THE ENVIRONMENT OF SOUTH FLORIDA, A SUMMARY REPORT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1011

U.S. DEPARTMENT OF THE INTERIOR

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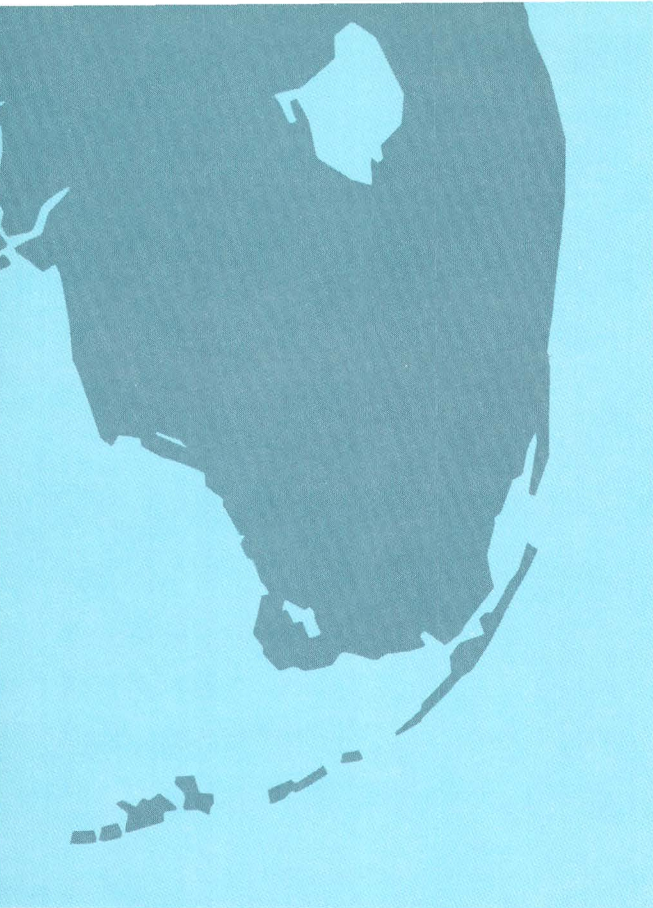

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By B. F. McPherson, G. Y. Hendrix,
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A description of the south Florida ecosystem and changes resulting from man's activities

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Foreword

The South Florida Environmental Study indicates a growing awareness of the necessity for man to understand the relationship between his own actions and the response of the natural environment to them. Studies of this kind provide a means for man, if he so chooses, to select activities which should be undertaken to enhance the human condition and yet avoid the disastrous ecological consequences that sometime result from actions taken without understanding the natural processes that may be affected.

This study summarizes events that began in 1971 as the efforts of seven Federal agencies to deal with one particular problem—a controversial proposed jetport at the edge of Everglades National Park—and carries them to the point where Federal, State, regional, county, and local government bodies could begin to function innovatively as a working team.

Progress to date has occurred in two stages: Phase one, the results of which are summarized in this report, was the Federal effort to develop the scientific information base needed by Federal, State, and local land-resource managers to make informed decisions affecting both the economy and environment of south Florida. Phase two, already well underway, is the cooperative attempt by all levels of government and their appropriate agencies to utilize the information developed during the phase one effort to make land and water-use decisions for south Florida that not only protect the region's outstanding natural resources but provide economic vitality as well.

Such a working rapprochement between the economy and the environment demands wide citizen participation. Phase two is working to raise general understanding of the basic system of man and nature —the economy and the environment—and how it interacts. As a byproduct of this cooperative process, the general public is becoming involved to the point that it understands the factors that control its destinies. With this understanding comes the ability of citizens to express their desires to resource managers and elected officials. I believe that every additional measure of wisdom that accrues to the citizenry of this Nation enriches our decisionmaking process and contributes to the maintenance of our economy, our environment . . . our very way of life.

As a result of the phase one work, it is concluded that the following steps should be taken to protect the south Florida ecosystem from further damage and degradation:

1. Determine, through local and State governments, human population carrying capacity for the region and for the subunits of the region that is compatible with the goal of no further environmental degradation and with resources and energy constraints;
2. Adopt, through local and State governments, a land-use plan based on this determination of carrying capacity;
3. Pass State and local legislation that supports the land-use plan and creates enforcement machinery for its implementation; and
4. Monitor the essential natural resource, economic, sociologic, and energy factors to ensure that the regional policy and land-use plan are being followed. Centralize, standardize, and publish this information on a regular basis.

The problems that set this study in motion have not all been solved. Indeed, many of them have changed and some have totally disappeared. But a host of new ones have taken their places and wait now upon the wisdom we have so far gleaned.

What has been created is a better grasp of the underlying causes for south Florida's environmental problems and some new ways of getting a handle on the slippery nature of change. The challenge that remains is to arrive at rational solutions and to implement them. This cannot be "done," in the sense of finishing. It will require a continuing dialogue and coordinated effort from all the parties that have been involved.

What follows is a study of the components and processes that constitute the south Florida environmental system, a look at the resources of both man and nature and how they can be made to fit together to form alternative viable futures. It is intended to serve as a departure point for the on-going phase two study and for the State and county land-use plans yet to emerge.

Thomas S. Kleppe
Secretary of the Interior
August 23, 1976

Preface

In 1968 the planned construction of an international jetport in the Big Cypress Swamp of south Florida by the Dade County Port Authority triggered a controversy and a series of events that involved private and public interest. Local conservation groups and concerned citizens questioned the potential effects of such a jetport and the attendant urban growth in the Big Cypress Swamp both on the nearby Everglades National Park and on the south Florida environment. The Federal Government initiated, through the U.S. Department of the Interior, a preliminary study to evaluate the environmental impact of the proposed jetport. That study (Leopold and others, 1969) indicated that the proposed jetport would adversely affect not only the ecosystem of Everglades National Park, but that of the remainder of south Florida as well. For that reason the Federal Government opposed the construction of the jetport at the proposed location.

In the pact with Dade County and the State of Florida, the Federal Government agreed, however, to aid in the location and purchase of a new and acceptable site for the jetport. An obligation of the Federal Government under this pact was to implement an ecological study of south Florida. Five bureaus of the Department of the Interior—National Park Service, Geological Survey, Bureau of Sport Fisheries and Wildlife (now Fish and Wildlife Service), Bureau of Outdoor Recreation, and the Bureau of Indian Affairs—and two former Interior agencies—Federal Water Quality Administration (now Environmental Protection Agency) and Bureau of Commercial Fisheries (now National Marine Fisheries)—were asked to participate. These bureaus and agencies completed 51 separate reports (available through the U.S. Department of Commerce, National Technical Information Service). This summary report, which is an overview of the south Florida environment, is based on and covers the highlights of the 51 reports. The abstract of each is included in the References.

The South Florida Environmental Study identified and described the natural ecosystems of south Florida as they functioned before man began to have major impacts on these systems. Where remnants of natural systems still function as before, they were measured and described.

The study also encompassed the agricultural and urban developments of south Florida and their impacts on the ecosystems. Man is a natural component of the system and, like all living components, seeks to attain some degree of balance or equilibrium with the rest of the system.

This report concludes phase one of the South Florida Environmental Study and fulfills in part the Department of the Interior's obligation to Dade County and the State of Florida to study and report upon the south Florida environment.

A second phase of the South Florida Environmental Study, now nearing completion, began in 1974 with a joint agreement among the State of Florida, the U.S. Department of the Interior, and the University of Florida Center for Wetlands, designating specific products from three participating bodies.

The Center for Wetlands was to (1) prepare land-use maps of the south Florida region as a whole and of three demonstration counties within the region—Lee, Collier, and Hendry—showing them in their primitive state, as they were in 1953, and as they had become by 1973; and (2) to produce models of the ecological systems defined and/or described in the phase one study. These models were to determine, to the extent possible, flows and storages of energy in the south Florida environment and in select instances to make predictions and recommendations for water, land, and energy use, and for a carrying capacity that could sustain a viable economy and environment in the region.

The Florida Division of State Planning agreed to prepare and publish four reports—one for the south Florida region as a whole and one each for the three counties, Hendry, Lee, and Collier. The reports were to be written in laymen's language and contain the results of the Center for Wetlands modeling studies, together with copies of the regional maps. It was also agreed that the State would fund a full-time planner in each of the three demonstration counties, to work with the county planning departments on integrating the modeling study results and recommendations with the developing county land-use plans. The State effort was also to relate these activities to the Division of State Planning's legislated responsibilities under the Florida Environmental Land and Water Management Act of 1972.

The Department of the Interior, in addition to substantial funding of the phase two project, agreed to help provide the data base for the Center for Wetlands modeling and to arrange for its own agencies' review of the resulting products. It is Interior's responsibility under terms of the joint agreement to publish the technical report emanating from the Center for Wetlands modeling studies. That report will be published by the National Park Service.

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Synopsis

After 1900 men came in increasing numbers to south Florida and began extensive modification of the vast wilderness of swamps, forests, marshes, prairies, and bays. The original south Florida ecosystem that evolved over thousands of years gave way to a new three-part ecosystem which incorporated an agricultural component, an urban component, and a component of the original ecosystem that is largely undeveloped but still has been affected by man. These components are interrelated through the flow of energy and resources.

The remaining natural component of the south Florida ecosystem includes freshwater and terrestrial systems such as ponds and sloughs, sawgrass marshes, wet prairies, hammock forests, bay heads, cypress forests, pine forests, mixed swamp forests, and dry prairies; and coastal systems such as bays, coral reefs, mangroves and saline marshes, and beaches and dunes.

The freshwater and terrestrial systems are controlled, in part, by the moisture in the soil, or by the duration and the depth of inundation; these in turn are determined by the amounts and frequency of rainfall, the infiltration capacity of the soil and underlying bedrock, and by land altitude. High areas that are seldom flooded usually support pine forests, hardwood hammock forests, or grassland systems. Low areas that are flooded part of the year are wetlands,

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[3] U.S. Fish and Wildlife Service, Raleigh, North Carolina.

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which include prairies, marshes, or swamp systems. The hydrologic environment, however, is not the sole control on a system. Fire, tropical storms, frost and cold weather, saltwater intrusion, and man also affect systems.

Freshwater is a key environmental factor in that it not only affects a system directly but that it also affects other controlling environmental factors such as fire, soil, temperature, and saltwater intrusion. Freshwater is also a key factor manipulated by man.

Many of the plants and animals of south Florida are adapted to and dependent on the seasonal fluctuations of freshwater levels. During wet seasons, aquatic plant production abounds; small crustaceans and fish feed on the growing plants or plant remains. With abundant food and space, aquatic animal populations increase. As water levels decline during the dry season, the small aquatic animals are forced to concentrate in scattered ponds, tributary creeks, and sloughs. The concentrated biomass then becomes a rich source of food for larger fish, alligators, snakes, birds, and mammals.

The coastal systems of south Florida are dependent on currents, tides, waves, and in most cases freshwater runoff to circulate and transport salts, nutrients, and other essential products. Freshwater runoff also dilutes seawater. Mangrove forests usually grow where freshwater runoff is greatest and salinity is seasonally reduced, whereas coral reefs occur in areas of little or no runoff and normal seawater salinity. In estuaries and bays, salinity varies during the year depending on the amount of runoff and evaporation. Within these systems, salinity is a major controlling factor on the distribution of organisms.

The coastal systems are also affected by other environmental factors such as cold weather, water turbidity, and tropical storms. Coral reefs, for example, flourish only in shallow clear warm seas and cannot endure temperatures below about 18°C (64°F). Bays and estuaries also benefit from clear water and are adversely affected by turbidity, which reduces sunlight penetration to sea grass and algal beds and thus reduces productivity. Tropical storms often alter coastal systems and are the major natural force that changes the distribution of mangrove forests.

Mangrove forests serve several important functions in the regional system of south Florida. They provide the nutrients and the shelter essential for maintenance of estuarine productivity and coastal fisheries. Tidal flushing carries mangrove leaf litter and seeds into coastal water where they are broken down by microorganisms and are made available as food to estuarine and marine species. The tangled mangrove roots and submerged trunks provide small animals with shelter from predators. Mangroves help to keep the water clear by trapping debris and sediment, and they also provide some protection to upland environments during tropical storms.

Shallow bays and estuaries are feeding and nursery grounds for many marine and estuarine species. Food is not only flushed into the bays and estuaries from mangrove forests and marshes but it also is produced in the bay by sea grass and algal communities. Juveniles of many marine species derive food and protection in estuaries and bays and thus require these habitats to complete their life cycles. More than 75 percent of marine commercial and sport fish of south Florida utilize and depend on bays and estuaries. The importance of these fish is stressed by the fact that marine commercial and sport fishing in the State generates more than $600 million annually.

Man has been altering the ecosystem of south Florida extensively for 70 years. About 35 percent (7,700 km^2 or 3,000 mi^2) of the natural habitat of the ecosystem has been destroyed by agriculture or urbanization. The remaining natural habitat is now threatened by exotic plants and animals, altered water levels and flows, severe fires, pollution, loss of animal and plant populations, and by further growth and development.

Man's most dramatic and long-term effects on the ecosystem have resulted from drainage. Wetlands originally occupied about 75 percent of south Florida, but through the years much of this land has been drained. In southeast Florida, drainage has lowered water levels as much as 1.5 to 1.8 m (5 to 6 ft) below the 1900 level and has disrupted the natural systems. In southwest Florida, drainage has lowered water levels as much as 0.6 to 1.2 m (2 to 4 ft) over a 195-km^2 (75-mi^2) area near Naples and has lowered them an undetermined amount over the remaining western Big Cypress Swamp. Drainage reduces productive wetlands, promotes organic soil oxidation and damaging fires, and has permitted seawater intrusion in some areas of excessive water-table lowering. Drained lands usually become farms and urban areas that themselves further alter the environment.

The introduction by man of exotic plants and animals has also altered parts of the natural systems of south Florida and threatens to alter much more. Exotic species often compete with and ultimately replace native ones and thus drastically change systems. Drainage and land clearing have increased the opportunity for exotic species to become established by stressing native species and reducing their ability to compete. Perhaps the most dramatic invasion is the rapid spread of cajeput, Australian pine, and Brazilian pepper.

The populations of many of south Florida's wildlife species have declined. Eleven species of birds and three species of mammals are endangered. Perhaps the most dramatic is the decline of wading birds from about 2.5 million in 1870 to about 150,000 in 1973.

The introduction of toxic chemicals, nutrients, and pathogenic organisms in increasing amounts threatens to further alter the ecosystem of south Florida. Most are transported to and accumulate in the aquatic environment where they degrade the quality of the water and alter or destroy life. Water quality has deteriorated over much of the region, and the deterioration is greatest in the east coast urban area. Most canals that drain urban or agricultural land contain toxic chemicals and high concentrations of nutrients. High nutrient concentrations favor the growth of dense stands of nuisance aquatic plants that clog canals and further degrade water quality. Canals also can serve as pathways to the estuaries for pollutants.

Dredge and fill and bulkheading are major threats to estuaries and marine fishery resources of south Florida. These activities not only reduce the vital littoral zone that serves as a nursery and feeding area but they also alter freshwater and nutrient inflow. Moreover, dredging increases the amount of sediment suspended in bay water; this sediment blocks out light necessary for photosynthesis. Tides transport the suspended sediment to other parts of the the estuary where it may settle and suffocate plants and animals far removed from the dredging operation.

Agricultural and urban systems require freshwater to sustain them, and thus they compete with the remaining natural systems. Urban water shortages were indicated by the need to impose water-use restrictions in southeast Florida during the 1970–71 drought, and by progressive lowering of water levels each dry season in coastal parts of southwest Florida. The present difficulty in water supply is linked to urban demands that require increasing diversions of water from the natural and agricultural systems. Altered flow patterns of freshwater in the natural system adversely affect wetland and estuarine systems. The agricultural systems also depend on an adequate water supply, without which productivity drops.

Water-management methods have been proposed to increase the availability of freshwater to satisfy the future urban and agricultural demands and to alleviate the stress on the natural systems during prolonged drought. In southwest Florida a water-management method to increase availability of water would require, at this time, only reducing the discharge of water from canals. In southeast Florida, however, saving more water would require management techniques such as backpumping excess storm water and increasing the storage of Lake Okeechobee. Reducing canal flow by backpumping storm water into the conservation areas could save possibly 50 percent of the total canal runoff, which ranges from 28 to 193 m^3/s (1,000 to 6,800 ft^3/s) in southeast Florida. Backpumping, however, may have some adverse environmental effects on the natural system. For example, in parts of the Everglades it would raise water levels, prolong inundation, probably alter water quality, and thereby cause vegetative changes. Backpumping would also decrease the flow to the estuaries and thus alter salinity and nutrient input there. In addition, backpumping would provide some degree of flood protection for land now unsuitable for residential development and thereby enhance land values in formerly undevelopable tracts.

Agricultural and urban systems rely on the remaining natural systems not only for such commodities as land, but also for the benefits or "free services" provided by the natural systems. These services include maintaining a stable quality environment through oxygen production, recycling nutrients, dispersing and detoxifying pollutants, retaining biological diversity, and producing fish and wildlife. If the natural systems are destroyed or greatly reduced, the services they once provided free must be provided by the agricultural or urban systems, usually at a high cost.

Agricultural and urban systems require an input of energy in addition to that supplied by the sun, wind, and rain. Most of this energy is imported as fossil fuel or as a fossil-fuel product. Urban societies, in particular, require a large input of outside energy to build and maintain their complicated structure of transportation, schools, laws, communication networks, buildings, and public services. Continued growth or even maintenance depends on the availability of energy. As cities grow, so do energy requirements; if these are not met, stress occurs and the quality of life deteriorates.

In recent years, urban growth in south Florida has been rapid. The population increased from slightly less than 0.5 million in 1940 to 2.5 million in 1970. If present trends continue, by 2000 south Florida would have more than 4.4 million residents, or about an 80-percent increase from 1970.

History of the South Florida Environmental Study

Perhaps it was inevitable that Dade County would propose to build the world's largest airport complex. Such a complex would serve the tourist industry, which in 1970 provided nearly $2.1 billion to the economy of the area (Davis, 1972). Businessmen for many years have advocated a policy of expanding tourism that naturally would require enlarging the aviation center serving south Florida.

