32 per cent clay, in Coot Bay for example, and was the dominant fraction of all the regions studied. Variations in character of the mixture of shell and other coarse calcareous material were found at all stations with the highest percentage of fines in the shallow bay margins where wind currents tend to deposit fines, and the coarsest material found in the bay centers where wind and wave sorting is most active or along the shore where storms deposit coarse shell from farther out in the open bays.

Organic content was highest in the center of Whitewater Bay where the greatest deposition of land-derived organic material, mostly of plant origin, was observed and at stations adjacent to the mangrove shores of the bays. In the latter instance, the organic material was composed of plant remains from the adjacent swamp. However, aquatic plant remains are usually of greater importance. The accumulation of aquatic plant material is greatest in the northern and western sides of the bays, having been deposited there by the prevailing southeasterly winds.

In Coot and Whitewater Bays the bottom sediments were arranged in two fairly distinct layers. One was formed of compact marl and incorporated shell and plant detritus. On this an upper layer of flocculent material and neutrally buoyant coarse plant material with a thin coating of calcium carbonate scum was usually deposited. The non-consolidated layer on the surface was subject to water movement and could be observed to move slowly back and forth with local water turbulence. The consolidated marl layer was firm and brought into suspension only during periods of strong winds. High salinity seemed to cause compaction while long-term low salinity brought about a loosening of the marl.

DISCUSSION AND CONCLUSIONS

As a result of this work predictions can be made of changes in the ecology of the area studied, under differing temperature, rainfall and runoff conditions. This is possible since approximate limits have been established for plant and animal distribution under different salinity, temperature and substratum conditions, and the limits of these variable can be predicted under various amounts of rainfall and runoff.

These studies emphasize that estuarine research must take into account the history of water supply to a given area in order to predict accurately the effects of changes in this supply.

The Everglades Park estuary is like other estuaries in Florida and elsewhere in many of its hydrographic characteristics and in its flora and fauna. On the east coast of Florida the estuaries are similar in nearly all respects as far north as the northern end of the Indian River, at Daytona Beach. On the west coast the estuaries are similar at least as far north as Tampa Bay, north of there rainfall cycles are not as pronounced, so salinity variations may not be so marked. North of Daytona Beach on one coast and of Tampa on the other, the estuaries vary in temperature, substratum and runoff characteristics to varying degrees, but many of the following remarks apply. Hence this study can assist in predicting the past biological characteristics of other regions in Florida and nearby areas as well as those in the study area.

Coot and Whitewater Bays have probably always been regions of very low salinity since they lie at the focal point for runoff from the Everglades. In the original state the Everglades drainage extended as far north as Ocala in central Florida. The probable magnitude of runoff that funneled into the

Shark River estuary prior to about 1920, when drainage operations began in the Lake Okeechobee region, may be inferred from estimates made by Johnson (1958). He calculated that runoff from the central Everglades that passed the area now traversed by the eastern 40 miles of the Tamiami Trail was probably about 2.3 million acre-feet in average rainfall years and as high as 10.7 million acre-feet in peak rainfall years. He also recognized that the watershed has probably always had droughts similar to those experienced by the area at present. During such droughts runoff was negligible, as is now the case.

However, we believe that the effects of drought were probably much less severe in the past than now, since the central Everglades had at least 50 per cent more fibrous peat soil than is found there today (Davis, 1946). This soil, lost through drainage-induced oxidation and reduction by fires, had great water holding capacity and undoubtedly acted as a vast sponge, releasing water slowly over a long period.

The period when water is released in sufficient quantity to cause marked dilution of seawater in the estuary we have named the hydroperiod. During pre-drainage times the hydroperiod probably extended throughout the year and into the following rainy season. The following estimates of predrainage salinity patterns (i.e. those prevalent prior to the first development of the Everglades for agriculture about 1920) are made on the basis of unpublished estimates of runoff, on the work by Spackman and Dolson (1961), on the work by Davis (1946), and on our own observations of the present distribution of animal and plant remains in the bottom muds.

Coot Bay and Whitewater Bay, as well as the swampy regions to their north, were probably fresh (0.0 ppt) to slightly salty (10.0 ppt) in pre-drainage years of average runoff. Salinities there probably ranged between 0.0 and 5.0 ppt during years of above-average runoff. During drought periods of more than one year's duration salinities probably increased to between 15.0 and 35.0 ppt throughout this area as they do now, but this increase probably was not as abrupt as now.