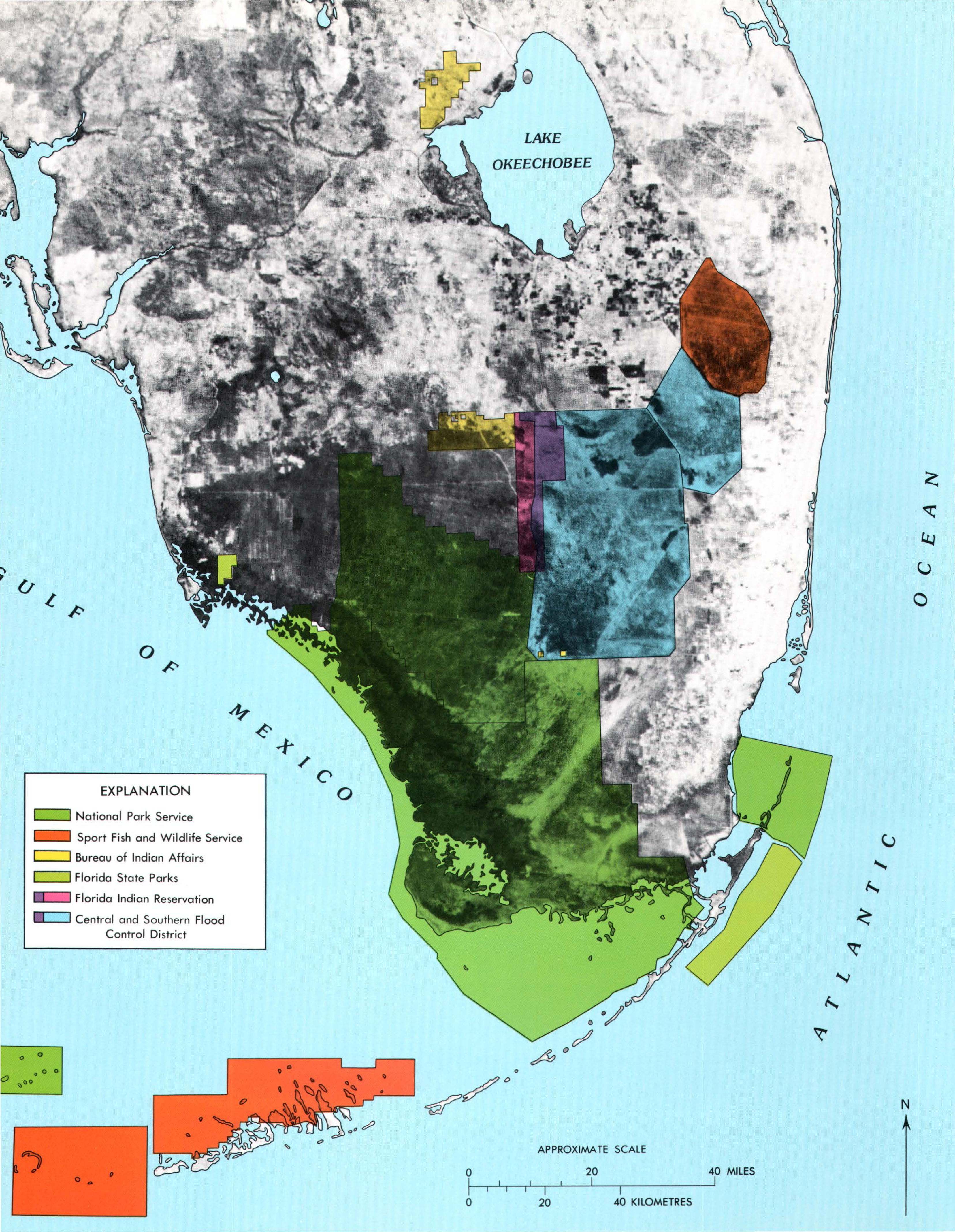
As an alternative to enlarging the existing aviation center, the Dade County Port Authority began a search for a suitable location for a jet training facility late in 1965. The immediate need to supply a jet training facility, coupled with the outlook for additional traffic, suggested to the business community a need to create a large aviation complex to serve all south Florida. By September 1968, the Port Authority selected a 101-km^2 (39-mi^2) site in the Big Cypress Swamp shown in figure 1. This site, bounded on the north and west by cypress forest and swamps, was 10 km (6 mi) north of the Everglades National Park and adjoined Conservation Area 3 of the Central and Southern Florida Flood Control District (FCD). The Port Authority authorized purchase and began construction in September 1968.

At the time of the Port Authority's decision there were at least three strong environmental concerns in south Florida: (1) Protection of Everglades National Park; (2) increased interest in public acquisition of the Big Cypress Swamp; and (3) mounting resistance to uncontrolled urban growth.

The jetport issue soon became a national issue. On February 28, 1969, the FCD called for public debate on a jetport in the Big Cypress Swamp. The U.S. Department of the Interior had strong interests in the region because of its responsibility for federally administered lands, as did the State of Florida for State-administered lands (fig. 2). The Department of the Interior interests had led, several years earlier, to the formation of a work group to informally study environmental problems; this group formulated most of the questions. The consensus of the meeting was that studies would be required to obtain the information needed to answer the questions asked for the Port Authority. On May 19, 1969, in West Palm Beach, the FCD called a second meeting wherein spokesmen for the Department of the Interior stated that the information seemed inadequate to make a judgment on the compatibility of the jetport with the ecology of south Florida. During the early part of 1969, the jetport issue received national coverage in newspapers and magazines and on television. Senator Henry Jackson announced that on June 3 he would convene a session of the Senate Committee on Interior and Insular Affairs to hear testimony on south Florida's water supply, environmental pollution, and jet airport problems of the Everglades. On June 2 the Secretary of the Interior, Walter J. Hickel, established a select committee to investigate the ecological impact of the jetport and to deliver by August its findings and recommendations. The Federal Government had now committed itself to help resolve the jetport issue.

The select committee's report, known as the "Leopold Report" (Leopold and others, 1969), stated that the proposed jetport would lead to drainage and development of the eastern part of the Big Cypress Swamp, which in turn would cause permanent alteration of the south Florida ecosystem, including the Everglades National Park. The report analyzed the ecology and functioning of the ecosystem and the airport plans for development and found that the proposed development was incompatible with the surrounding ecology. These findings and those from other reports (Freiberger, 1972; Klein, 1972; Klein and others, 1970; Little and others, 1970; Natl. Acad. Sci. Eng., 1970; OVERVIEW, 1969; and Stephens, 1969) meant that the Department of the Interior and probably the Department of Transportation would not approve any further construction of the jetport. This put the Dade County Port Authority in the position of finding a new jetport site.

FIGURE 1.—Map of south Florida showing features mentioned in the report.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Bureau of Indian Affairs
Florida State Parks
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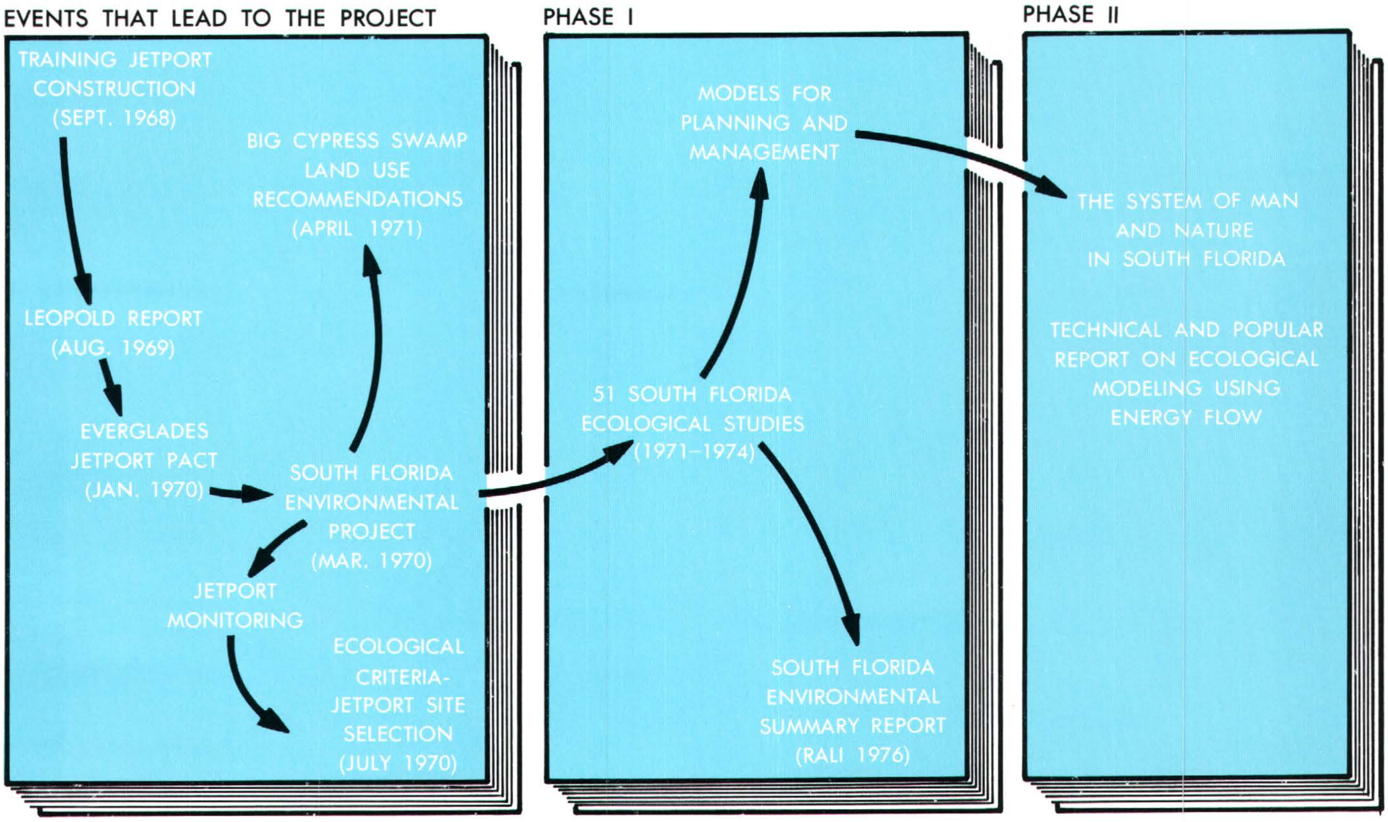


FIGURE 3.—Chronology of the South Florida Environmental Project.

The Federal Government, however, through the Federal Aviation Agency, acknowledged the urgent need of Dade County for a new and larger airport, and agreed to help in the location and purchase of such an airport. This agreement was called the Everglades Jetport Pact. As part of the pact, the Federal Government allowed the use of the existing Big Cypress jet training facility until an acceptable jetport site could be purchased. In addition, each party to the agreement had certain obligations. Dade County agreed to restrict the size of the existing training facility and to provide for ecologically safe operations. The State of Florida also agreed to assist the county in finding a new site, but would provide little financial assistance for the training facility or for additional service roads. The Federal Government promised to draw up reasonable site-selection criteria for any future site, to monitor the ecological impact of the jet training facility, to provide recommendations for land use in the Big Cypress Swamp, and to undertake an ecological study of the region. When the pact was signed on January 16, 1970, the Department of the Interior assumed responsibility for providing the background ecological information required to answer the questions asked for the Dade County Port Authority a year earlier.

◄ **FIGURE 2.—Federal- and State-administered lands in south Florida.**

In order to meet the Department of the Interior's obligations in the Everglades Jetport Pact, the Secretary of the Interior ordered on March 9, 1970, the formation of the South Florida Environmental Project. The Director of the National Park Service was designated as the chairman, and the Park Service was chosen to coordinate the project and meet the agreements of the pact. The National Park Service, Geological Survey, Bureau of Sport Fisheries and Wildlife, Bureau of Outdoor Recreation, Bureau of Indian Affairs, Environmental Protection Agency, and the National Marine Fisheries Service were asked to contribute services and representatives. These agencies had four main tasks: (1) To establish ecological criteria for any future jetport site; (2) to monitor the environment around the existing jet training faciilty in the Big Cypress Swamp; (3) to provide a land-use plan for the Big Cypress Swamp; and (4) to organize an ecological study of south Florida. The chronology of the South Florida Environmental Project is shown in figure 3.

The immediate job of the project was to obtain background information on environmental conditions around the existing training facility in the Big Cypress Swamp. The Geological Survey assumed responsibility for monitoring the water quality within the facility while the Environmental Protection Agency monitored water quality in the surrounding area.

The project staff began to draw up jetport site selection criteria. The stated purpose of the criteria was to eliminate conflicts over the selection of a jetport site by providing the Port Authority with ecological guidelines acceptable to the Federal Government. The criteria were sent to the Port Authority on July 16, 1970. Thereafter a site-review team, consisting of five members, one of whom was the coordinator of the South Florida Environmental Project in Miami, was to select potential sites and to judge their suitability on the basis of these criteria. When the review team makes its final selection, the Department of the Interior has agreed to examine in depth the site selected and to decide on its acceptability.

After criteria had been established, the South Florida Environmental Project concentrated on providing a land-use plan for the Big Cypress Swamp. The Department of the Interior released this plan in April 1971, and the South Florida Environmental Project was then free to organize an ecological study of south Florida. Subsequently, Congress passed legislation in 1974 establishing the Big Cypress Swamp as a national preserve, part of the National Park System (P.L. 93–440), thus in effect creating a freshwater reserve for the south Florida region. A total of 230,679 ha (570,000 acres), originally thought to be in about 30,000 ownerships but presently known to constitute closer to 70,000 parcels of land, were to be acquired by the National Park Service over a period of 6 years from passage of the act, using $116 million authorized by Congress and $40 million of donated funds that the State of Florida had previously appropriated for this project.

For the ecological study of south Florida, it was decided early in 1971 that each participating agency would submit a plan for studies that fell within each agency's expertise. Studies that could not be done by available agency personnel would be contracted to non-Federal individuals and groups. At the end of 3 years, reports on 51 studies were completed.

The individual studies were originally designed to answer many questions about the ecology of south Florida that had been asked early in the jetport controversy. Since the beginning of the project, however, new questions have been posed. To provide some of the answers to new questions, the project was extended to include a second phase, a definition of "the system of man and nature in south Florida" (fig. 3). Phase two is based on Study No. 1 of the 51 separate studies that constituted phase one. It involves the identification and "tracking" of all energy inputs, storages, and flows in the south Florida ecosystems, now so inextricable a mix of natural and human-imported energies. It is a combination of field research, storage and flow models, and computerized projections of possible futures based on different sets of conditions that could affect the existing system of man and nature in south Florida. The analysis is to be done at three levels: regional, county, and natural ecosystems.

South Florida as a regional system of man and nature

The early ecosystem

Before 1900 south Florida was a vast wilderness of bays, marshes, swamps, pine forests, and prairies. Each of these natural features was defined by physical and chemical conditions of the land, by climate, and by representative plants, animals, and microbes, which together constituted an ecosystem. Each ecosystem was sustained by sunlight, wind, rain, nutrients, and along the coast by tides and currents. Each, however, was not isolated, but was dependent on nearby ecosystems for some of its nutrients, water, or wildlife. Freshwater runoff, for example, nourished the interior marshes and carried needed nutrients to the bays. Each of the interdependent ecosystems, then, was a subsystem of the regional ecosystem.

Ecosystems evolve in geologic time. The living components adapt to one another and to the nonliving environment. If climate and other environmental conditions remain relatively stable, ecosystems tend toward steady-state or climax conditions. In south Florida, warm weather and abundant freshwater and sunlight over the last few thousand years allowed relatively stable and biologically productive ecosystems to develop. The waters of the region abounded with fish and other aquatic animals, and these in turn supported large numbers of reptiles, birds, and mammals.

Indians came into the region more than 2,000 years ago but had virtually disappeared by 1800. They were mostly coastal dwellers and relied primarily on fish and shellfish, supplemented with wild game and wild plants. During the 1800's the Seminole Indians were driven into south Florida where they developed a way of life compatible with the ecosystem. The Seminoles were an agricultural people, but in south Florida they supplemented farming with hunting. Gardens were kept, but because of the scarcity of dry land they were limited (Tebeau, 1973). Less than 300 Seminoles were living in the region (Kersey, 1973) in the late 1800's. Their general way of life was disrupted during the 1900's by modifications made to the ecosystem.

The changing system—population growth and land-use changes

After 1900 men came in increasing numbers to south Florida and began to modify the ecosystem. Areas were drained for farming; bay-front areas were filled; and trees were removed. All this activity required additional sources of energy and material other than those available locally, so machinery, money, and fuel were brought into south Florida.

The south Florida ecosystem that had developed over thousands of years gave way to a new three-part ecosystem which incorporated an agricultural component, an urban component, and a component derived from the natural ecosystem. These components are interrelated through the flow of energy and resources. The agricultural and urban systems rely on the remaining natural systems to provide for the commodities and free services of land, water, and oxygen production. These are needed for recycling nutrients, dispersing and detoxifying pollutants, retaining biological diversity, and producing fish and wildlife. If the natural systems are reduced, the services they once provided free must be provided by an energy subsidy, which is often costly. (A further discussion of systems ecology and ecological modeling is given in Appendix I.)

Remnants of the pristine ecosystems . . .

A tranquil lake in the Big Cypress Swamp . . .

Scrub cypress in early morning . . .

Contrast with . . .

A modern urban profile in Miami.

Outdoor recreation, which is largely dependent on the remaining natural systems and their services, is an important component of the south Florida economy and lifestyle. The subtropical coastal environment is conducive to year-round tourism and outdoor recreation such as swimming, fishing, boating, and surfing, which contribute substantially to the economy of the region (U.S. Bur. Outdoor Recreation, 1973).

Much of the land suitable to meet the growing population pressures has already been developed. Lands remaining often require dredge and fill, additional drainage, or other types of land preparation to make them habitable. Such activities are usually destructive to natural systems (Birnhak and Crowder, 1974).

The temporal and spatial distribution of water may be considered the primary ecological factor in the south Florida regional ecosystem, particularly as it relates to man and his role in the system. The source of freshwater is rainfall that is temporarily stored in Lake Okeechobee, the Big Cypress Swamp, the conservation areas, Everglades National Park, and the shallow aquifers. Each of the storages is directly or indirectly connected to the sea, which can be considered the sink of the freshwater system. Water is transported throughout the hydrological system by canals, rivers, creeks, sloughs, sheet flow, and underground flow and through the air as water vapor. Recent dry-season water deficiencies are linked to an expanding population, which requires diversions of water from the natural and agricultural systems. The agricultural systems also depend on an adequate water supply, without which lower productivity results.

Agricultural and urban systems require an input of energy beyond that supplied naturally. Most of this energy is imported as fossil fuel or as a fossil-fuel product. For example, farmers not only use energy (fuel) directly for tractors but also indirectly in farm machinery, pesticides, and fertilizers that require energy for their production. Modern urban societies, in particular, require large inputs of outside energy to build and maintain their complicated structures of transportation, schools, laws, communication networks, buildings, and public services. As cities grow, so do energy requirements; if these are not met, stress occurs and the quality of life deteriorates.

In recent years urban growth in south Florida has been rapid. Population increased from slightly less than 0.5 million in 1940 to 2.5 million in 1970. If present trends continue, by 2000 south Florida would have more than 4.4 million residents, or about an 80-percent increase from 1970. As the permanent and

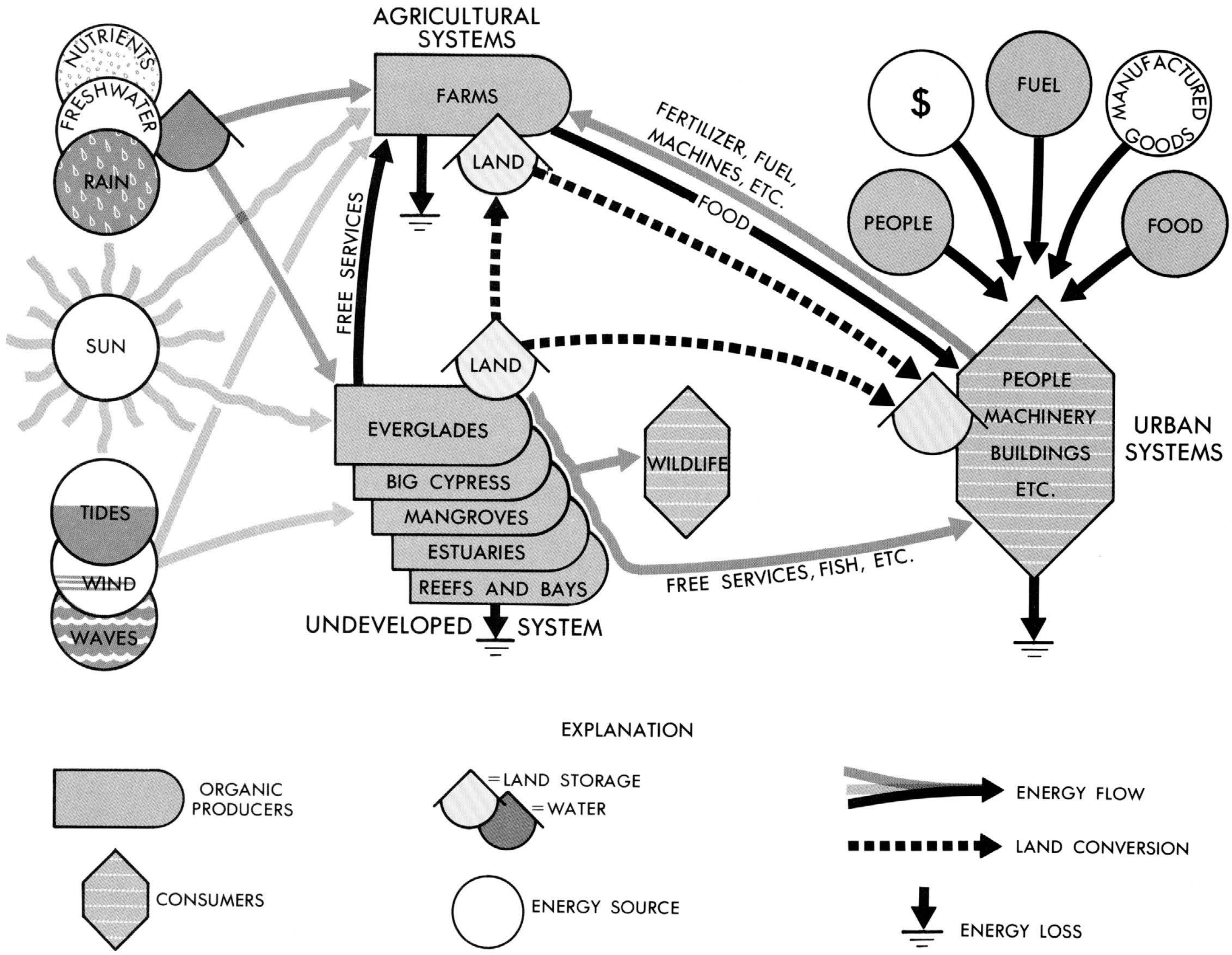


FIGURE 4.—Flow of energy in the south Florida regional ecosystem.

visiting population increases, more services such as parks, schools, utilities, and transportation are needed. As a result, the cost per capita to supply basic needs often increases, and it becomes increasingly difficult and expensive to furnish these services without disruptive effects.