Following completion of the major drainage projects in the watershed in about 1941, runoff conditions changed markedly. Records of runoff past the eastern 40 miles of the Tamiami Trail during the period 1941-57 averaged 473,200 acre-feet, rising to 1.4 million acre-feet in the peak rainfall year of 1947. It appears that runoff during the 1941-1957 period (when Geological Survey records are available) was characteristic for the present reduced drainage basin, and that runoff that we observed during the 1957-62 period (when records ceased to be available) was probably typical of conditions in the watershed at least as far back as 1941.

Under the conditions of runoff experienced during 1941-62 the hydroperiod, which had formerly lasted the whole year, appears to have been reduced by about three months, meaning that the runoff during average to slightly above-average rainfall years lasts only about nine months, ending in late winter. During March, April and May of each year of average rainfall and runoff from the present watershed, there is too little fresh water to dilute Coot and Whitewater Bays, and these as well as the surrounding regions approach marine conditions; at present Coot Bay salinities range between 10.0 and 30.0 ppt in average runoff years. In years of above-average rainfall, salinity values range between 6.0 and 18.0 ppt. In years when rainfall in the watershed falls below 40 inches, Coot Bay salinity is between 25.0 and 40.0 ppt. During the period of observation (July, 1957 through May, 1962) Coot Bay bottom salinity averaged 23.7 ppt. This is believed to be more than double the average long-term salinity during pre-drainage times (i.e., before 1920).

During the present drainage period (1941-62) salinity in southeastern Whitewater Bay, as far west as Clearwater Pass, probably has averaged 15.0 to 18.0 ppt. During average rainfall and runoff years salinity in southeastern Whitewater Bay has probably ranged from 10.0 to 25.0 ppt, falling to 0.0 to 25.0 ppt in years of above-average runoff. During periods of drought the region has probably undergone annual salinity ranges between 15.0 and 40.0 ppt.

In pre-drainage times the region west of Clearwater Pass (including the Shark River estuary) probably was characterized by low salinity, with the daily tides failing to intrude much beyond the present Oyster Bay oyster reefs. At present the tides intrude twice daily to Clearwater Pass and slightly beyond. The pre-drainage runoff through the Shark River was probably sufficiently heavy to form delta deposits, chiefly of peaty material, in the region now known as Ponce de Leon Bay. Mangrove forests probably grew on these deposits as they now do along the present Shark River estuary.

The drainage area of Florida Bay is restricted to the southern coastal area of Dade and Monroe Counties. Rainfall in the northern part of this watershed is heavy (averaging 50-55 inches) but it runs off rapidly and salinities rise as a result of the high evaporation rate of the Florida Bay region. Probably the past salinity characteristics of Florida Bay have been very similar to those observed at the present time. The changes which began in the Everglades about 1920, which had considerable effect on the Coot-Whitewater Bay complex and on areas from there north to Lake Okeechobee, did not affect Florida Bay salinity. The opening in 1957 of the canal between Coot Bay and Florida Bay affected conditions in the former but has had very little affect on the latter, because of its great volume. In average rainfall years salinity values between 15.0 and 18.0 ppt prevail for a short time during the peak of runoff along the shore in the northeast quadrant of Florida Bay,increasing both to the south and west till they reach 35.0 ppt in the area of mixing with the Atlantic Ocean and the Gulf of Mexico. During the dry season of average rainfall years salinities have ranged from 35.0 ppt at the Gulf and Atlantic edges to 45-50.0 ppt in the central and northern parts of the bay. During severe drought periods salinity values rise to 60.0 to 70.0 ppt.

Although the drainage area tributary to Florida Bay is small, it is important as a moderating influence on the evaporation-induced high salinities in Florida Bay. The rainfall on the northern part of the watershed in the vicinity of Homestead is especially important, since there is a marked reduction in annual precipitation to the south. Thus, if runoff from this limited watershed were to be reduced by canalization and upstream use to the area within the boundaries of the park, hypersalinity would become a permanent condition. Salinities of 45.0 to 70.0 ppt would probably become common except for short periods during peaks of runoff. Such conditions of hypersalinity would quickly be transmitted to Coot and Whitewater Bays by net gain of salt on each tidal intrusion through Buttonwood Canal, so that Coot Bay and much of eastern Whitewater Bay would also become hypersaline during dry years. Such conditions were observed during the peak of the drought of March through May, 1962.

It appears that the waters of the study area are destined to undergo further alteration as upstream reclamation and water use keeps pace with a rapidly growing industrial and urban population. If, as now seems possible, the watershed is reduced to the area within the boundaries of the Park, it is probable that Coot and Whitewater Bays and swamps inland 4 to 5 miles will become nearly marine in character. The hydroperiod would then probably be reduced to the period of the normal rainy season, June through September, plus the approximately two months that surface water requires to run from the north Park boundary to Whitewater Bay. By the end of this six month period high salinities from Florida Bay will have overcome the diluting effect of the runoff and probably will limit the effective hydroperiod to about five months. Coot Bay salinities would probably average about 30.0 ppt, and range between 15.0 and 40.0 ppt in years of average rainfall. During drought periods the range probably would rise to 35.0 to 55.0 ppt, or higher. Whitewater Bay would probably have similarly increased salinities, with wide fluctuations in wet years between 5.0 and 35.0 ppt due to high runoff in a relatively short time period. In drought periods salinities would probably range between 35.0 and 50.0 ppt throughout.

The effects of such salinity patterns on the biota would be pronounced. In pre-drainage times (before about 1920) the Coot Bay and Whitewater Bay region probably had a relatively small number of plant and animal species, either secondary fresh-water animals such as the killifishes, with limited tolerance to salt, or euryhaline species (i.e. those able to tolerate extremely low as well as high salinities). During pre-drainage times these areas, as well as the mangrove swamps to their north, were probably much like that found in the West Lake region today. That is, *Chara hornemannii, Ruppia maritima* and *Batophora oerstedi* were the dominant plants, while the common animals were probably about seven species of near-euryhaline fishes: the snook, *Centropomus undecimalis,* tarpon, *Megalops atlantica,* striped mullet, *Mugil cephalus,* striped mojara, *Diapterus plumieri,* tidewater silverside, *Menidia beryllina,* American eel, *Anguilla rostrata,* emerald goby, *Gobionellus smaragdus;* two crustaceans: the blue crab, *Callinectes sapidus,* ivory barnacle, *Balanus eburneus;* and three molluscs: the pointed venus, *Anomalocardia cunimeris,* Mitchil's macoma, *Macoma mitchelli,* and the Florida marsh clam, *Polymesoda floridana.* In addition to these there were probably large numbers of salt-tolerant cyprinodont fishes (the marsh killifish, *Fundulus confluentus,* mosquitofish, *Gambusia affinis,* and sailfin molly, *Mollienesia latipinna),* as well as one crustacean, *Palaemonetes intermedius,* one mollusc, *Congeria leucophaeta,* and large quantities of dragonfly nymphs.

Under these conditions the area was a prime winter feeding ground for the coot *(Fulica americana)* that gave the name to Coot Bay, and large numbers of herons, egrets and ibis. With increasing salinity, the *Chara-Ruppia-Batophora* community has largely disappeared, and with it the large bird populations. During drought periods of pre-drainage times, rising salinity undoubtedly permitted invasions by high-salinity forms. Then these probably suffered extensive mortality at the onset of the summer rains. The scarcity of oyster shells in Coot and Whitewater Bays indicates that water conditions were too fresh until recently to support large oyster populations. It is expected that oysters will become widespread in the region as salinity values increase.

Under runoff conditions ordinarily prevailing at present, where salinities in Coot and Whitewater Bays fluctuate between 10.0 and 30.0 ppt, the number of common species of plants and animals has increased markedly over that believed to have been present during pre-drainage times. The list of animals present now includes at least 24 species of fish (Table 5), 8 crustaceans, 16 molluscs, 2 echinoderms, 3 polychaete worms (Table 10), one seed bearing plant, *Ruppia maritima,* and 3 species of algae. In addition to these, the young of at least a dozen more species, common offshore as adults, are able to enter the region. These species, that are marine as adults but nearly euryhaline as larvae and juveniles, include the gray snapper, *Lutjanus griseus,* lane snapper, *L. synagris,* red drum, *Sciaenops occelata,* and pink shrimp, *Penaeus duorarum.*

If future man-made changes in drainage restrict runoff to the area within the Park boundary, making the Coot Bay-Whitewater Bay region basically marine in character, it may be expected that these waters will be invaded by 200 or more species of marine plants and animals (Tabb and Manning, 1961) as permanent residents. These will die or be driven out of the region during the years of peak runoff but will return following the end of the reduced hydroperiod.