Because of generally unplanned growth, south Florida has an increasing number of socioeconomic and environmental problems. Land zoning has been relatively ineffective in regulating growth patterns because it has been based on political, rather than ecological, boundaries and on short-term economic benefits. The problems related to growth can be expected to increase and intensify unless growth patterns change and long-range land-use planning is implemented.

A regional land-use plan with enforcement provisions is one way to regulate growth and development. Such a plan requires analysis of complex social, economic, and environmental factors. Systems analysis provides a method for generating a plan of this type. In south Florida the foundation has been laid for such an analysis using ecosystem models that simulate the energy sources, storages, and flows in the region.

Ecosystem models as an approach to resource management

Man and nature interact to form a system of interdependent and interconnected parts. The study of this system is called systems ecology. Unlike some other branches of science that describe change as an effect caused by one part acting upon another part, systems ecology describes change as the interaction of parts. Models are useful to visualize and analyze such systems (Appendix I).

Systems ecology and ecological modeling concepts were used in the south Florida study to evaluate environmental problems (Lugo and others, 1971, 1973; Bayley and Odum, 1971; and Carter and others, 1973). Most of the ecological models presented in this report are qualitative. However, in phase 2 of the study, being done by the University of Florida's Center for Wetlands, quantitative data are used in the models to predict changes in the systems under different management alternatives.

South Florida is a large and complex mixture of subsystems influenced to varying degrees by man. The subsystems interconnect by energy pathways and form a regional ecosystem as shown in figure 4. The energy sources that drive the system include sun, rain, wind, waves, tides, freshwater, nutrients, fossil fuel, food, manufactured goods, people, and capital. The energy-fixing components (organic producers) include the plant biomass in the Big Cypress Swamp, the Everglades, the mangroves, the estuaries, reefs, and bays and on the agricultural land. Consumers, which convert this biomass into food and which also transform natural energy into power or capital, include wildlife, tourists, residents, machines, buildings, and others. The energy-fixing systems are linked to and provide the basic support for the urban system. The urban and the agricultural systems, however, are highly subsidized by and dependent on fossil fuels and fossil-fuel products.

Although the conceptual diagram shown in figure 4 is informative and led to the preceding generalizations, actual resource planning requires information obtained from more detailed, specific site studies to be effective. The systems ecology approach for resource planning has been applied in DeSoto, Charlotte, and Lee Counties during a pilot study by the Florida Coastal Coordinating Council and the University of Florida (Wetterqvist and others, 1972). In that study, subsystems were classified and energy flows diagrammed to produce a model from which tentative suggestions were made for planning in the southwest Florida coastal zone. Another example is a study of the urban systems of Lee County (Brown and Genova, 1974) in which detailed recommendations were made.

A model of the regional ecosystem, such as that shown in figure 4, provides an overview and can help in identifying deficiencies in the information needed for formulating specific land-use recommendations, but it lacks the detail and quantification needed for resource planning and decisions. By breaking down the regional ecosystem into subsystems, more detail is provided. In this report the regional ecosystem is divided as follows:

Freshwater and terrestrial ecosystems:
Canals and lakes
Ponds and sloughs
Sawgrass marshes
Wet prairies
Pine forests
Cypress forests
Mixed swamp forests
Bay heads
Hardwood hammocks
Palmetto and dry prairies

Coastal ecosystems:
Sandy beaches
Mangrove and salt marshes
Shallow estuaries and bays
The reef tract

Man-dominated ecosystems:
Agricultural
Urban

Because of the special importance of water in south Florida, a separate section of this report devoted to hydrologic systems discusses problems concerning water quantity and quality.

To be most useful in resource management, systems models should be quantitative; they not only should show relationships between energy sources, storages, producers, and consumers but should show the magnitude of these relationships as well. For example, computer simulation of a sawgrass marsh model indicated that high inputs of phosphorus would result in increased transpiration and fires in the marsh (Bayley and Odum, 1971). As part of the south Florida study, quantitative data on the regional ecosystem are being amassed by a team at the University of Florida's Center for Wetlands. With these data and with the models developed in this study, computer simulation will be used to predict the effects of various management alternatives on the south Florida ecosystem.

Ecosystems of south Florida

Freshwater and terrestrial ecosystems

The natural freshwater swamp, marsh, and terrestrial systems of south Florida whose extents are shown in figure 5 lie within five physiographic regions (fig. 6): (1) the Everglades; (2) the Atlantic Coastal Ridge; (3) the Eastern Flatlands; (4) the Western Flatlands; and (5) the Big Cypress Swamp (Davis, 1943). The Everglades and the Big Cypress Swamp are predominantly freshwater marsh and swamp systems. The Atlantic Coastal Ridge is mostly terrestrial. The Flatlands are composed of swamp, marsh, and terrestrial systems. All these natural systems are affected to some degree by man.

Relations between systems

A seasonal abundance of freshwater in south Florida has favored the development of a number of swamp, marsh, and terrestrial systems. Each is controlled, in part, by the moisture in the soil or by the duration and the depth of inundation; these in turn are determined by the amounts and frequency of rainfall, the infiltration capacity of the soil and underlying bedrock, and by land elevation. High areas that are seldom flooded usually support pine forests, hardwood hammock forests, or grassland systems. Low areas that are flooded part of the year are wetlands, which include prairies, marshes, or swamp systems (fig. 7). The hydrologic environment, however, is not the sole control on a system. Fire, tropical storms, frost and cold weather, saltwater invasion, and man also affect the systems.

Freshwater is a key environmental factor in that it not only affects a system directly but it also affects other controlling environmental factors such as fires, soil, temperature, and saltwater invasion. Freshwater is also a key factor manipulated by man.

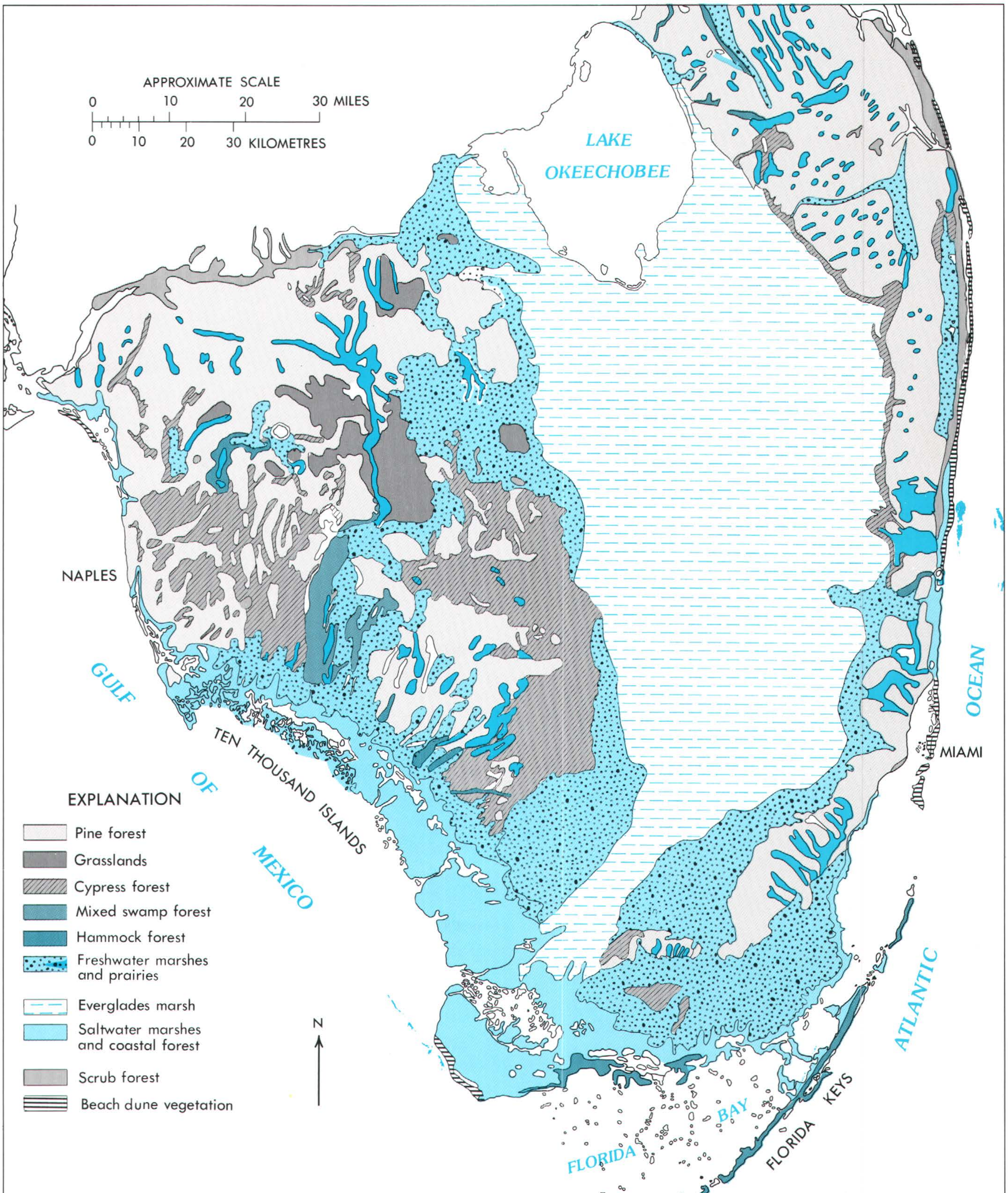
Water, sunlight, and nutrients are essential ingredients for organic plant production, which sustains each system. Marsh and swamp systems require seasonal flooding to maintain adequate levels of production. In the marshes, herbaceous plants and periphyton are the primary producers; in the swamps, trees are the primary producers. Terrestrial plants, which do not tolerate much flooding, rely mainly on rainfall and soil moisture. Plant production sustains each system by providing the food for the two other major components of a system: the animals and the saprophytes (bacteria, yeast, fungi).

Many plants and animals are adapted to and dependent on the seasonal fluctuations of water level. During wet seasons, aquatic-plant production abounds; small crustaceans and fish feed on the growing plants or plant remains. With abundant food and space, aquatic-animal populations increase. As water levels decline during the dry season, the small aquatic animals are forced to concentrate in scattered ponds, tributary creeks, and sloughs. The concentrated biomass then becomes a rich source of food for larger fish, alligators, snakes, birds, and mammals.

Rainfall is the ultimate source of water in south Florida. It is maximal over the Atlantic Coastal Ridge (1,524 mm/yr or 60 in/yr) and decreases incrementally away from the ridge. The annual rainfall pattern, however, does not correlate with the physiographic regions and their ecological systems. These regions and systems are more closely correlated with the distribution of water, soil type, and land elevation.

Under ideal conditions, systems undergo orderly, successional changes until a relatively stable situation is reached in which a system is in equilibrium with its climatic environment and is capable of self-perpetuation as long as the climate does not change radically. The stable system is called a climax; antecedent unstable ones are subclimax. Each system in this successional change has its own species, organization, and conditions, and these are different from all others. In addition, each system creates the habitat and conditions for its successor. The concept of orderly change ending in a climax has been applied mainly to vegetation but is generally applicable to ecosystems, which include biological components as well as the physical environment.

FIGURE 5.—Vegetation in south Florida as it existed before manmade alterations. Modified from J. H. Davis, Jr. (1943).



Swamp forests grow where land is inundated by water for months.

Marshes also require prolonged inundation.

In south Florida, rainfall is generally adequate to allow native plants their characteristic successional patterns, but droughts have regularly stressed vegetation and altered this process. The plant systems have evolved in this pattern and are adapted to seasonal changes in water depth. Figures 8 and 9 summarize the main successional sequences. Although succession is reversible, as indicated by arrows in both directions, it ends ultimately, if not checked, in a hardwood forest climax. Because of droughts, fires, and, more recently, man's intrusions, systems seldom reach climax; most are limited in their development and are subclimax. In addition, the alterations imposed by man, such as the introduction of exotic plants, appear to have set in motion changes in the details of this succession (Alexander and Crook, 1973).

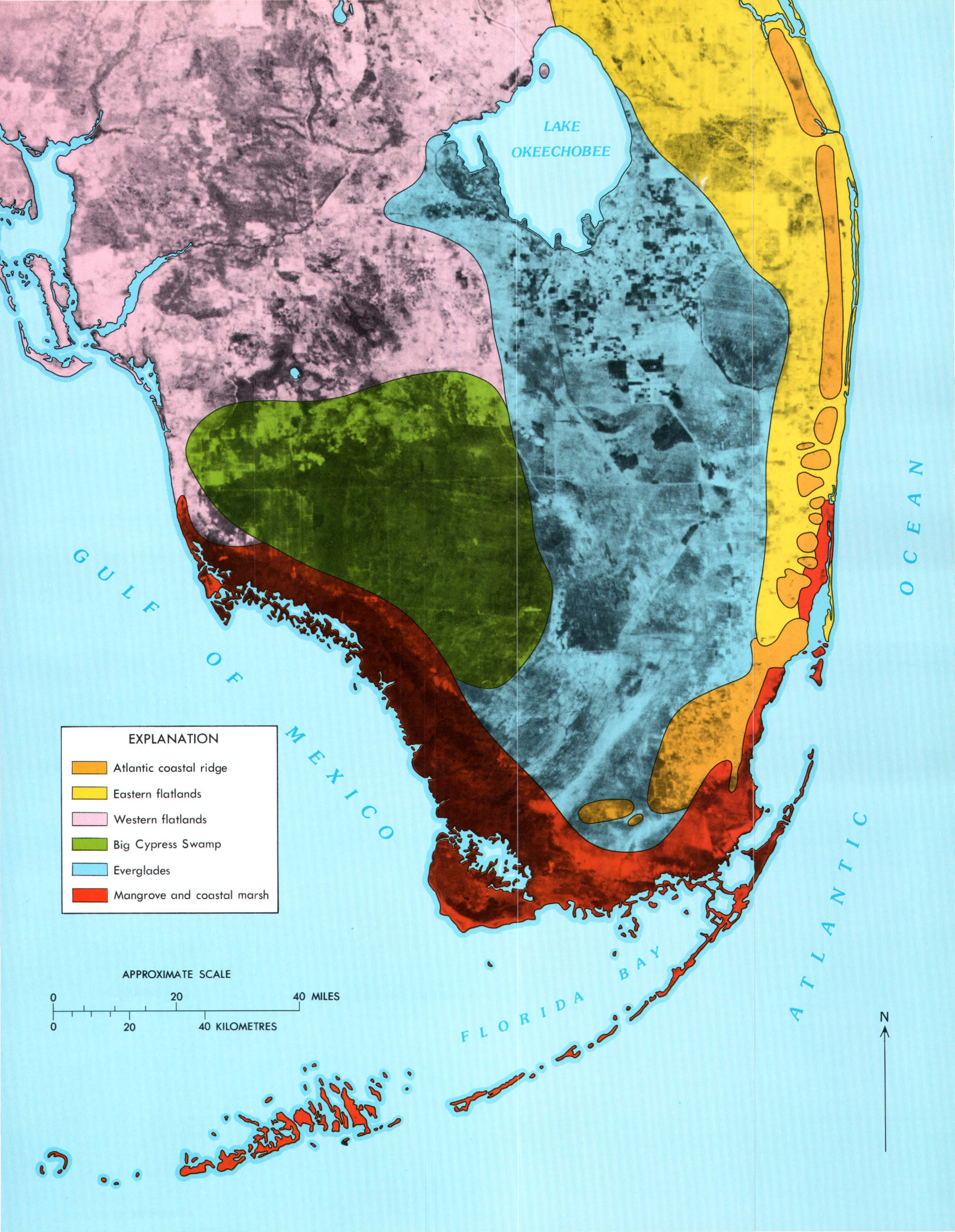
Fire has an important effect on freshwater and terrestrial systems. It maintains some systems, such as pine forests or sawgrass marshes, and limits others, such as hardwood forests. Lightning has always caused some wildfires during the summer thunderstorms, but during the wet season wildfires tend to be less severe than fires during the dry season because the moisture protects roots and soil. During the dry season, fires often burn into the roots and soil, killing even fire-resistant species. Muck fires can burn for weeks and months. Such fires occurred in the mid-1940's and resulted in reduced soil levels and destruction of many tree islands and hammocks (Alexander and Crook, 1973).

South Florida's systems have both tropical and temperate components. Land animals are almost completely temperate-zone species, but the plants are derived from both zones. Temperature affects these plants in two ways: high temperatures restrict the southward migration of temperate plants, and low temperatures restrict the northward migration of tropical species. Tropical plant species are frost sensitive and some defoliate after exposure to 7°C (45°F). Damage increases with duration of cold (Alexander and Crook, 1973).

Temperature is variable with soil type, water conditions, and land altitudes. Areas of sandy soils tend to be warmer than areas of muck. Water moderates air temperature. Swamps and marshes tend to be warmer in the winter and cooler in the summer than forest and prairies (Alexander and Crook, 1973).

Hurricanes and tropical storms affect ecosystems through their local and immediate destruction and through their more extensive and long-term alterations such as salting of land by tidal flooding and changing of coastal elevations and outlines. Coastal ecosystems are more susceptible to these changes than are interior systems.

FIGURE 6.—Physiographic regions of south Florida. ►


LAKE OKEECHOBEE
GULF OF MEXICO
ATLANTIC OCEAN
FLORIDA BAY
EXPLANATION
Atlantic coastal ridge
Eastern flatlands
Western flatlands
Big Cypress Swamp
Everglades
Mangrove and coastal marsh
APPROXIMATE SCALE
0
20
40 MILES
0
20
40 KILOMETRES
N

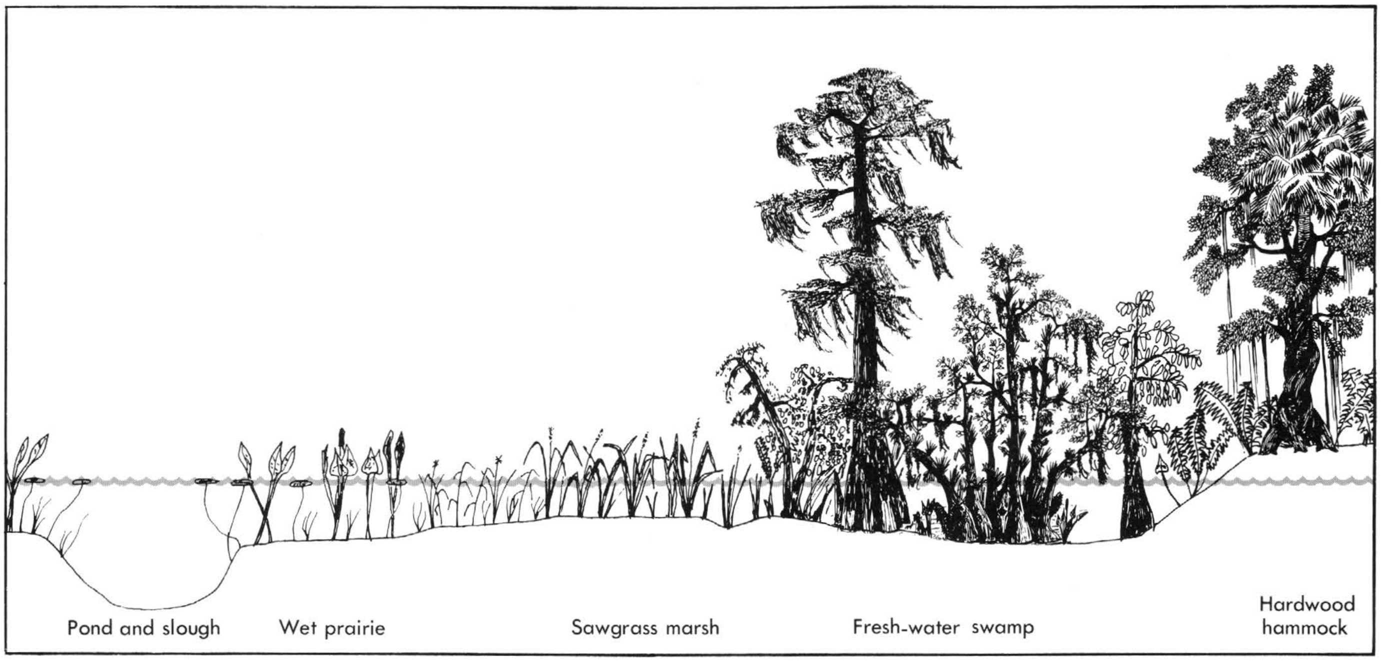


FIGURE 7.—Generalized vegetative profile showing the relation of relative water depth to vegetative community.