In Florida Bay very heavy runoff, with attendant low salinity, will cause a short-term reduction in numbers of species there, but this will last only for short periods.

Up to this point we have suggested what animal and plant populations are likely to result under low (0 to 15 ppt) and intermediate (15-35 ppt) salinities in Coot and Whitewater Bays. If the region becomes constantly hypersaline (35-70 ppt), the animals which entered the area when salinities were moderate (15-35 ppt) will begin to disappear again, and only the euryhaline species will be able to exist. It should be noted that many of the same species are present at low and at high salinities; the additional species enter or leave the community at intermediate salinities. The tolerance of most animals to low salinities reaches a peak during warm periods of the year, while maximum tolerance to high salinities is reached during the colder months. This would suggest that widely tolerant species would be most abundant in Florida Bay during the late fall and winter months when high salinities prevail, and that these same animals would move into the fresher waters along the upper reaches of the estuary during the warm summer months.

The salinity in Coot Bay and in Whitewater Bay reached 42 ppt in March 1962, a higher value than ever before recorded there. If salinities increased to levels much higher than this other effects would be expected in the animal populations. Salinities of 50-60 ppt limit spawning and survival of young of many species, so that recruitment must be from salinity-stable areas outside the hypersaline regions. Emery, *et all.* (1957) suggest that salinity values as high as 60-70 ppt approach the lethal limit for the majority of marine animals.

In addition it is believed that the character of the water masses of Coot, Whitewater and Florida Bays will change appearance with an increase in average salinity to 30-40 ppt. Salinity approaching that of sea water tends to precipitate particulate matter so that the region would become one of noticeably clearer water. This would permit maximum growth and development of algae and marine grasses, which would further stabilize the bottom. Such conditions are favorable conditions for angling and sightseeing, but are far different from the conditions that existed in the estuary prior to 1920, when the waters were stained by humic acids, organic particles and marl in suspension. Under hypersaline conditions (above 45-50 ppt) the turtle grass, *Thalassia testudinum* is adversely affected. The blades of the "grass" die back and thus expose the bottom muds. If high salinity periods persist for periods of 3-5 months the turtle grass cover of Florida Bay becomes reduced by defoliation so that wind scour reaches the marl muds and turbidity increases markedly. Such turbidity conditions further limit the numbers of species that may be found in the region beyond that already reduced by hypersalinity. If the water resources of estuaries in the Everglades Park area can be manipulated to produce any desired salinity, the region might be made most desirable from the viewpoint of the angler and sightseer by reducing runoff slightly below the present level so that conditions approach that of the sea or 30-40 ppt salinity. Then there would be a wide variety of marine animals for angler exploitation and a high degree of water clarity and aquatic plant development. If, on the other hand, the goal were to return the Coot Bay-Whitewater Bay region to the pre-drainage condition it would be necessary to provide between 1.5 and 2.0 million acre-feet of fresh-water runoff annually, spread over at least 10 months of the year with a peak in January and February. Under these conditions the region would probably revert to a good wintering ground for wading and swimming birds since the waters would once again support big populations of killifishes, euryhaline fishes, crustaceans and molluscs.

An average flow of about 500,000 acre-feet of runoff from the watershed north of the Tamiami Trail seems necessary, during the period June to December, to maintain the present ecological status of the area and to moderate the effect of high-salinity Florida Bay water that now enters the region through Buttonwood Canal.

If the runoff can be manipulated at this level, the region will continue to have periods of low salinity during which the area can function as a nursery or sanctuary, in which small fish, shrimp and crabs can grow and develop with a minimum of predation and competition from the numerous marine species found just offshore. If runoff to this area is reduced below this level, and the salinity increases to marine and hypersaline levels the rate of predation and competition will increase sharply.

Most of the effects of man-made changes on plant and animal populations in Florida estuaries (and in many particulars in estuaries in adjacent regions of the Gulf of Mexico and the South Atlantic) are a result of alterations in salinity and turbidity. These changes, such as building of canals, island construction, causeway fills and dredged openings to the sea, alter the character of the plant and animal inhabitants. High salinities (30-40 ppt) favor the survival of certain species like sea trout, redfish and other marine fishes, and therefore improve angling for these species. On the other hand these higher salinities reduce survival of the young stages of such important species as commercial penaeid shrimp, menhaden, oysters and others. It seems clear that the balance favors the low to moderate salinity situation over the high salinity. Therefore, control in southern estuaries should be in the direction of maintaining the supply of sufficient quantities of fresh water which would result in estuarine salinities of 18 to 30 ppt.

LITERATURE CITED

Bayer, F. M.
1952. New Western Atlantic records of octocorals *(coelenterata: anthozoa)* with descriptions of three new species. J. Wash. Acad. Sci., *42* (6) : 183-189.

Brongeersma-Sanders, M.
1957. Mass mortality in the sea. *In:* Treatise on marine ecology and paleoecology. Geol. Soc. America, Mem. 67, *1:* 941-1010.

Collier, A.
1938. Hydrography of inland bays. Ann. Rept., Texas Game, Fish and Oyster Comm., 1937-38: 33-38.

Collier, A. and J. W. Hedgpeth
1950. An introduction to the hydrography of tidal waters of Texas. Publ. Inst. Mar. Sci., Texas, *1* (2) : 121-194.

Cooke, C. W.
1945. Geology of Florida. Fla. Geol. Surv., Bull. 29: 1-339.

Cooke, C. W. and S. Mossom
1929. Geology of Florida. Fla. Geol. Surv., 20th Ann. Rept., pp. 29-227.

Davis, C. C.
1948. Notes on the plankton of Long Lake, Dade Co., Florida, with descriptions of two new copepods. Quar. J. Fla. Acad. Sci., *10* (2-3) : 79-88.

Davis, J. H.
1940. The ecology and geologic role of mangroves in Florida. Carnegie Inst. Wash., Publ. 517:303-412.
1943. Natural features of southern Florida. Fla. Geol. Surv., Geol. Bull. 25: 17-301.
1946. Peat deposits of Florida, their occurrence, development and uses. Fla. Geol. Surv., Geol. Bull. 30: 1-247.

Dawson, C. E.
1955. A contribution to the hydrography of Apalachicola Bay, Florida. Publ. Inst. Mar. Sci., Texas, *4* (1) : 13-37.

Dragovich, A., Finucane, J. H. and B. Z. May
1961. Counts of Red Tide Organisms, *Gymnodinium breve,* and associated oceanographic data from Florida West Coast, 1957-1959. U. S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish., No. 369: 1-175.

Emery, K. O. and R. E. Stevenson
1957. Estuaries and lagoons. *In:* Treatise on marine ecology and paleoecology. Geol. Soc. America, Memoir 67, *1:* 679-693.

Finucane, J. H. and A. Dragovich
1959. Counts of Red Tide organisms, *Gymnodinium breve,* and associated oceanographic data from Florida West Coast, 1954-1957. U. S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish., No. 289: 1-220.

Florida Water Resources Study Commission
1956. Florida's water resources. Fla. St. Bd. Conserv., Rept. to the Governor of Florida and the 1957 Legislature, pp. 1-91.

Florida State Board of Conservation
1954. Summary of observed rainfalls to 31 December, 1952. Div. Water Surv. and Res., Fla. Water Surv. and Res. Pap., 11: 1-334.

Ginsburg, R. N.
1956. Environmental relationships of grain size and constituent particles in some South Florida carbonate sediments. Bull. American Assoc. Petr. Geol., *40* (10) : 2384-2427.

Goodell, H. G. and D. S. Gorsline
1961. Data report — the hydrography of Apalachicola and Florida Bays, Florida. Fla. St. Univ., Sedimentological Res. Lab., Contrib. No. 1: 1-316.

Gunter, G.
1945. Studies on the marine fishes of Texas. Publ. Inst. Mar. Sci., Texas, *1* (1): 1-190.
1950. Seasonal population changes and distribution as related to salinity, of certain invertebrates of the Texas coast, including the commercial shrimp. Publ. Inst. Mar. Sci., Texas, *1* (2): 7-53.

Gunter, G. and H. H. Hildebrand
1951. Destruction of fishes and other organisms on the south Texas coast by the cold wave of Jan. 28-Feb. 3, 1951. Ecology, *32* (4): 731-736.

Harper, R. M.
1927. Natural resources of southern Florida. Fla. Geol. Surv., 18th Ann. Rept., pp. 27-206.