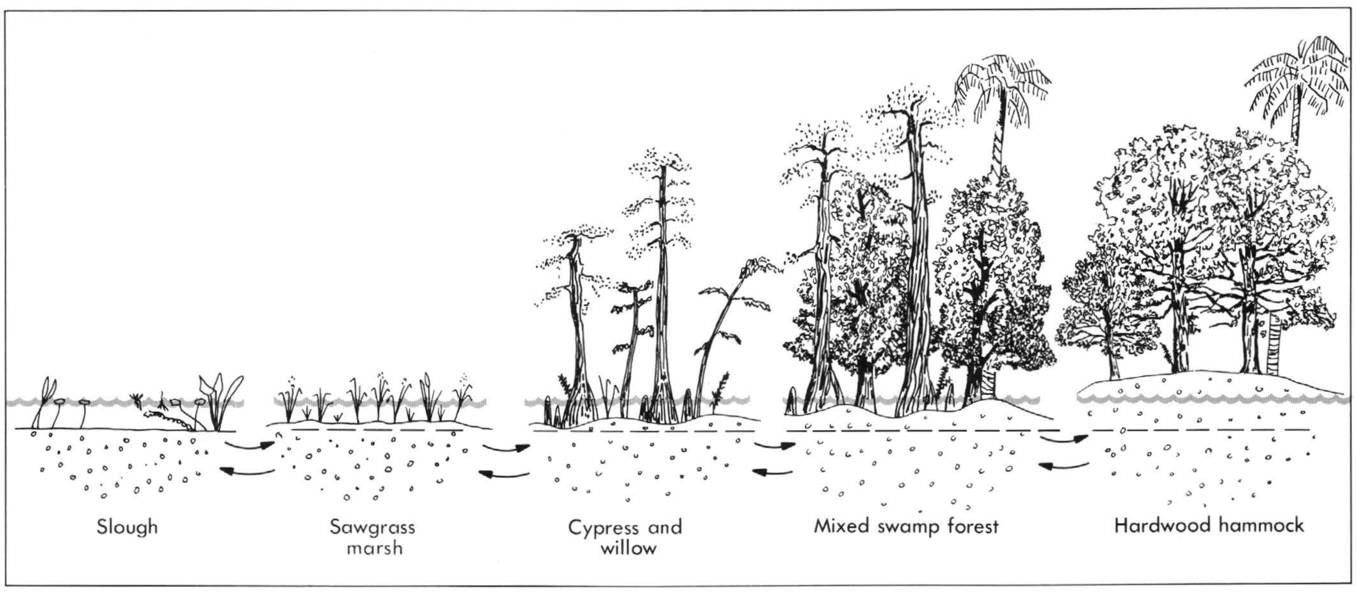


FIGURE 8.—A sequence of vegetation change in south Florida. Succession proceeds towards hardwood hammock. Fire or other factors may check the succession or reverse it.

Effects of man

Man has altered the ecosystems of south Florida extensively for 70 years. Drainage, dredge and fill, and lumbering have destroyed and altered habitats. Poaching, polluting, and introducing exotic species that compete with and replace native species have directly destroyed life.

The most dramatic long-term effects on ecosystems have resulted from drainage. Wetlands originally occupied about 75 percent of south Florida; much of this land has been drained through the years. Drainage not only reduces productive wetlands but also allows other severe environmental effects including organic soil oxidation, damaging fires, and seawater intrusion. Drained lands usually become farms and urban areas that further alter the environment.

Early uncontrolled canal drainage in southeast Florida lowered water levels 1.5 to 1.8 m (5 to 6 ft) below the 1900 level and stressed natural systems. Uncontrolled fires modified, damaged, and eliminated much vegetation and soils (Alexander and Crook, 1973).

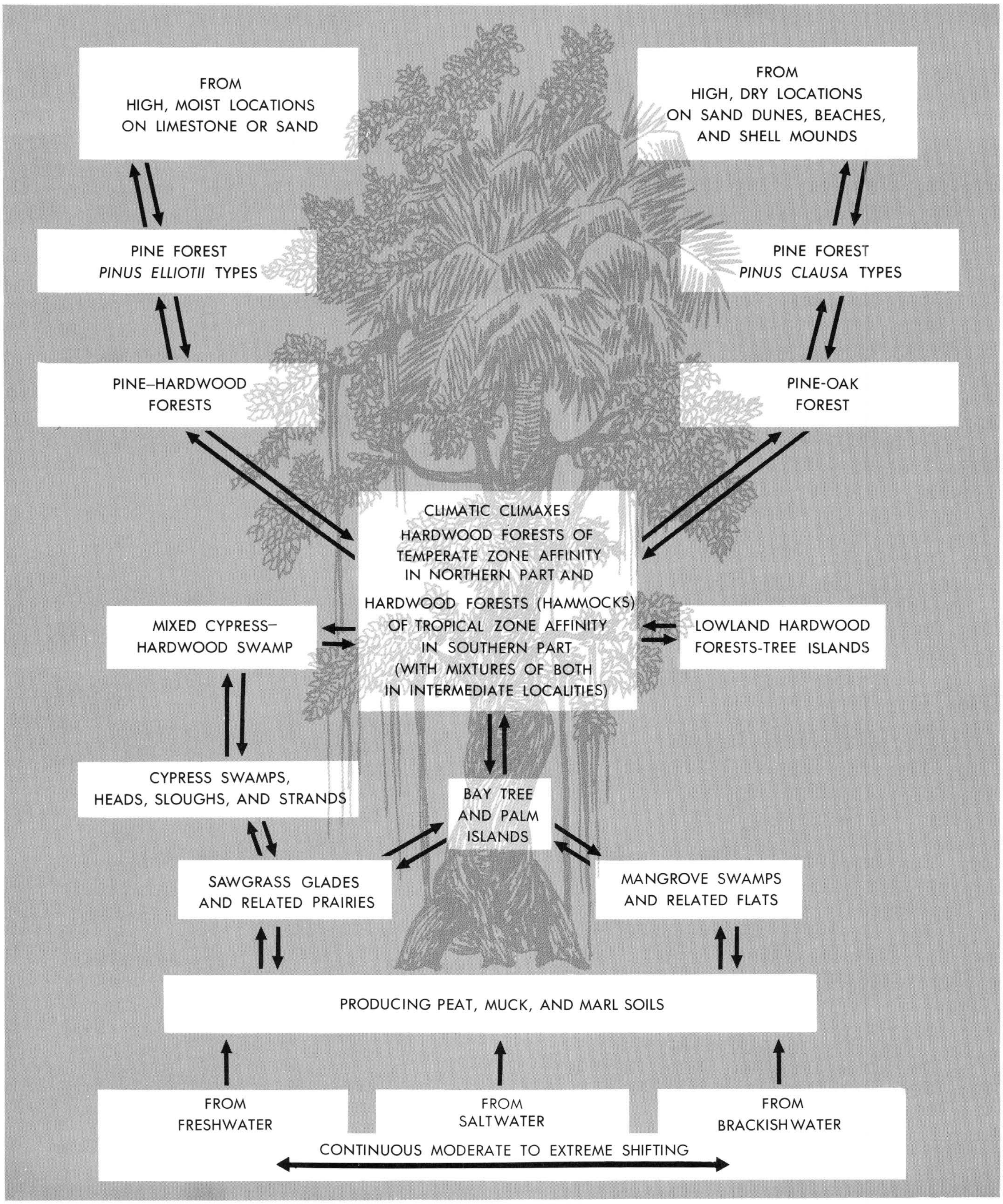


FIGURE 9.—Generalized plant succession in south Florida. From Alexander and Crook (1973).

Man's most dramatic and long-term effects on the south Florida ecosystem have resulted from drainage. This canal drains the western Big Cypress Swamp.

The results of drainage of the above canal—formerly a pond in a strand just west of the Fakahatchee.

In the 1950's water control in the Everglades and urban coast began to take precedence over uncontrolled drainage. A water-management plan was adopted that involved the use of three conservation areas; these areas, which were completed by 1962, provide storage for water regulation. Water is stored during the wet season and released as needed during the dry season. As a result of impoundment, periods of inundation and water depths were increased in parts of the conservation areas, and changes in vegetation were thus caused. Some changes have been toward new assemblages of plants rather than toward previous pre-drainage plant groups (Alexander and Crook, 1973; Hagenbuck and others, 1974).

Natural systems in the west part of south Florida were less drastically altered during the first half of the century than those in the Everglades (Crowder, 1974e). Few large canals were dug in the west before 1940, and these (such as the Barron River Canal) had a less severe effect than those through the Everglades. In general, systems in the Everglades were adapted to longer and deeper inundation than those to the west. The Everglades systems thus suffered more from the reduced period of inundation than did the more terrestrial systems in the west. Also, organic soils were localized and less extensive in the west than in the Everglades, and therefore soil loss was less.

In the 1960's, however, drainage became extensive in southwest Florida. The Golden Gate Canal system inland from Naples effectively lowered water levels 0.6 to 1.2 m (2 to 4 ft) in 195 km^2 (75 mi^2) of wetlands in the western Big Cypress Swamp (Klein and others, 1970). The early ecological effects of this drainage are that pine and maple are replacing cypress forest (Alexander and Crook, 1973).

Once drained, land in south Florida is commonly farmed, and further disruption of the pre-drainage ecosystems results. Natural vegetation is usually cut and removed, and fertilizers and pesticides are utilized. Cattle grazing has a more moderate impact on the systems; not all natural vegetation is removed, and pesticide and fertilizer use is slight. Urban development often follows farming, and this development of course perpetuates and intensifies environmental alteration. Not only pesticides and fertilizers but toxic metals and polychlorinated biphenyls (PCB's) from agricultural or urban sources are now distributed in south Florida and are a threat to man and to the natural systems (Crowder, 1974h; Klein and others, 1973; Carter and others, 1973).

The forests of south Florida have been lumbered for many years. Selected harvesting of mahogany and buttonwood occurred along the southern coast as early as 1800 and continued until about 1940. Pines were first harvested extensively in the Western Flatlands in the mid-1920's and later in the Big Cypress Swamp. Cypress trees were cut mainly between 1940 and 1957. Lumbering had its greatest direct effect in the Big Cypress Swamp where almost all large slow-growing cypress were removed, as in the Fakahatchee Strand. Lumbering also subjects a system to indirect changes. It can increase the chance of fire by bringing in men and machines, by creating fuel from dead brush, and by drying the forest litter through canopy removal. Lumbering, fire, and drainage thus commonly act in combination to change a system.

Off-road recreational vehicles such as swamp buggies (vehicles with high tires), halftracks, and airboats damage wetland vegetation. The extent of the damage depends on type and number of vehicles and types of vegetation and soil. In the Everglades, drier areas are slower to recover than wetter sites, and wet prairie recovers more rapidly than sawgrass.On the average, 50-percent recovery of vegetation occurred in the Everglades marsh after 4 to 5 months of protection. Tree islands, however, are extremely vulnerable to long-lasting damage from halftracks (Schemnitz and Schortemeyer, 1972).

The use of off-road vehicles is increasing. In 1952, 484 airboat-operator permits were issued as compared with 2,932 in 1972. The repeated use of off-road vehicles, particularly the large-wheeled or tracked ones, may create slow-healing scars (Schemnitz and Schortemeyer, 1972).

Man's introduction of exotic species is a major threat to the natural systems. Exotic species can often compete with and ultimately replace native ones. South Florida is particularly vulnerable because of its warm climate. The tropics harbor a numerous and diverse range of plant and animal species. These tropical plants and animals often die in cold weather and cannot survive and reproduce in temperate areas. In south Florida, however, climatic conditions favor the survival of many tropical species. Another factor that favors the spread of exotics in south Florida is the alteration of existing natural systems. Drainage and farming usually increase the chance for exotic plants to become established by stressing native plants and reducing their ability to compete.

Three exotic tree species—cajeput, Australian pine, and Brazilian pepper—are already common in south Florida and are spreading. Their effects range from competition with and elimination of native plants to pronounced effects on animal wildlife. Australian pines grow to the edge of saltwater where their dense roots inhibit nesting of turtles and crocodiles. Cajeput and Brazilian pepper form dense canopies that exclude native vegetation and offer poor wildlife habitat. The ability of cajeput to thrive in both wetlands and woodlands threatens to change the biological character of south Florida (Alexander and Crook, 1973; Crowder, 1974a).

Exotic aquatic plants such as water hyacinth and hydrilla have spread rapidly to inland waters, including parts of the conservation areas. Hydrilla is particularly difficult to control because it is submerged, grows rapidly, and sprouts readily. Each year about $10 million are spent in Florida to control aquatic plants, but infestations continue to grow (Crowder, 1974a).

Man's introduction of exotic species is a major threat to the natural systems. Two of the most prolific exotic plants are cajeput . . .

. . . and water hyacinth.

Exotic vertebrates also pose a threat to the freshwater and terrestrial ecosystems. Species that are fecund, aggressive, and adaptive are particularly threatening in that they may replace native species and alter food webs. Of the 16 or so exotic fishes established in south Florida, the walking catfish, the pike killifish, and several species of cichlids are potentially the most dangerous to native fishes. About 20

Canals form an extensive network for distributing water throughout south Florida.

species of exotic reptiles and amphibians are established, but they are localized. The marine toad, the knight anole, and the Cuban tree frog prey on smaller native counterparts. Birds are represented by a variety of exotic species, most of which occur along the southeast coast. They compete with native species, and some feed on fruit and grain.

Wildlife has suffered from man's impact on the freshwater and terrestrial ecosystems. Some species of amphibians, reptiles, birds, and mammals have declined in population (Rodgers and Crowder, 1974; Crowder, 1974b and c; Rodgers, 1974; Natl. Audubon Soc., 1973; Schemnitz, 1972). The alligator is listed as endangered and, until recently, was threatened with extinction by illegal hunting. They are now increasing in numbers (Rodgers and Crowder, 1974; Schemnitz, 1972). Seven other reptile and amphibian species, however, are declining in number (Crowder, 1974b). Eleven species of birds and three species of mammals native to the freshwater and terrestrial ecosystems are endangered (U.S. Dept. Interior, 1974). The most dramatic decline is in populations of panther, bear, and wading birds. A 1972 report estimated that only 92 panthers and 145 bears are left (Schemnitz, 1972). Wading birds decreased from about 2.5 million in 1870, to about 1.5 million in 1935, to about 300,000 in 1960, and to about 150,000 in 1973 (Crowder, 1974c; Natl. Audubon Soc., 1973).

Canals and lakes

South Florida has two large lakes, Lake Trafford and Lake Okeechobee; Lake Okeechobee is the largest and most important. Lake Okeechobee functions as the primary water-storage area of the FCD water-management system and as a biologically productive system.

Lake Okeechobee is fed from the north mainly by the Kissimmee River and by a system of pumping stations along its south shore, a system which, during wet periods, pumps surplus water from the north part of the Everglades agricultural area into the lake. Generally, during dry periods, water is released from the lake to sustain the agricultural areas just south of the lake and to supply water to the urban lower east coast. When levels in the lake exceed scheduled elevations during some rainy seasons, releases are made through the St. Lucie Canal and the Caloosahatchee River (Klein and others, 1973).

Canals form an extensive network to distribute water and to discharge seasonal excesses into estuaries. Before the 1930s', canals were constructed primarily to provide the drainage and flood protection that were essential to land development. These canals were connected directly with the estuaries and during dry seasons often allowed saltwater to penetrate inland. The drought of 1943–45 created conditions that demonstrated the need for control structures to prevent the inland migration of saltwater, and such structures were subsequently placed in most canals near the coast.

Canals are biologically productive systems that support a variety of aquatic plants, animals, and microorganisms, many of which also thrive in ponds, sloughs, and marshes. Canals retain water throughout the year, whereas sloughs and marshes become dry for several months during most years. Canals, therefore, provide an environment for the year-round growth of aquatic plants and survival of aquatic organisms during drought. Fish and other aquatic animals retreat to canals as adjacent marshes dry.

The quality of canal water is often degraded by the inflow of pollutants, particularly in urban and agricultural areas. The pollutants may be transported in solution or associated with sediment. Biological uptake may be restricted because of poor light conditions, deep water (which hinders interaction with the bottom sediment), rapid water movement, and other factors.

Canals that drain agricultural or urban land often have relatively high concentrations of nutrients. These high concentrations in stagnant canals favor the growth of nuisance aquatic plants. Two troublesome plants, water hyacinth and hydrilla, often form dense stands that clog the canals, hinder the flow, and adversely affect the recreational use of the canals. Algae also degrade canals with dense blooms and scums, both of which detract from the recreational and aesthetic value of the canals.

Dense growth of aquatic plants may contribute to low concentrations of oxygen in canals. In addition to producing oxygen through photosynthesis, plants consume oxygen through respiration. Thus at night when photosynthesis ceases, plants deplete oxygen. Plant materials lower oxygen concentration when they are broken down by bacteria. Concentrations of oxygen tend to be low near the bottom of canals where dead plants and other organic materials settle and bacterial respiration is greatest. A large accumulation of dead plants, particularly under low-flow conditions, may result in anaerobic conditions throughout the canal. Floating plants reduce oxygen levels by blocking out the sunlight necessary for photosynthesis. Anaerobic conditions can result in the death of fish, noxious odors, and health hazards.

Maintenance of canal systems by periodic removal of sediment and aquatic plants is costly. In the absence of such maintenance, however, canals would soon cease to function as water-transport systems.

South Florida's lakes and canals provide recreation such as sport fishing and boating. Fish production abounds in these systems and their peripheral marshes during the wet season; fish are later concentrated in the canals and lakes as water levels decline and marshes dry.

The major freshwater commercial fishery in south Florida is in Lake Okeechobee. On the average more than 1.8 million kg (4 million lb) of catfish and turtles are taken annually, and a record 3.2 million kg (7 million lb) was taken in 1971 (Natl. Marine Fisheries Service, Miami, unpub. data). Review of the Okeechobee commercial fisheries suggests that this fishery is underexploited and that restrictions could be relaxed to allow a higher sustainable yield. The removal of more fish is not expected to adversely affect the sport fishery (Crowder, 1974g) and could aid the overall condition of the lake by removing nutrients (in the form of fish flesh) (Marshall and others, 1972).

Lake Okeechobee provides more than 140,000 fisherman trips annually (Ager, 1970). But the lake began in the early 1970's to exhibit increasingly noticeable eutrophication caused by the inflow of domestic, industrial, and agricultural wastes. Nutrient-enriched, highly mineralized water from about 283,000 ha (700,000 acres) of agricultural land either flows or is pumped into the lake and surrounding conservation areas. With extensive fishkills becoming common in the Okeechobee rim ditch because waters low in dissolved oxygen flowed into the lake (Crowder, 1974g), the State in 1973 funded the Special Project to Prevent the Eutrophication of Lake Okeechobee. The project was to conduct and integrate research aimed at turning around the processes which were degrading the lake with overenrichment (eutrophication). Preliminary conclusions, in a May 1975 interim report [4], acknowledged "*the South Florida ecosystem is presently under a high degree of stress as a result of man's disordering of the system's evolved patterns of coping. . .*" [italics from the report], but that "catastrophic trends appear to be reversible, provided effective management for optimum water storage and quality is implemented in the very near future."

A May 1976 draft report [5] on management plans promises early publication of findings and recommendations which, it stated, "should be considered as one of the first comprehensive steps in the state's planning process to develop optimum management programs. State level planning," it continued, "will lead to the Water Use Plan in 1978, the Water Quality Plan in 1978, and ultimately the Florida Comprehensive Plan in 1979."

Ponds and sloughs

Ponds and sloughs remain flooded longer during the dry season than other wetland systems. Pond depressions ordinarily contain some water unless the dry season is unusually prolonged. Ponds occur in sloughs and swamps as slightly deeper areas, as solution holes in the limestone bedrock of the coastal pine forests, and as potholes in the sandy flatlands. The pond-slough system is widely distributed, but it is most abundant in the Everglades. The largest pond-slough systems are the Shark River Slough (fig. 10), Taylor Slough, and parts of the northern Everglades. Isolated large sloughs are the Okaloacoochee Slough, Corkscrew Marsh, and Devils Garden Slough in southwest Florida (fig. 1).

Depressions occupied by ponds and sloughs may be caused by solution of the limestone by organic acids. Solution holes of the coastal ridge, as deep as 4.5 m (15 ft), were formed during the last ice age when sea level was much lower than the present level and water percolated downward to dissolve areas of limestone (Craighead, 1971).

If organic matter accumulates in ponds and sloughs faster than it is removed or faster than the underlying bedrock is dissolved, depressions will be filled. Under these conditions the general successional trend is from pond to marsh to swamp to hardwood hammock (fig. 8). Various processes may slow or change this succession. Fires during the dry season, for example, may

[4] Written communication, 1975, Florida Division of State Planning, interim report on the Special Project to Prevent the Eutrophication of Lake Okeechobee.

[5] Written communication, 1976, Curry Hutchinson, Dale D. Walker, Stephen E. Gatewood, and Rotha MacGill, Florida Division of State Planning.

remove accumulated sediment and deepen ponds and sloughs. Alligators also help check this succession by digging and removing sediment and plants from ponds (Craighead, 1971).

Sloughs are important watercourses in south Florida. They deliver freshwater to bays and estuaries, a function similar to that of rivers in other areas. Flow through a slough, however, is slower than through a river. Because of this, water is subject to evapotranspiration and chemical changes for longer periods in a slough than in a river. Also, the shallowness and biological character of sloughs favor alteration of water quality before the water enters the estuarine environment. Some processes of alteration are particularly important in maintaining good quality water in the estuaries. Removal of pollutants and excess nutrients as water moves through the slough, for example, is necessary to prevent degradation of the receiving estuaries.

Life in ponds and sloughs is a diverse assemblage of aquatic plants, animals, and microorganisms. A conspicuous component of the system is the emergent marsh vegetation such as cattail, arrowhead, pickerelweed, fire flag, water rush, and spikerush. Other important vascular plants include immersed species, such as bladderwort and niads, and floating species such as waterlettuce, duckweed, and water hyacinth. Characteristic nonvascular plants include green and blue-green algae, flagallates, and diatoms.

Periphyton, an assemblage of algae, other microorganisms, and small animals, is an important component of the pond-slough and the wet prairie systems. It thrives in shallow sunlit water where it adheres to a substrate or floats. It often forms dense calcareous mats several inches thick that are attached to the bottom or to vascular plants. Because of its concentration of microorganisms, which require oxygen and other nutrients, periphyton has a pronounced effect on water chemistry. Filamentous algae, a major group in the periphyton mat, release oxygen through photosynthesis and precipitate calcite.

Animals in ponds and sloughs range in size from microscopic zooplankton to 3-m (10-ft) alligators. Most are not confined strictly to ponds and sloughs but occur in other aquatic habitats. Common invertebrate animals are aquatic insect larvae, copepods, amphipods, freshwater prawns, and crayfish. Vertebrates are represented by fishes, frogs, and salamanders and by aquatic reptiles, birds, and mammals. About 60 species of fishes (44 native and 16 exotic) occur in south Florida (Crowder, 1974g). Common fishes of ponds and sloughs include mosquito fish, sailfin molly, sheepshead minnow, flagfish, least killifish, catfish, mudfish, gar, sunfish, and large-mouth bass. Examples of aquatic reptiles closely associated with ponds and sloughs, as well as other aquatic systems, include alligators, snapping turtles, soft-shelled turtles, and water snakes. A large number of bird species feed in and nest near ponds and sloughs; these include the large wading birds such as the great blue heron, the Louisiana heron, the wood ibis, and the great egret; waterfowl such as the Florida duck, the wood duck, and the coot; and a number of other common birds such as the green heron, the anhinga, and the kingfisher. Large numbers of other waterfowl migrate to and winter in south Florida (Rodgers, 1974). Raccoon and otter are representative mammals associated with the aquatic environment.

The larger, predatory animals that feed in ponds and sloughs require a large biomass of smaller aquatic animals to sustain them. The production of this biomass is related to the extent of water inundation. The availability of the biomass, on the other hand, is related to seasonal water-level fluctuations. Small animals live and reproduce over a wide area of wetland during high water. As water levels recede in the dry season, these small animals are forced into the remaining deep slough and pond areas that still contain water. Alligators, wading birds, and otters congregate at the sloughs and ponds at this time to feed. Wading birds often feed in numerous ponds scattered over many square kilometres. In some species, such as the wood ibis, reproductive success is related to the availability of food in the dry season.

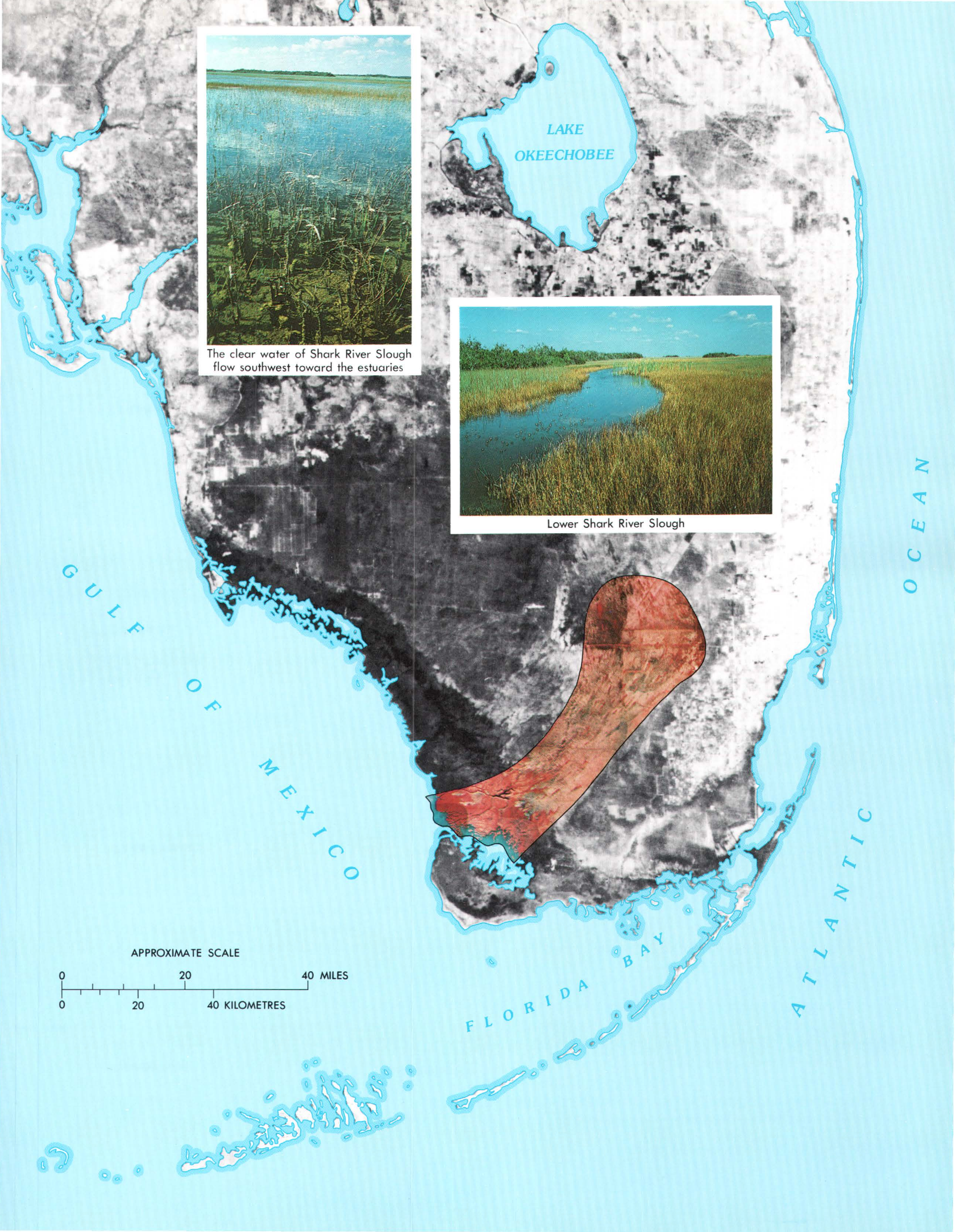
During the dry season, ponds and sloughs serve as feeding areas and survival holes. Because predators are not completely efficient, some small aquatic animals, which would die without water, survive and are able to repopulate the wetlands when water levels rise.

The pond-slough ecosystem has been altered by drainage, particularly in the northern Everglades; about 2,520 ha (6,300 acres) have been destroyed in Broward County alone (Birnhak and Crowder, 1974). In that part of the system that remains, the period of inundation has been altered by drainage or water impoundment. Perhaps the best indication of change is seen in the populations of index species; today there are about 150,000 wading birds, but there were 2.5 million in south Florida in 1870 (Crowder, 1974c; Natl. Audubon Soc., 1973).

Sawgrass marsh

Sawgrass marsh occupies about 70 percent of the remaining Everglades. In the northern Everglades the sawgrass is tall and dense; in the south it tends to be short and less dense, except where it forms a tear-

FIGURE 10.—The Shark River Slough. ►



The clear water of Shark River Slough flow southwest toward the estuaries

Lower Shark River Slough

Sawgrass marsh occupies about 70 percent of the Everglades.

shaped tail at the downstream end of tree islands. Sawgrass marsh ranges from almost pure stands to mixed stands. Herbaceous marsh plants that commonly occur with sawgrass include maidencane, arrowhead, and spikerush. Small trees and brush such as wax myrtle, holly, and willow are also mixed with sawgrass.

Sawgrass marsh usually occurs on land slightly higher than that of the sloughs and wet prairies but lower than that of bay heads and hardwood hammocks. Water inundates the marsh for varying periods during the year to depths ranging from a few inches to several feet; optimum inundation period is in the order of months. Soils differ, ranging from a thick peat to a thin veneer of marl over limestone.

Severity of fire is a major factor in the sawgrass marsh. Sawgrass often burns during the dry season, but the roots remain protected by moist soil; this type of fire serves to prune trees and brush from the sawgrass. In severe droughts, however, sawgrass roots may be burned and the community destroyed.

Approximately 200,000 ha (500,000 acres) of sawgrass have been destroyed, mainly in the northern Everglades (Birnhak and Crowder, 1974). The remaining sawgrass communities have been affected in varying degrees. Davis (1943) observed thinning of sawgrass in the northern Everglades which he attributed to drainage and subsequent soil subsidence and severe fires. Craighead (1971) reported that after severe fires, willow colonized large areas south of U.S. Highway 41 that were originally pure sawgrass stands.

Large sawgrass marshes remain in the conservation areas and in Everglades National Park. It has been suggested that marshes in the conservation areas be used to renovate waste water from the coastal cities as a means of recycling and conserving freshwater now lost to the ocean. Recent studies (Steward and Ornes, 1973a, b, c) indicated that sawgrass has a low nutrient requirement and a limited capacity for removing nutrients from water; therefore it appears unlikely that sawgrass plants could be used effectively to renovate urban waste water with high nutrient concentrations without causing significant changes in the sawgrass communities. These studies further indicated that enrichment with phosphorus and potassium in amounts generally equivalent to that of sewage effluent resulted in dynamic shifts of associated plants in the marsh, including phytoplankton blooms that are indicative of a disrupted environment.

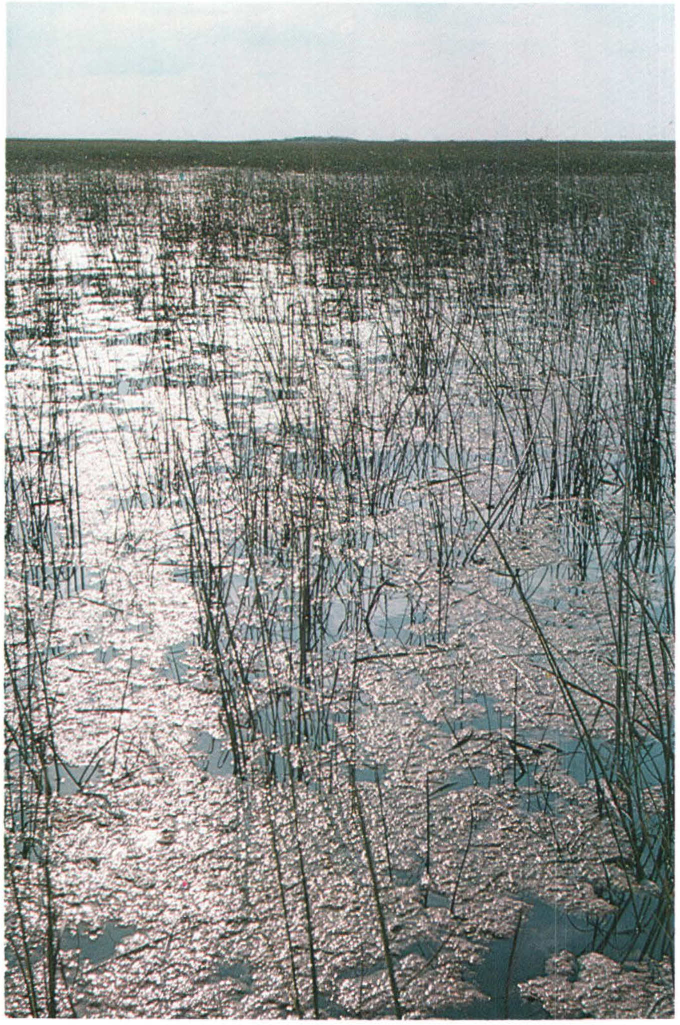
Wet prairies

Wet prairies are seasonally inundated lands intermediate in depth and periods of flooding between sawgrass marshes and sloughs. Characteristic plants include the algal components of periphyton, and a variety of vascular plants such as maidencane, spikerush, beakrush, and water dropwort. Soil in the prairies is usually a calcareous marl, which is precipitated, at least in part, by green and blue-green algae and other microorganisms in the periphyton.

During the wet season, animals of the wet prairies include an assemblage of aquatic and semiaquatic species similar to those of the sloughs. As water levels fall in the dry season, the aquatic animals such as the freshwater prawns and fish are forced into the deeper sloughs and ponds. Water levels rarely recede more than a foot below the land surface except in abnormally dry years (Loveless, 1959).

Wet prairies occur throughout the Everglades, in parts of the Big Cypress Swamp, and in the sandy flatlands, particularly the Devils Garden area. In the Everglades they occupy large areas called "flats," which are extensive on the boundaries of Shark River Slough and the northwest Everglades. In the Big Cypress Swamp, wet prairies occur as flats and as small, isolated areas associated with ponds and marshes. In the flatlands they are characteristically small areas associated with bedrock depressions in the pine forests and dry prairies.

Wet prairies have suffered alteration and destruction since 1900. About 1,300 km^2 (500 mi^2) have been destroyed, including most of the wet prairies immediately west of the Atlantic Coastal Ridge (Birnhak and Crowder, 1974). In Broward and Palm Beach Counties alone, 80 percent of the wet prairies were destroyed



A periphyton mat at the water surface is typical of Everglades wet prairies.

(Birnhak and Crowder, 1974). Alteration—through drainage, water impoundment, and the spread of exotic plant species—has also been extensive in the remaining wet prairies. In the western Big Cypress Swamp, drainage for urban development has suppressed periphyton production and affected all levels of the food web dependent on this production (Carter and others, 1973). In the central Everglades, wet prairies have been affected recently as a result of changes in water impoundment in the conservation areas (fig. 11). In the mid-1950's, wet prairies were common in the central and east-central parts of Conservation Area 2 and in the west and south sections of Conservation Area 3, as indicated by extensive stands of water rush and maidencane (Loveless, 1959). Before the construction of Levee 35, west of Fort Lauderdale, in 1961, much of Conservation Area 2 went dry annually; after construction the area remained flooded. Similarly, the south part of Conservation Area 3 has remained flooded for long periods as a result of levee completion in 1962. As a result of changes in impoundment, wet prairies have been mostly eliminated in Conservation Area 2 and reduced in Conservation Area 3 (Dineen, 1972) but have been increased in parts of Conservation Area 1 (Hagenbuck and others, 1974).

Pine forests

Pine forests occur on rock outcrops and sandy flatlands that are seldom flooded for more than a few weeks each year. They once occupied about 5,180 km^2 (2,000 mi^2) but have been reduced by about half (Birnhak and Crowder, 1974). The major areas of pine forests are in the Big Cypress Swamp, on the Atlantic Coastal Ridge, and on the sandy flatlands north of the Big Cypress Swamp and northeast of the Everglades. In much of the Big Cypress Swamp the pine forests grow on small islands of limestone several inches to several feet higher than surrounding cypress forest land. In the northern Big Cypress Swamp, however, and in the flatlands to the north and northeast, these forests occur extensively on a relatively high sandy soil. Interspersed with the pines are prairies and depressions or low areas of marsh and swamp. In the western Big Cypress Swamp, pines and cypress grow together over large areas of poorly drained soil. On the Atlantic Coastal Ridge, generally 3 to 7.5 m (10 to 25 ft) above sea level, pines grow on extremely rough and solution-pitted oolitic limestone. Interspersed within the pine forest are numerous hardwood hammocks and small areas of swamp associated with the solution holes. Low transverse valleys or glades containing vegetation similar to that in the Everglades dissect the ridge to break the continuity of the pine forest. Organic soils are thin or absent in the pines of the Atlantic Coastal Ridge but thicken in the hammocks, solution holes, and the transverse glades. The pines on the ridge once formed a more or less continuous band from Miami southwestward into Everglades National Park (fig. 12). Most of this forest outside the park, however, has been destroyed.

Characteristic plants of the pine forests are the slash pine and a variety of hardwood trees and shrubs, palms, grasses, and other plants. Cabbage palms and saw palmetto are widely distributed throughout. Grasses are often the dominant ground cover; common genera include beardgrass, wiregrass, and panicgrass.

The distribution of pine-forest plants is influenced by temperature and soil conditions, among other factors. Along the coastal ridge, generally south of Miami, pine forests are characterized by an understory of tropical trees and shrubs such as poisonwood, myrsine, tetrazygia, marlberry, bustic, varnishleaf,

Fire may have either beneficial or detrimental effects on south Florida's ecosystem.

satinleaf, silver palm, and the cycad, coontie. To the north and west tropical species are replaced by cold-tolerant species. On the pine islands of the Big Cypress Swamp, where soils are neutral or alkaline, cabbage palm, wax myrtle, gallberry, and a variety of grasses and sedges are typical understory plants. In the northern Big Cypress Swamp and in the sandy flatlands where soils are acidic, cabbage palms decline, and saw palmetto often dominates as the understory shrub, particularly on the drier lands. Other common plants characteristic of the acid, sandy soil of the flatlands are staggerbush, rusty lyonia, shiny blueberry, and running oak (Davis, 1943).