Hay, W. P. and C. A. Shore
1918. The decapod crustaceans of Beaufort, North Carolina, and the surrounding region. Bull. U. S. Bur. Fish., *35:* 369-475.

Hedgpeth, J. W.
1953. An introduction to the zoogeography of the northwestern Gulf of Mexico with references to the invertebrate fauna. Publ. Inst. Mar. Sci., Texas, *3* (1): 110-224.

Hela, I.
1952. Remarks on the climate of southern Florida. Bull. Mar. Sci. Gulf and Carib., *2* (2): 438-447.

Holthuis, L. B.
1951. A general revision of the *Palaemonidae* (Crustacea, Decapoda, Natantia) of the Americas. I. The sub-families *Euryrhynchinae* and *Pontoniinae.* Allan Hancock Found., Occ. Pap., No. 11: 1-332, pls. 1-63.
1952. A general revision of the *Palaemonidae* (Crustacea, Decapoda, Natantia) of the Americas. II. The Sub-family *Palaemoninae.* Allan Hancock Found., Occ. Pap., No. 12, 1-396, pls. 1-55.

Hoy, N. D. and M. C. Schroeder
1952. Age of subsurface "Tamiami" formation near Miami, Florida. J. Geo., *60* (3): 283-286.

Johnson, L.
1958. A survey of the water resources of Everglades National Park, Florida. Rept. to Everglades Nat'l Park, pp. 1-36 (mimeo.).

Joseph, E. B. and F. E. Nichy
1955. Literature survey of the Biscayne Bay area. Part II. Algae, marine fouling and boring organisms. The Oceanogr. Inst., Fla. St. Univ., Tallahassee, Fla., 1-33 (mimeo.).

Klein, H. and C. B. Sherwood
1961. Hydrologic conditions in the vicinity of Levee 30, northern Dade County, Florida. Fla. Geol. Surv., Rept. of Investigations, 24, Part 1: 1-24.

Manning, R. B.
1961. A redescription of the palaemonid shrimp, *Leander paulensis* Ortmann, based on material from Florida. Bull. Mar. Sci. Gulf and Carib., *11* (4): 525-536.
1961a. Some growth changes in the stone crab, *Menippe mercenaria* (Say). Quart. J. Fla. Acad. Sci., (1960) 23 (4): 273-277.

Marmer, H. A.
1954. Tides and sea level in the Gulf of Mexico. *In:* Gulf of Mexico, its origin, waters, and marine life. U. S. Fish and Wildl. Serv., Fish. Bull., 89: 101-118.

Matson, G. C. and F. G. Clapp
1909. A preliminary report on the geology of Florida, with special reference to the stratigraphy. Fla. Geol. Surv., 2nd Ann. Rept., pp. 25-173.

Matson, G. C. and S. Sanford
1913. Geology and ground waters of Florida. U. S. Geol. Surv., Water-Supply Pap., 319: 1-445.

McClendon, J. F.
1918. On changes in the sea and their relation to organisms, Part I. Carnegie Inst. Washington, Publ. 252, Pap. Tortugas Lab., *12* (11) : 215-234.

McNulty, J. K.
1961. Ecological effects of sewage pollution in Biscayne Bay, Florida: sediments and the distribution of benthic and fouling macro-organisms. Bull. Mar. Sci. Gulf and Carib., *11* (3) : 394-447.

McNulty, J. K., Work, R. C. and H. B. Moore
1962. Level sea bottom communities in Biscayne Bay and neighboring areas. Bull. Mar. Sci. Gulf and Carib., *12* (2) : 204-233.

Moberg, E. G.
1927. Observations on the effect of tidal changes on the physical, chemical and biological conditions of the Sand Diego Region. Bull. Scripps Inst. Oceanogr., Tech. Ser., 1: 1-17.

Moore, H. F. and E. Danglade
1915. Conditions and the extent of the natural oyster beds and barren bottoms of Lavaca Bay, Texas. Rept. U. S. Fish Comm., 1914: 1-45.

Odum, H. T.
1957. Primary production measurements in eleven Florida springs and a marine turtle grass community. Limn. and Oceanogr., *2:* 85-97.

Odum, H. T. and C. M. Hoskin
1958. Comparative studies on the metabolism of marine waters. Publ. Inst. Mar. Sci., Texas, *5:* 16-45.

Parker, G. G.
1942. Notes on the geology and ground water of the Everglades in Southern Florida. Proc. Soil Sci. Soc. Fla., 4A: 47-76.