Fire is important in the pine-forest system. Without fire, hardwood trees flourish, and in about 25 years hardwood hammock forests replace the pine forest (Alexander and Crook, 1973). Fire checks this succession by reducing the spread and density of the hardwood trees. Fires caused by lightning are common in the wet season, but in general fires during this season are not severe; because of moisture they are not extremely hot, and they do not burn deep into the rock and soil. Such fires prune the hardwood trees and shrubs and do little damage to the fire-adapted species. Man-caused fires, on the other hand, often occur in the dry season and can be destructive if water levels are low enough to allow the fire to burn into the soil and to burn at a high temperature. In such cases the fire-adapted pines may be killed if their roots are burned. Man-caused fires are now the most common type (Hofstetter, 1973).

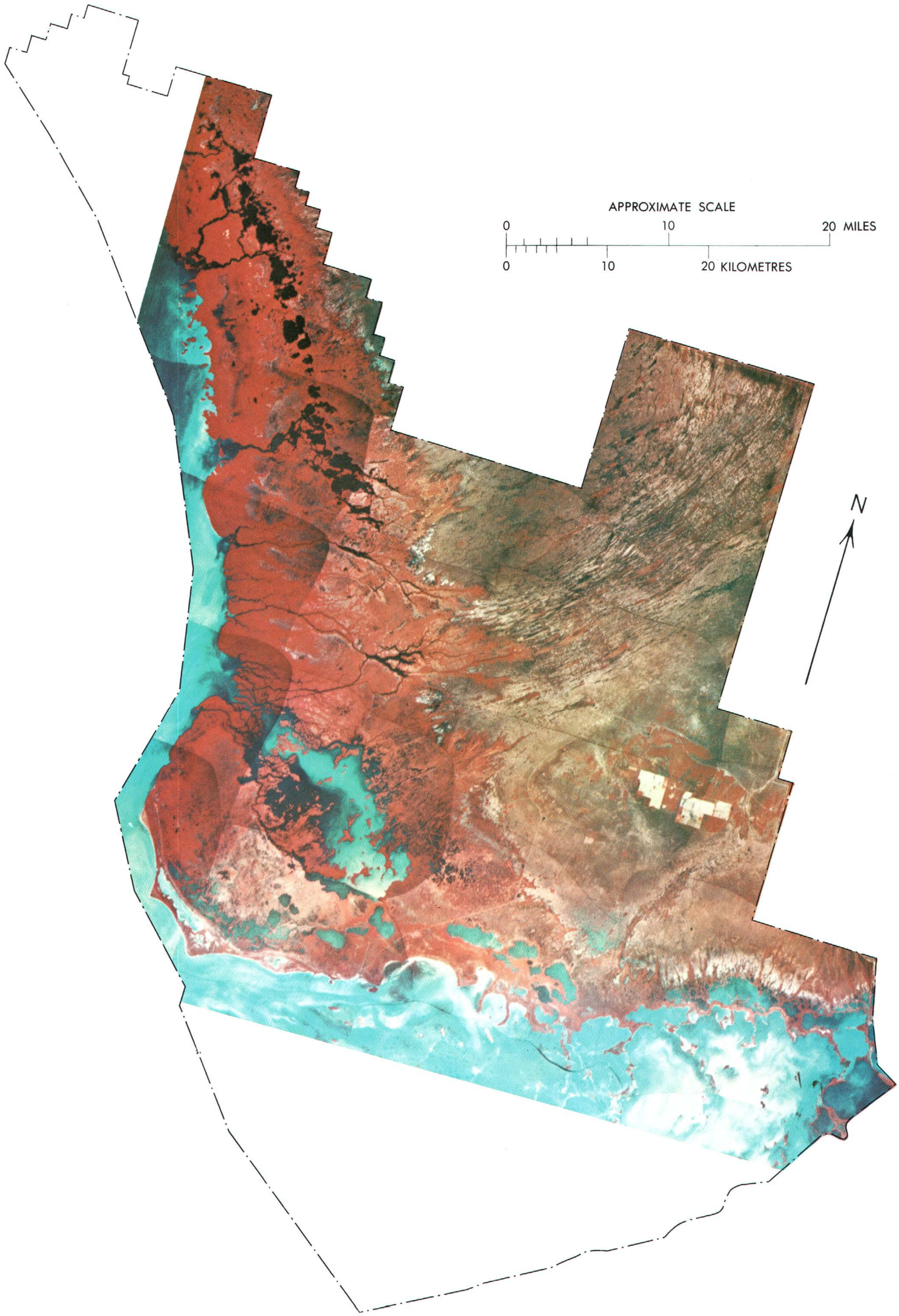
Not all man-caused fires occur in the dry season. Some are started during high-water periods to maintain the pine forest. Burning during high water reduces the competing hardwoods and the amount of dry, burnable litter that might cause a severe fire during the dry season. Much of the pine forest of Everglades National Park is burned intentionally (control burning) each year during high water for this reason.

Animals of the pine forests include numerous arthropods and other invertebrates, a variety of amphibians, reptiles, birds, and mammals. Representatives of 202 families of arthropods, including 84 insect families, were recently collected in the pine forests on the Atlantic Coastal Ridge (Hofstetter, 1973). Spiders are often conspicuous in the pines; major

FIGURE 11.—The water conservation areas. ►

Water level gage in a slough in Conservation Area 3

Vast expanses of shallow water (light color) interspersed with tree islands and sawgrass (dark color)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families in Everglades National Park are the jumping spiders, crab spiders, cobweb weavers, and the orb weavers (Hofstetter, 1973). Amphibians and reptiles, including frogs, toads, lizards, snakes, and turtles, are represented by about 44 species (Crowder, 1974b). Species such as the indigo snake and the Florida pine snake have declined in population (Crowder, 1974b). A large variety of birds reside in or migrate through pine forests; bobwhite quail, turkey, and mourning doves are representative game birds. Some birds, such as the southern red-cockaded woodpecker and the southern bald eagle, associated with pine forests as well as other habitats, are now endangered species (Rodgers and Crowder, 1974). Common mammals include mice, squirrels, opossums, armadillos, raccoons, and deer. Panther, once widely distributed, are now endangered (Rodgers and Crowder, 1974).

Pine forests are the most threatened of the major natural systems (Hofstetter, 1973), as a result of land clearing for agricultural or urban development. The remaining pine forests, mainly in Everglades National Park, have also suffered change during the last 30 years. Hammock species, particularly poisonwood, have invaded pine lands during the years of fire protection before control burning (Alexander and Crook, 1973).

In the Eastern Flatlands, pine forests were logged in the 1920's. Regrowth has occurred, and pines, along with young wax myrtle, have spread into the margins of some ponds. This spread is attributed to decreased flooding (Alexander and Crook, 1973). In the Western Flatlands, pine forests have been logged since 1925. More recently these forests have been cleared for urban usage, farming, and citrus groves, and fires have caused total destruction of pines in some locales. The greatest threat to the remaining pine-forest system is the rampant invasion by cajeput.

Cajeput is also invading the Eastern Flatlands. Cajeput now grows in cypress, pine, and old farmland where it has, in many places, formed domes resembling cypress domes. All age classes are present, so continued spreading is indicated. Brazilian pepper and Australian pine are also common invaders (Alexander and Crook, 1973).

Cypress forests

Cypress forests occupy about 2,075 km^2 (800 mi^2) chiefly in the Big Cypress Swamp (fig. 13) and smaller areas along the eastern edge of the northern Everglades and in the southern Everglades.

In the Big Cypress Swamp area, forests include open areas of small cypress trees and a scattered

◄ **FIGURE 12.—The Everglades National Park.**

A cypress dome in the Big Cypress Swamp.

sparse growth of herbaceous plants, such as sawgrass or beakrushes, growing on a thin layer of marl soil or sand over limestone. Cypress domes and strands of larger trees grow over much of the forest. Domes are circular or egg-shaped features that are dome shaped in profile on the horizon. Strands are elongate areas of large trees that follow depressions. Shrubs and small swamp trees such as wax myrtle, coco plum, and pond-apple are common understory species within the domes and strands.

Cypress domes occur where bedrock surfaces are low. The largest trees are near the center of the dome where bedrock is lowest and organic soils and water are deepest. Trees decrease in size toward the periphery. Vernon (1947) suggested that the large trees were oldest and that domes were explained by a gradual rise in water related to sea-level rise, which allowed cypress to spread progressively out from the center of the dome. According to Craighead (1971), the change in tree size probably reflects growth rate rather than age, and trees in deep nutrient-rich organic soil grew faster than those on the thin infertile soil.

Large cypress trees were present in the strands in the early 1900's, but logging has since removed most of them. However, one major area of large virgin cypress remains at Corkscrew Swamp where the National Audubon Society maintains a sanctuary. Some trees there tower 39 m (130 ft) and have a girth of 7.5 m (25 ft).

Cypress requires abundant moisture for 1 to 3 months after seedfall for germination. Water facilitates germination by allowing the hard seedcoats to swell and soften. Seeds covered by water as long as 30 months may germinate if the water recedes. After germination, the seedlings require dry conditions for a time, and to survive they must grow high enough to stay above the seasonal floods of the next rainy season. Once established, larger trees can grow in the absence of seasonal inundation. Lowered water levels, however, make cypress susceptible to fire.

A remaining stand of large cypress.

An aerial view of the Fakahatchee Strand. Large royal palms rise above the forest canopy.

Mixed swamp forests

Mixed swamp forests are areas of dense stands of trees, shrubs, vines, ferns, and epiphytes that usually occur as elongated strands that follow low drainage areas. Elevation of land within a forest is variable. Most of the forest, however, is seasonally flooded for months. The forest is usually a mixture of shrubs and trees. Cabbage palm, red maple, wax myrtle, coco plum, sweetbay, and redbay are widely distributed. Cypress, willow, pop ash, and pond-apple tend to be more common in deeper water. Hammock vegetation, such as laurel oak, dahoon, wild coffee, myrsine, and occasionally live oak and pine, grow on the higher land. Although the forests are generally a mixture of trees, one species may predominate over a small area. Willow often dominates burned areas. Pop ash, pond-apple, or cypress are often predominant in deep water. Bay trees are sometimes dominant, especially on tree islands in parts of the Everglades; such islands are called bay heads. Cabbage palm predominates at the seaward end of some strands. Large cypress trees dominated much of the forest before logging.

The Fakahatchee Strand is the largest mixed swamp forest in the Big Cypress Swamp. The strand was logged in the late 1940's and early 1950's, and virtually all large cypress trees were removed. Maple, oak, willow, and other swamp hardwoods became dominant after the removal (Alexander and Crook, 1973).

The strand is still known for its rich and diverse flora, which includes at least 39 species of orchids, some of which are found nowhere else (Luer, 1964), 20 species of ferns, and 11 species of bromeliads (Finn, 1966). Numerous small lakes are distributed along the axis of the strand.

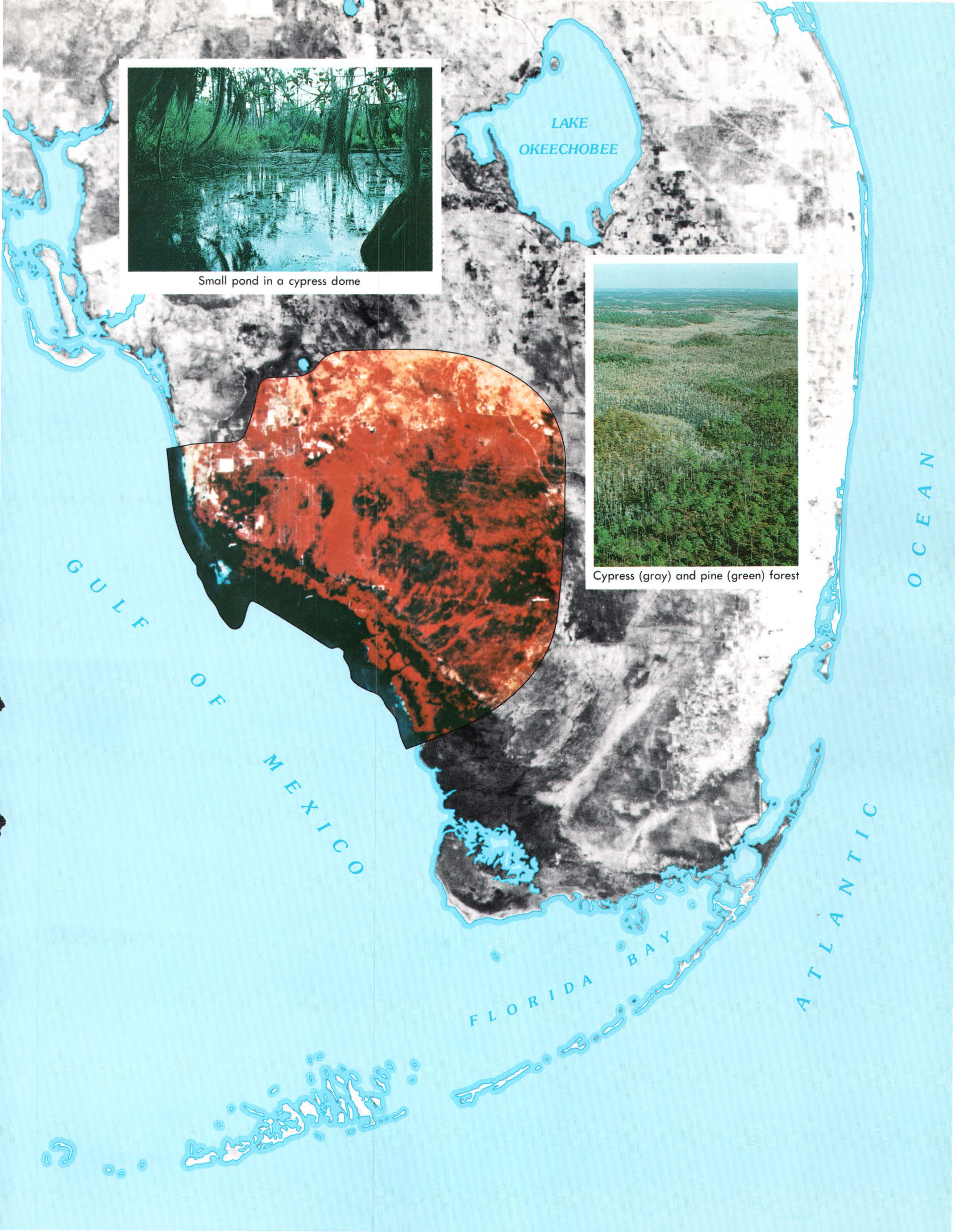
Trees and shrubs are the primary producers of the mixed swamp forest. Their production sustains the animals and microbes. The Fakahatchee Strand, an undrained swamp, produced twice the total biomass and four times the woody growth as a nearby, but recently drained, swamp. Stress on the drained swamp-forest system was indicated by a thinning of the canopy; leaf litterfall was 45 percent greater in the drained swamp than in the undrained swamp. Thinning of the canopy decreases productivity and increases sunlight penetration. Increased sunlight accelerates drying of leaf litter and makes the system vulnerable to fire damage (Carter and others, 1973).

Cycling of mineral nutrients on the swamp-forest floor is also controlled by moisture conditions. Moist conditions accelerate litter decomposition by at least a factor of 1.3, creating favorable conditions for macrodecomposers to further accelerate the process by 1.6 times. As a result, concentrations of mineral nutrients increase more rapidly in the litter of the Fakahatchee than in the drained strand (Carter and others, 1973).

Bay heads

Bay heads are tree islands with broad-leaved, evergreen, and swamp hardwoods. These heads are common through much of the Everglades where they

FIGURE 13.—The Big Cypress Swamp watershed. ►



Small pond in a cypress dome

Cypress (gray) and pine (green) forest

Bay heads are tree islands.

Hardwood hammocks grow on higher land that is seldom flooded and is protected from fire.

occur on peat that is several feet higher than the surrounding marsh. Bay heads are a particular type of mixed swamp forest, distinguished from that described earlier by the predominance of bay trees and their relatively small areas. These heads also commonly have coco plum, pigeon plum, buttonwood, dahoon, and a variety of other swamp trees. Bromeliads, orchids, and ferns are often abundant. Red mangrove and paurotis palm are common near the coast (Craighead, 1971).

Bay heads often develop at solution holes or depressions in the bedrock. The accumulation of peat in depressions may allow trees to colonize the sites, and these trees, in turn, contribute to further peat buildup. Willows are one of the first colonizers; they may in time be replaced by other swamp trees such as the bays. As more peat accumulates, bay heads tend to become elevated and hammocklike. Ultimately, in the absence of peat loss through severe fires, the bay heads will become hardwood hammocks (Alexander and Crook, 1973; Davis, 1943).

Hardwood hammocks

Hardwood hammocks are areas of dense vegetation including hardwood trees and shrubs, palms, ferns, and epiphytes. They are widely distributed and grow in most terrains where conditions of favorable land elevation and fire protection occur. Hammocks grow on land slightly higher than that of surrounding marshes, wet prairies, cypress forests, or mangrove forests and in open country where they stand out on the horizon as tree islands. Tropical hammock forests are among the most diverse systems in south Florida, containing more than 100 species of trees and shrubs. The animals of hardwood hammocks are represented by many of the pine-forest species.

In the northern part of the region, temperate-zone trees, such as red maple and laurel oak, predominate in the lower hammock forest areas, and live oak and cabbage palm predominate in higher areas. To the south, broad-leaved tropical trees and shrubs, such as strangler fig, wild tamarind, pigeon plum, gumbo limbo, poisonwood, redbay, and coco plum, become dominant on numerous small tree islands in the Everglades, in pine forests, or as hammocks along Florida Bay or on the higher Keys. Many tree islands of relatively low elevation, particularly in the Everglades, have swamp hardwood trees.

Hammock forests represent a climax community developed in the absence of fire. Areas surrounded by deep water or areas of dense vegetation that retain high humidity and soil moisture are protected from fire and thus may favor the growth of these forests. Hammocks develop slowly as organic material accumulates and builds up the land. The general sequence is shown in figure 8.

Temperature and water salinity, in addition to fire, influence hammock development and diversity. Frost restricts some tropical species, and coastal spray or tidal flooding, especially during storms, inhibit species near the sea.

Because hammocks are on higher land, they have long been sites of human occupation. Most large hammocks in the Everglades show signs of habitation such as old pottery, metal containers, or planted citrus trees. Indians lived on and farmed these hammocks originally; later they were used by white settlers and hunters. Large areas of hammock forest along the Caloosahatchee River, along the Atlantic Coastal Ridge, and on Key Largo have been destroyed fairly recently by agricultural and urban development. Hammocks have also been affected both by lowered water levels, which increase the chance of severe fires but which also favor hammock growth in areas formerly flooded, and by exotic species which have invaded some areas.

Palmetto and dry prairies

Palmetto and dry prairies occur primarily in the northern Big Cypress Swamp and to the north and northeast in the Eastern and Western Flatlands (Davis, 1943). In the flatlands, numerous small areas of prairies are scattered through the pine forests. In the northern Big Cypress Swamp, a large area of prairie lies east of Immokalee.

Palmetto and dry prairies occur on relatively high, well-drained, sandy soil that is seldom flooded. Depressions or potholes are common, and these hold water seasonally. Characteristic plants are saw palmetto, beardgrass, gallberry, wiregrass, and carpetgrass. Pine trees and cabbage palms are sometimes widely scattered. However, cabbage-palm hammocks occur where sands are underlain by calcareous materials that tend to make soils neutral or alkaline. Cabbage palms are not common in acidic sandy soil (Davis, 1943).

Numerous swamps, marshes, and wet prairies are scattered in depressions through the dry prairies. The depressions are usually smaller than an acre or two and nearly circular. Typically, the water is deepest in the center. Wet prairies form an outer zone or ring that typically grades into ponds or deep-water marshes in the center of the depression. Some depressions are large and elongate. The Okaloacoochee and Twelvemile Sloughs and Corkscrew Marsh are examples.

Animals of the palmetto and dry prairies are similar to those of the pine lands. A few notable exceptions specifically characteristic of the dry prairies are the Florida burrowing owl, Audubon's caracara, and the Florida grasshopper sparrow (Rodgers and Crowder, 1974).

Palmetto and dry prairies are used as pasture and farmland and more recently for residential development. About 50 percent of these systems have been destroyed (Birnhak and Crowder, 1974). Although the vegetational features of the flatlands are still recognizable, as described by Davis (1943), they are frequently marked by levees and drainage ditches, farm and pasture land, and citrus groves (Alexander and Crook, 1973). Exotic plants are a threat to the remaining dry prairie system. Cajeput, in particular, is invading the Eastern and Western Flatlands (fig. 14), encroaching into dry prairies as well as the associated pine forests, marshes, and swamps (Alexander and Crook, 1973).

Palmetto prairie in southwest Florida.

Coastal ecosystems

The south Florida coastline can be divided into four ecological areas: sandy beaches, mangroves and salt marshes, shallow bays, and the Florida reef tract. These areas blend from one to another. Mangroves and sand extend from the shoreline into the bays, and the bay-bottom grass beds spread out past the Florida Keys onto the reef tract.

Water is the medium that links the coastal ecosystems. Saltwater from offshore currents moves over the reef tract, through the bays and mangroves, and back offshore carrying physical and biological products from one coastal environment to another. Freshwater, moving overland from the mainland through the mangroves, into the bays, and out to sea, transports terrestrial products to marine habitats. Where moving water acquires sufficiently different characteristics, it supports different plant and animal communities.

The Florida Current, moving around the tip of Florida and continuing northward as the Gulf Stream, provides clean, warm, saline water to the coastal area, water that helps produce the conditions required for coral formation and that supports a diverse tropical marine flora and fauna. In addition, the Florida Current transports and distributes juvenile fish and invertebrates, as plankton, to coastal water.

Tidal currents flush oceanic water in and out of the bays, mixing it with freshwater from rains and terrestrial runoff. The sediments and shallowness of the bays encourage the growth of extensive marine grass beds. These grass beds are highly diverse and productive habitats adapted to some fluctuation in salinity and temperature. The bays themselves derive some of their nourishment from the mangrove and salt marshes and tidal flushing and terrestrial runoff.

Any major change in the coastal environment will have an effect throughout the coastal ecosystem. Diminishing nutrient production in one part of the system will show up as less biological production in another part, and disturbed sediments are often redistributed, smothering a distant habitat. In addition, alteration of freshwater runoff changes the distribution of coastal salinity.

Sandy beaches

In south Florida, sandy beaches are best developed along the Atlantic coast as far as the south tip of Key Biscayne, and along the Gulf coast. The typical Atlantic coastal beach is the result of two natural forces working together: an onshore wind-generated wave action and a longshore current moving southward. Prevailing winds, produced by southward-advancing winter cold fronts, and eddy currents, created by the northward-moving Gulf Stream, generate a current that moves past Cape Hatteras south to the tip of Florida. This current is strongest during the winter and transports large quantities of silica sand southward. Wave action mounds this sand into coastal bars. Where the bars break the water's surface, prevailing onshore winds may blow the sand up the shore where it accumulates as a coastal ridge or a series of inland dunes. Offshore bars commonly are capped by dunes to form a string of islands separated from the mainland by lagoons, locally called lakes or rivers.

The sandy coastline is constantly changing. Whole beaches may be washed away during a storm, new inlets may appear between the sea and the lagoons, old inlets may close, widen, or migrate, sand dunes may build or erode, and sandbars may form seaward of the existing beach to create a new string of barrier islands.

Sandy beaches are poorly developed south of Key Biscayne, but some occur as small pockets in the Florida Keys and the shallow bays behind the Keys. Normally the sand in the pocket beaches is composed of calcium carbonate derived from limestones along the lower mainland and the upper and lower Florida Keys. The shorelines of Florida Bay are mostly lime muds. Around Cape Sable and northward, beaches become shelly and contain increasing amounts of silica sand. From Cape Romano northward past Naples, silica sand mixed with shell forms the beaches.

The most extensive beaches on the southwest tip of Florida are the 16-km (10-mi) long beach on Cape Sable and the 10-km (6-mi) long Highlands Beach. Both are made up of shell and quartz sand over a marl base and were formed and rearranged largely by severe storms. Indeed, on Cape Sable these storms have built a coastal prairie nearly 600 m (1,800 ft) wide that extends landward in a series of low dunes. North from Naples, the sandy beach is similar to Atlantic coast beaches. However, wave action along the Gulf is weaker, the coastal dunes are smaller, and the distribution of animals and plants on these beaches differs somewhat from those of the Atlantic beaches (Martens, 1931).

Littoral sands have been compared to deserts because of the relatively low diversity of marine animals and plants living there. The shifting nature of sand makes a poor substrate for those plants and animals which attach themselves, and marine plants generally are not found on wave-combed submarine sands. Most marine invertebrates and fishes in such environments are burrowing types. Bivalve mollusks have adapted well to the soft deep sands and are represented by many species. Sea urchins, burrowing snails, crabs, and flat fish are common. However, luxuriant growths of marine algae, mollusks, barnacles, sea squirts, and worms attach themselves to rock platforms. One important biological feature of the sandy coast northward from Key Biscayne is the massive worm reefs which build upon local rocky platforms. These worms, sometimes called honeycomb worms, filter sand particles from seawater and then build sandy tubes around themselves. The reefs provide shelter for a host of fish and marine invertebrates.

Above sea level, shifting sands may form dunes or a series of dunes where plants are more common because the plant root systems act as holdfasts against the moving sand. Beach vegetation usually grows in zones that reflect each plant's adaptability to marine influences and a shifting substrate. The vegetation forms three typical zones along the Atlantic sandy coasts: a sea oats zone, a saw palmetto zone, and a scrub zone (Kurz, 1942). The sea oats zone is closest to the shoreline where the sand is least consolidated and is marked by grasses like sea oats and sand spurs or low shrubs and vines like sea purslane, the railroad-vine, and the beachberry. They grow on the seaward

FIGURE 14.—The Western Flatlands and the west coast. ►

Palmetto prairie

Red mangroves are vital to the estuarine food webs.

slope and on top of the first beach dunes. The saw palmetto zone is on the landward side of the dunes and in depressions behind the dunes. This zone may form impenetrable thickets of saw palmetto, seagrape, coco plum, and wax myrtle. These two zones are usually narrow and grow close to the shoreline on the beaches in the Florida Keys, and saw palmetto is typically replaced by shrubs of baycedar and sea-lavender (Davis, 1943). On the sandy Gulf beaches north of Naples, cabbage palms appear in the saw palmetto zone forming thick stands along the beach. A third zone of variable nature occurs behind the saw palmetto zone. On the Atlantic coast, it may be a scrub zone of dwarfed oaks, sand pines, and rosemary bushes. Elsewhere the zone may be a coastal hammock, a pine flatland, or a mangrove swamp. This third zone represents a transition from the beach to the dominant type of inland vegetation. Dunes in the third zone are relatively old and stable compared to dunes of the saw palmetto and sea oats zones.

Mangroves and salt marshes

Mangrove forests and associated salt marshes form a crescent-shaped region around the south tip of Florida. This region ranges in width from a thin fringe of trees along the rivers and behind coastal dunes to mangrove flats and thickets that spread as much as 24 km (15 mi) inland. Mangrove forests achieve their greatest development along the deep estuaries behind and north of Cape Sable, where they penetrate the freshwater marshes along the Shark River and its tributaries (fig. 15).

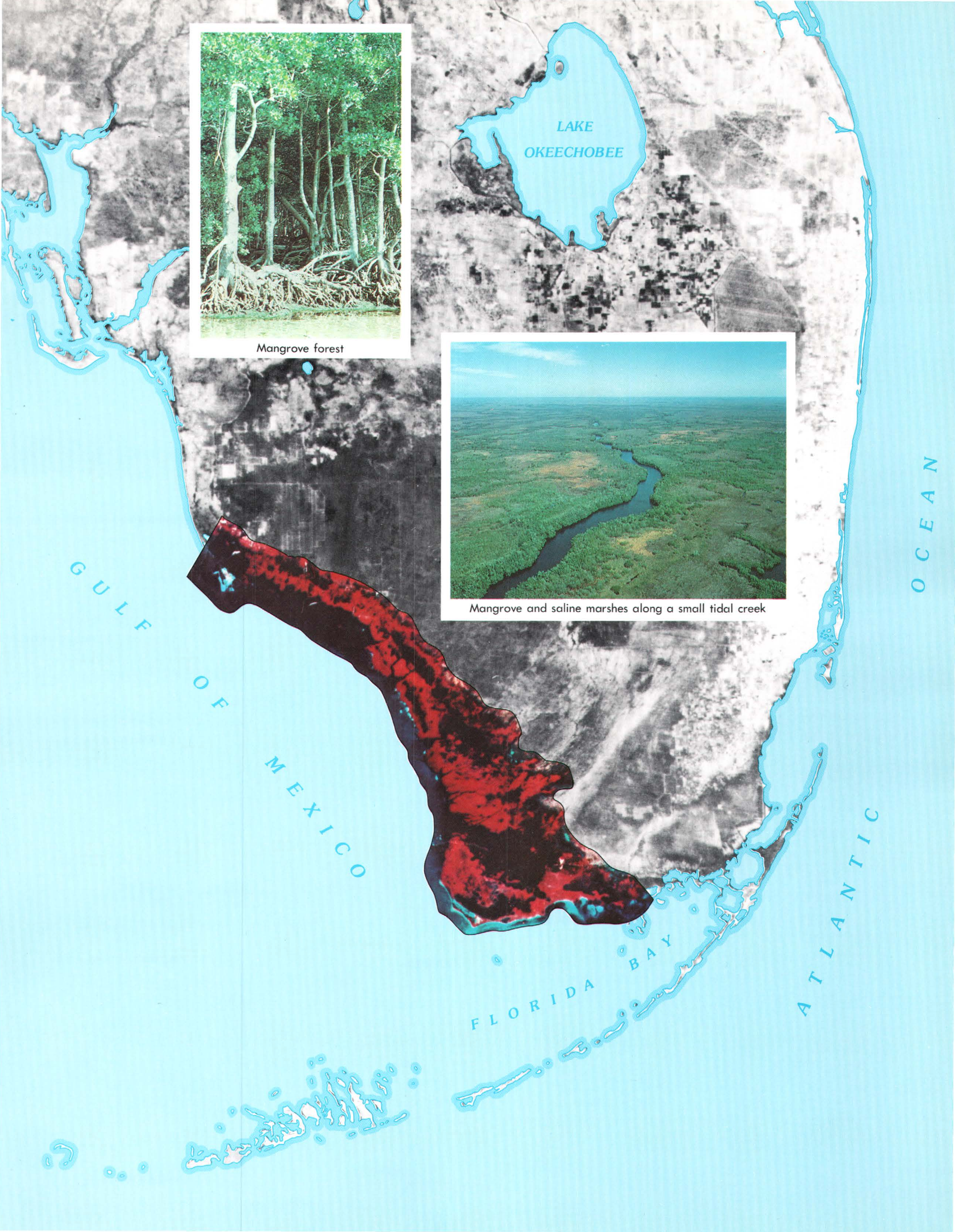
In addition to fringing the coastline, mangroves form small to moderate-sized islands. The mangroves of the Ten Thousand Islands area form an intricate network. Instead of being built upon sediment mounds, they stand on oyster bars that grow perpendicular to the tidal flows and thus give the islands their characteristic shape (Craighead, 1971). In contrast, mangrove islands within Florida Bay are generally round or elliptical and are of two types. One is completely covered with mangroves; the other is an atoll-like rim of mangroves enclosing a depression. The second type has probably been derived from tree islands that existed in freshwater swamps when sea level was lower.

Mangrove trees on the mainland develop into large stands along tidal riverbanks, where the sediment is deepest, and form extensive forests, called mangrove flats, on the numerous islands and inland tidal flats created by these rivers. Even though elevations along the riverbanks are generally higher than in the center of the flats, breaks in the banks allow frequent flooding into the flats. Because mangrove trees typically decrease in size toward the center of the island flats, these depressions are probably ponds that are being filled from the periphery. This pattern of growth, plus evidence of deep mangrove peat beds hundreds of yards offshore, suggests that south Florida's coastline is gradually being flooded and that the mangrove forests are encroaching on the freshwater marshes (Craighead, 1971).

Larger areas of mangroves, the scrub mangroves, exist inland of the shoreline and mangrove flats. The trees are uniformly 1.2 to 1.8 m (4 to 6 ft) tall and form nearly impenetrable masses. They are stunted perhaps because a thick fibrous peat substrate prevents roots from penetrating more than a few feet. Another type of scrub mangrove grows where the underlying sediment is mud rock. These are rarely more than 1.2 m (4 ft) tall and of low density.

The mangrove zone in south Florida is mixed with ponds, prairies, mounds, and islands of differing vegetation. Craighead (1971) separates the saline mangrove zone into 13 principal plant associations: beaches and mangrove shores; batis marshes; buttonwood or madeira hammocks; saline buttonwood islands and strands; shell mounds; marl or coastal prairies; Cape Sable hammocks; Cape Sable prairies; ponds; mangrove flats; scrub mangrove; *Juncus* marshes; and riverbanks. Almost all this plant diversity is formed or maintained in some way by tidal inundation and hurricanes.

FIGURE 15.—Mangrove coastline of southwest Florida. ►



Mangrove forest

Mangrove and saline marshes along a small tidal creek

In 1960 hurricanes destroyed large sections of mature mangrove forests along Florida's southwest coast. Although trees were uprooted or defoliated, they showed signs of some recovery after a few weeks. Shortly after, however, the forests died, and the trees were attacked by wood-boring beetles. It appears that most of the forest was killed by a smothering layer of marl driven inland by hurricane tides. Seeds carried inland with the marl eventually sprouted to form batis prairies, marshes, buttonwood hammocks, and clusters of new mangrove seedlings. In time, mangroves and other trees will grow over the prairies and marshes.

Hurricanes have deposited debris and mud along an old shoreline in south Florida and thus created a low embankment (sometimes called the "Buttonwood Embankment"), which extends along the shoreline of Florida Bay to Flamingo and then continues to the North and Watson Rivers. Except where it is broken by rivers or has been destroyed by fires, the embankment forms a natural levee that impounds freshwater and separates the saline mangrove zone from the freshwater uplands.

Plants that grow in the saline mangrove zone are adapted to varying degrees of tidal inundation. The black mangrove and the white mangrove require periodic saltwater inundation. The red mangrove, which is the dominant mangrove species, can grow in salt, brackish, or freshwater, but seedlings must be covered by water until they are 3 years old. Because of the red mangrove's tolerance to freshwater, it extends farthest inland; however, it seems to be most susceptible to storm damage. Perhaps for that reason, mature mangrove forests and shorelines are dominated by large old black mangrove trees. Another common tree in the mangrove zone, the buttonwood, prefers higher and drier ground. It grows along riverbanks, embankments, old tree islands, and marl prairies where layers of hurricane mud have raised the ground elevation.

In their earliest stages, the marl prairies contain salt-tolerant ground covers like saltwort, glasswort, sea blite, sea purslane, samphire, waterhemp, sea daisy, and the cordgrasses. Many marshes and ponds in the prairies and mangrove flats contain freshwater during the rainy season. Such marsh plants as black rush, fringe rush, sawgrass, and cordgrass grow there because they tolerate changes in salinity.

Nutrient cycles in mangrove swamps

Mangrove forests are particularly important to the coastal ecology. Their leaf litter and seeds add rich organic material to the tidal waters. Leaf fall is greatest during the dry season, but seed production occurs during the rainy season when the likelihood of distribution by tropical storms is greatest. Not only are mangroves adapted to and dependent upon the seasonal changes in inundation, but the different species of mangroves and their characteristic forest types are distributed in relation to the amount of tidal flushing (Lugo and Snedaker, 1973; Carter and others, 1973). For example, red mangroves grow in areas of greater flushing than do black mangroves, so their organic contribution to the estuaries and bays is larger and creates an extremely rich and nutritive habitat. It is estimated that 75 to 90 percent of marine commercial and sport species of fish in south Florida utilize the estuarine habitats. Also, commercially important shrimp, lobster, and stone crabs spend part of their juvenile lives in the estuaries and mangrove-lined bays. These fishes and crustaceans are called estuarine-dependent species, and their existence and populations are directly related to the estuaries, bays, and mangroves.

The coastal mangrove fringe acts as an effective buffer to the upland environment during the storms. The mangrove line breaks the wind and high tides. In a similar manner, mangroves act as baffles that help keep the inland waters free of floating debris and suspended sediment. Prevailing onshore winds push the coastal waters through the tangle of mangrove roots where debris and sediment are trapped and filtered. Thus mangroves not only enrich coastal waters but also help to maintain water clarity; clarity helps enrichment by permitting sunlight to penetrate to the submersed plants.

Destruction of the mangrove shores

Clearing and filling extensive areas of Biscayne Bay, the Florida Keys, and part of the coastline of southwest Florida for urbanization has reduced the area of mangrove shoreline. The fill is usually dredged from the adjacent bays and estuaries, and in the process, mangroves not removed during construction are killed when their roots are smothered by the layers of fill. Filled areas are usually retained by bulkheads, the placement of which is extremely important to the future of south Florida's mangrove forests and saline marshes. If bulkhead lines are placed too far bayward, all the mangrove lands may be subject to development and fill. Improper development landward of the mangroves can alter the overland sheet flow of freshwater to the fringes. Mangroves depend on this seasonal flow (Lugo and Snedaker, 1973).

Shallow estuaries and bays

A series of interconnected bays—Biscayne Bay, Card Sound, Barnes Sound, and Florida Bay—lie between the mainland and the Florida Keys. They are semitropical environments supporting a variety of biological communities dependent upon the distribution of sediment, salinity, and tidal flow. The bays and estuaries are calm because they are protected by the reefs. They are open to the sea by inlets between the keys and are interconnected by narrow channels through shallow mudbanks. The bedrock consists of coralline and oolitic limestones. Thin layers of lime mud, quartz sand, freshwater calcite mud, or peat cover the limestone. The freshwater mud and peat, plus sediment-filled depressions in the limestone, indicate that these bays once were freshwater lagoons.

Florida Bay is a triangular area of about 2,200 km^2 (850 mi^2) (fig. 16) whose western side opens directly to the Gulf of Mexico. Except for numerous tidal channels between the Keys, it is completely enclosed to the south. The rock under Florida Bay is the oolitic limestone which in most areas is covered with a thin layer of fine calcareous sediment. Green algae may have formed most of this sediment. The depth of the bay is commonly 1.2 to 1.8 m (4 to 6 ft), but several long winding bars join to create a lacelike pattern of banks enclosing shallow depressions. Mangroves grow where the banks come near the surface and create small islands. The irregular lattice pattern was caused by the slow inundation of an Everglades-like marsh by a rising sea. Mangroves growing inland along rills and sloughs joined with mangroves on elevated shorelines to form a perpendicular meshwork which trapped marine sediments, thus forming the lattice pattern of banks and depressions.

The Ten Thousand Islands area along the southwest coast might also be considered a shallow bay. There, numerous oyster bars and mangrove islands create an intricate pattern of protected backwaters. Longshore currents from the north have deposited silica sand to form offshore bars parallel to the coastline. Dense mats of oysters grow on top of these sandbars perpendicular to the tidal flow and thus gain a feeding advantage. Mangroves grow on these intertidal bars and with time deposit tough fibrous layers of peat. Eventually, further growth of the oyster bars may so restrict tidal flow that oyster growth declines. The mangroves, however, will continue to cover the bars and connect adjacent islands. Later, sediments will fill the lagoons between the bars. Even so, mangrove land building appears to be balanced by the gradual drowning of offshore islands by a rising sea.

Shallow tidal flats and creek in southern Biscayne Bay.

Bay-bottom communities

Environmental conditions in south Florida's bays vary with location within the bays. Water depth and salinity, depth and composition of sediment, and strength of tidal flow determine the kind and distribution of biological communities within the bays.

Salinity of bay water fluctuates depending upon closeness to the mainland, water depth, and climatic season. During the rainy season the parts of the bay nearest the mainland receive freshwater runoff through the mangroves and coastal marshes or directly from rivers and canals, and their salinity is lowered. Water near low bars and flats within the bay also freshens during heavy rainfall. Plants and animals living in these nearshore areas are usually adapted to fluctuations in salinity. Occasionally, however, abnormally high rainfall and a large discharge of freshwater from canals and rivers stress and kill local marine plants and animals. On the other hand, during prolonged dry seasons the water in Florida Bay becomes hypersaline; also this change stresses the marine biota.