Parker, G. G. and C. W. Cooke
1944. Late Cenozoic geology of Southern Florida, with a discussion of the ground water. Fla. Geol. Surv., Bull. 27: 1-119.

Parker, G. G., Cooper, H. H. and N. D. Hoy
1948. Water levels and artesian pressure in observation wells in the United States in 1945, Part 2, Southeastern States. U. S. Geol. Surv., Water-Supply Pap., 1024: 11-81.

Parker, R. H.
1959. Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre. Bull. Amer. Assoc. Petrol. Geol., *43* (9) : 615-682.
1960. Ecology and distributional patterns of marine macro-invertebrates, northern Gulf of Mexico. American Assoc. Petrol. Geol. *In:* Recent Sediments, Northwest Gulf of Mexico, 1951-1958, pp. 302-381.

Perry, Col. Lynn
1948. Interpretation of rainfall records at Miami. Quar. J. Fla. Acad. Sci., *10* (4) : 147-149.

Phillips, R. C.
1960. Observations on the ecology and distribution of the Florida seagrasses. Fla. St. Bd. Conserv., Prof. Pap. Ser., 2: 1-72.

Robins, C. R.
1957. Effects of storms on the shallow water fish fauna of southern Florida with new records of fishes from Florida. Bull. Mar. Sci. Gulf and Carib., *7* (3) : 266-275.

Schroeder, M. C., Klein, H. and N. D. Hoy
1958. Biscayne Aquifer of Dade and Broward Counties, Florida. Fla. Geol. Surv., Rept. of Investigations, *17:* 1-56.

Simmons, E. G.
1957. Ecological survey of Upper Laguna Madre of Texas. Publ. Inst. Mar. Sci., Texas, *4* (2) : 156-200.

Smith, F. G. W., Williams, R. W. and C. C. Davis
1950. An ecological survey of the subtropical inshore waters adjacent to Miami. Ecology, *31* (1) : 119-346.

Spackman, W. and C. P. Dolsen
1961. The characteristics of modern organic sediments and their use in the identification of carbonaceous rocks and rock sequences. Proc. 1st Nat'l Coastal and Shallow-Water Res. Conf., Sponsored by National Science Foundation and Office of Naval Research, pp. 155-160.

Storey, M.
1937. The relation between normal range and mortality of fishes due to cold at Sanibel Island, Florida. Ecology, *18* (1) : 10-26.

Tabb, D. C., Dubrow, D. L. and R. B. Manning
1959. Hydrographic data from the inshore bays and estuaries of Everglades National Park, Florida, 1957-1959. Mar. Lab., Univ. of Miami, Rept. 59-5: 1-26 (mimeo.).

Tabb, D. C. and R. B. Manning
1961. A checklist of the flora and fauna of northern Florida Bay and adjacent brackish waters of the Florida mainland collected during the period July, 1957 through September, 1960. Bull. Mar. Sci. Gulf and Carib., *11* (4) : 552-649.

Tabb, D. C. and D. L. Dubrow
1962. Hydrographic data, Supplement I, from the inshore bays and estuaries of Everglades National Park, Florida, 1959-1962. Mar. Lab., Univ. of Miami, Rept. 62-9: 1-23 (mimeo.).

Tabb, D. C., Dubrow, D. L. and A. E. Jones
1962. Studies on the biology of the pink shrimp, *Penaeus duorarum* Burkenroad, in Everglades National Park, Florida. Fla. St. Bd. Conserv., Tech. Ser., 37: 1-30.

Tabb, D. C. and A. C. Jones
1962. Effect of hurricane Donna on the aquatic fauna of North Florida Bay. Trans. Amer. Fish. Soc., *91* (4) : 375-378.

Thomas, L. P.
1961. Distribution and salinity tolerance in the amphiurid brittlestar, *Ophiophragmus filograneus* (Lyman). Bull. Mar. Sci. Gulf and Carib., *11* (1) : 158-160.

Voss, G. L. and N. A. Voss
1955. An ecological survey of Soldier Key, Biscayne Bay, Florida. Bull. Mar. Sci. Gulf and Carib., *5* (3) : 203-229.

Wass, M. L.
1955. The decapod crustaceans of Alligator Harbor and adjacent shore areas of Northwestern Florida. Quart. J. Fla. Acad. Sci., *18* (3) : 129-176.

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