Tides affect environmental conditions in coastal areas by mixing waters of different salinities, rearranging bottom sediments, and distributing oxygen and nutrients. Tidal flow is strongest near inlets between keys and bars, but it is generally sluggish in the center of the bays. Animals and plants that require large amounts of oxygen or suspended nutrients in the water grow best near the inlets. However, some plants and animals prefer the deeper parts of the bays where tidal flow is weak.

An electric powerplant on the shore of south Biscayne Bay.

Marine plants generally flourish in areas of accumulated sediments and where the water is clear and shallow enough to allow photosynthesis. Those plants characteristic of the dominant bottom community in south Florida's bays are the marine grasses (turtlegrass, manateegrass, and *Diplanthera*) and the algae (*Penicillus, Halimeda,* and *Laurencia*). Turtlegrass is the most common grass and forms dense mats where the roots can penetrate 38 cm (15 in) or more into the sediments. Manateegrass replaces or mixes with turtlegrass in deeper water, whereas *Diplanthera* grows in shallow water. Leaf blades of grasses are effective baffles that hinder tidal flow and allow suspended sediment and debris to settle. This settling helps keep bay water clear and continuously adds to the sediment layers of the grass beds. Several species of marine algae replace or mingle with grasses where the bottom sediments are thin. Sponges, sea anemones, and sea feathers grow where sediments are thin over the limestone rock or have been removed by tidal action. In addition, small corals attach to the limestone and grow where the salinity is relatively high and uniform. Other common invertebrates on the bay bottom are the commercial shrimp, lobster, and stone crab. Numerous species of commercial and sport fish as well as sea turtles and the coastal dolphin live in the bays. Undisturbed and healthy bays support some of the richest fisheries and most diverse marine habitats in the world.

Dredging for fill and boat channels has removed acres of productive bay bottom. Sea grass communities do not easily repopulate these places because the sediment and water depth are altered. Moreover, dredging increases the suspended sediment in the bay water, blocking out light necessary for photosynthesis. Tides may transport this suspended sediment to other parts of the bay where it may settle, often suffocating plants and animals far removed from the dredging operation.

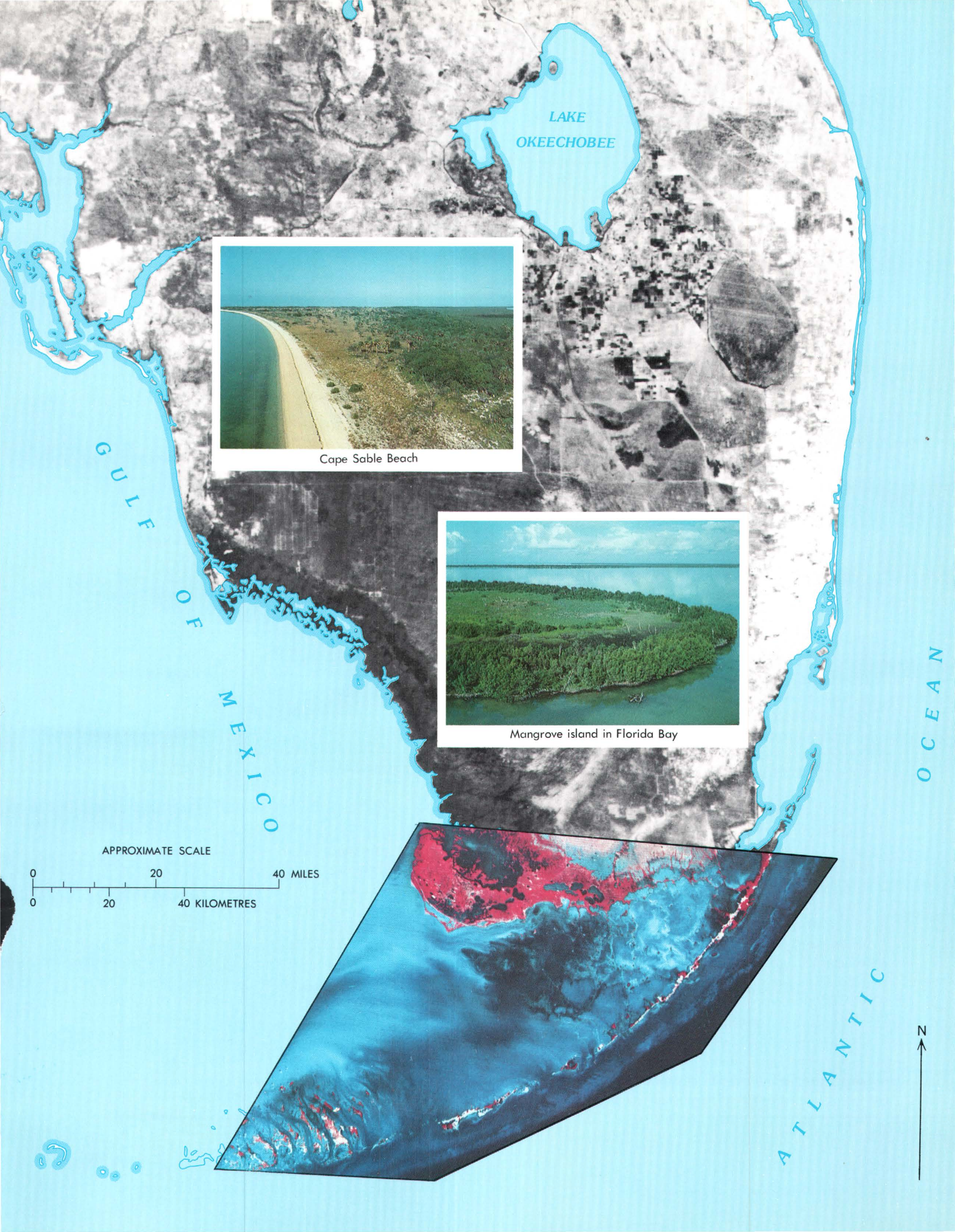
Drainage of adjacent upland and bulkheading the shoreline denies the bays important organic nutrients. Many of the organics utilized in the food chains of south Florida's bays and estuaries are obtained from tidal flushing of the mangrove forests and salt marshes (Lugo and Snedaker, 1973; Snedaker and Pool, 1973; Lugo, Evink, and others, 1973; Lugo, Sell, and others, 1973; Pool 1973; Pool and Lugo, 1973; Adams and others, 1973; Seaman and others, 1973; Evink, 1973), and leveling and filling these forests and marshes destroy an important source of nutrients. In addition, drainage through canals diverts the overland flow of water needed to flush nutrients into the coastal bays and, at the same time, dumps large amounts of low-salinity water into the bays.

Recent increased demand for electrical energy has created a new potential problem for south Florida bays. Since modern electric powerplants require large amounts of cooling water, they are usually built near large rivers or seacoasts. Water cycled through the powerplants is heated and usually is returned to the source at the elevated temperature. This heated water raises the local water temperature to levels that can be harmful to biological communities. Thermal pollution can be exceptionally harmful in south Florida bays where the shallow water is already warm and tidal flushing is weak. As an alternative to discharging the heated water directly to the source, a powerplant in south Dade County is pumping heated water through miles of shallow cooling canals dug in the mangroves and marsh near the bay. While this relieved the threat to the bay directly, it altered and destroyed much of the nutrient-rich mangrove area. New powerplants or expansions of existing plants may result in additional degradation of the natural coastal environment.

Marine fisheries

South Florida supports a thriving sport and commercial marine fishery. Sport fishing in the State generates an estimated $575 million annually, when all tourist expenditures are considered (Lindall, 1973). Sea trout, gray snapper, and red drum constitute most of the catch in southwest Florida. Along the southeast coast, anglers catch these as well as red snapper, grouper, grunt, and large pelagic fishes in-

FIGURE 16.—Florida Bay and the Florida Keys. ►



Cape Sable Beach

Mangrove island in Florida Bay

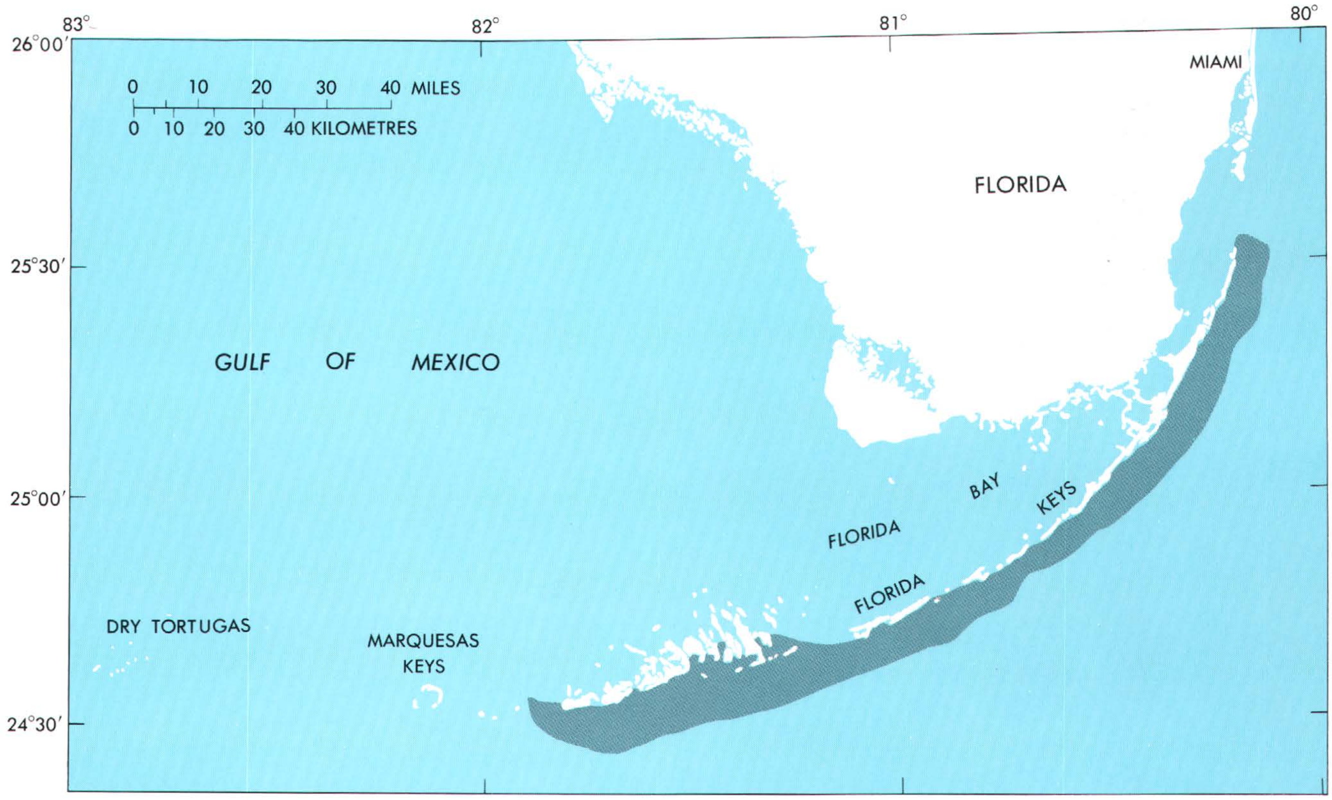


FIGURE 17.—The Florida reef tract.

cluding mackerel, billfishes, and dolphin. Snook and tarpon are avidly sought on both coasts, especially in coastal streams.

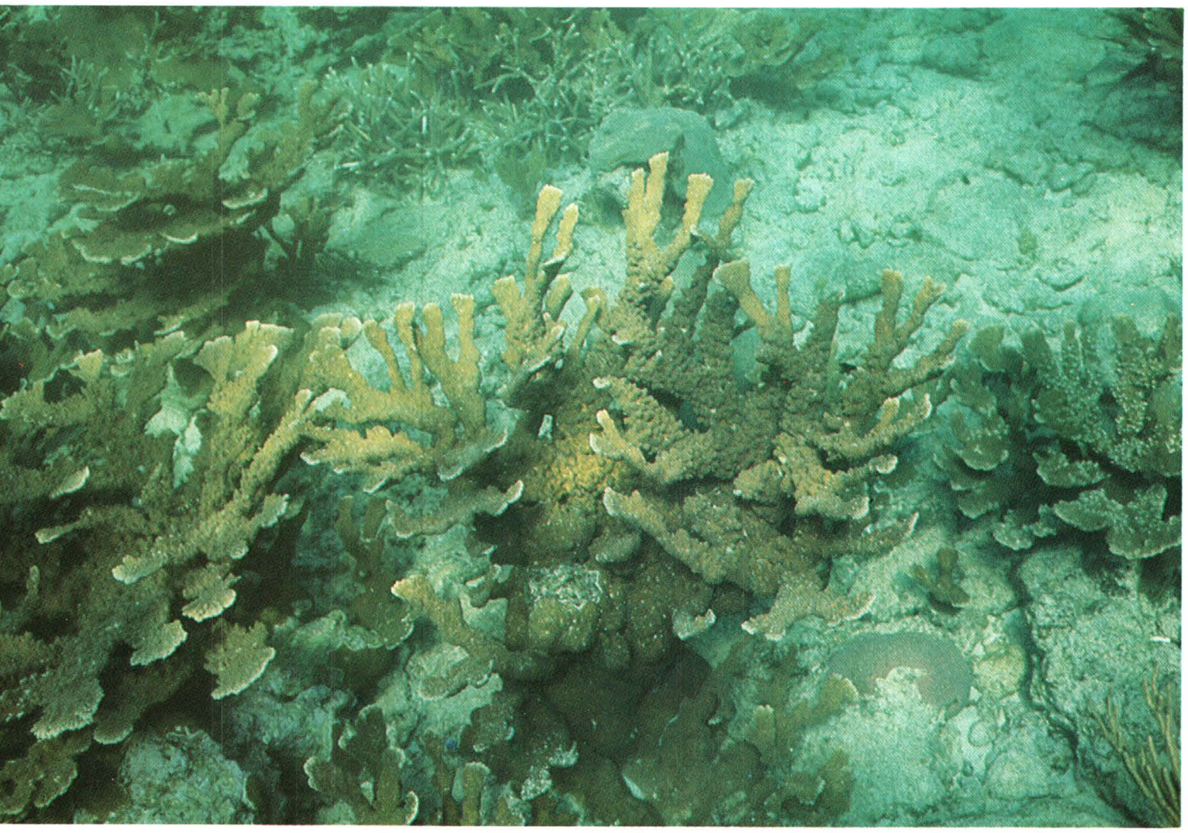
Commercial marine fisheries are important to the local economy. Lindall (1973) reports that in 1966–70 commercial marine fishing in south Florida yielded an annual catch of about 18.1 million kg (40 million lb) of estuarine-dependent species worth more than $10 million (dockside value). The major commercial finfish are striped mullet, white mullet, spanish mackerel, sea trout, and Florida pompano; these comprise 42 percent of the total catch, worth about $2 million annually. Shellfish, including pink shrimp, blue crabs, and stone crabs, constitute 52 percent of the catch worth about $8 million annually. Prochaska and Cato (1974) estimated the annual commercial fisheries yield during 1970–72 for the Florida Keys region to be 13.6 million kg (30 million lb) worth $16 million. This yield was 25 percent finfish ($1.7 million) and 75 percent shellfish ($14.3 million).

The estuarine fishes and many marine fishes of south Florida must live in the estuarine zone at least during part of their life cycle. As juveniles, they obtain food and may derive protection from large marine predators because the shallow brackish estuarine waters exclude these predators.

Estuarine and marine fishes are sensitive to changes in salinity, nutrients, temperature, and other environmental factors. Alteration of the estuarine environment by pollution, habitat destruction, and changing patterns of freshwater and nutrient inflows threatens south Florida's marine fishery resources. Estuarine pollution problems are most severe in Dade and Broward Counties.

Florida reef tract

Corals and coral reefs are most abundant and best developed offshore of the Florida Keys. These reefs, nearly 100,000 years old, form a tract almost 240 km (150 mi) long and about 6 km (4 mi) wide sloping to the edge of the Florida Straits (fig. 17). The reef tract slope is not uniform but consists of a series of banks and channels parallel to the keys. Reefs of two types are present in the reef tract: (1) patch reefs which grow in the back reef zone and (2) outer reefs which form the seaward edge of the reef tract platform. The present day corals are the same species which formed the Key Largo Limestone and built the upper Florida Keys. The best examples of living reefs exist off Key Largo where tidal channels are few and where the offshore water is relatively free of suspended sediment (Hoffmeister, 1974).



Staghorn coral on a south Florida reef.

Farming in south Florida benefits from the year-round growing season.

In the back reef area behind the outer reef, the water is calmer and silt accumulates. Small patch reefs are scattered here among sand banks and grass beds. Almost all the life forms of the outer reef occur on the patch reefs, but the dominance of animal species differs, as does the growing shape of some corals. Sea fans and feathers seem more common here than on the outer reef, and there is a higher percentage of grass-feeding fishes. These fishes appear to utilize the patch reefs as a daytime resting place and then move onto nearby grass beds to feed at night. Patch reefs often have a halo of white sand around their perimeter caused largely by the browsing of the black-spined sea urchins on the adjacent grasses (Ogden and others, 1973).

The greatest variety of corals and coral reef animals lives on the outer reefs. That environment has the stablest temperature and salinity and the clearest water. Most reef-building corals require clear water for photosynthetic algae living in their soft tissues. The corals in turn benefit from oxygen and nutrients produced by the algae. The Florida Current, which moves parallel to the reef tract, provides a rich source of plankton, a food source for many fishes and invertebrates of the outer reefs. The fish population on the outer reefs is one of the most varied in the world, containing more than 500 recorded species (Starck, 1968). In addition, there are more than 20 species of reef-building corals including the branching staghorn corals, large specimens of the star coral, and several species of brain coral. These corals provide a haven for fish, crustaceans, mollusks, worms, and sea urchins. Also, the dead coral limestone offers attachment surface to a multitude of marine algae and invertebrates. Nearly 1,400 species of marine plants and animals were recorded for a small area of the Florida reef tract (Voss and others, 1969). These coral reefs are perhaps the most diverse and colorful marine habitats within the continental United States.

Man-dominated ecosystems

Agricultural systems

Despite the obvious benefit of a year-round growing season, most of south Florida was originally not suited to farming because it was subject to annual flooding. Agricultural activity increased in the 1920's as more and more peat soil in the northern Everglades was drained. Drainage also opened land to farming between the Everglades and the Atlantic Coastal Ridge and in parts of the Western Flatlands. Increasing availability of farm machinery, fertilizers, and pesticides allowed for intensive farming and for farming of marginal lands. On rocky land, for example, machinery was used to break up the original rock surface (Nicholas, 1973).

Today, farming is concentrated primarily in the northern Everglades, the Western Flatlands, and the rocky glades west of the Atlantic Coastal Ridge (fig. 18). Sugarcane, vegetables, and citrus are the important crops. Vegetables from the region provide a large part of the Nation's winter supply.

Cattle are an important industry on natural grasslands and on improved pasture. Cattle ranching is most extensive in the Eastern and Western Flatlands and the Devils Garden area.

Farming and ranching benefit from the year-round growing season and environmental resources of the area. Usually, however, both require subsidies such as fossil fuel, heavy machinery, fertilizers, and pesticides to maintain high levels of net production (Lugo and others, 1971). An exception is cattle grazing on natural grasslands that, under light grazing pressure, are self-maintaining.

Much farming in south Florida depends on the rich muck land for the production of sugarcane, snap beans, celery, cabbage, sweet corn, and other crops. However, oxidation is progressively removing this important rich organic soil. An elevated water table precludes oxidation, but it also precludes agriculture as practiced today (Lugo and others, 1971).

As water levels are manipulated for agricultural development, muck is alternately covered by water and exposed to the air. During low-water periods of drying, oxidation of the muck occurs and the probability of fire increases. These processes result in muck loss and the release of nutrients to the irrigation ditches surrounding the area. Pesticides are also washed from the system and may cause biological damage elsewhere (Lugo and others, 1971).

Agricultural systems of south Florida are threatened by environmental and economic factors. Forced abandonment of farms is predicted in the intensively farmed muck land because of soil subsidence. Other farms will be abandoned because of expanding urbanization that increases land taxes or will be sold for urban and residential development as land costs increase (Alexander and Crook, 1973).

Urban systems

South Florida has experienced accelerated urban growth in the 20th century. Urbanization began along

FIGURE 18.—Lake Okeechobee and the adjoining agricultural ► area.

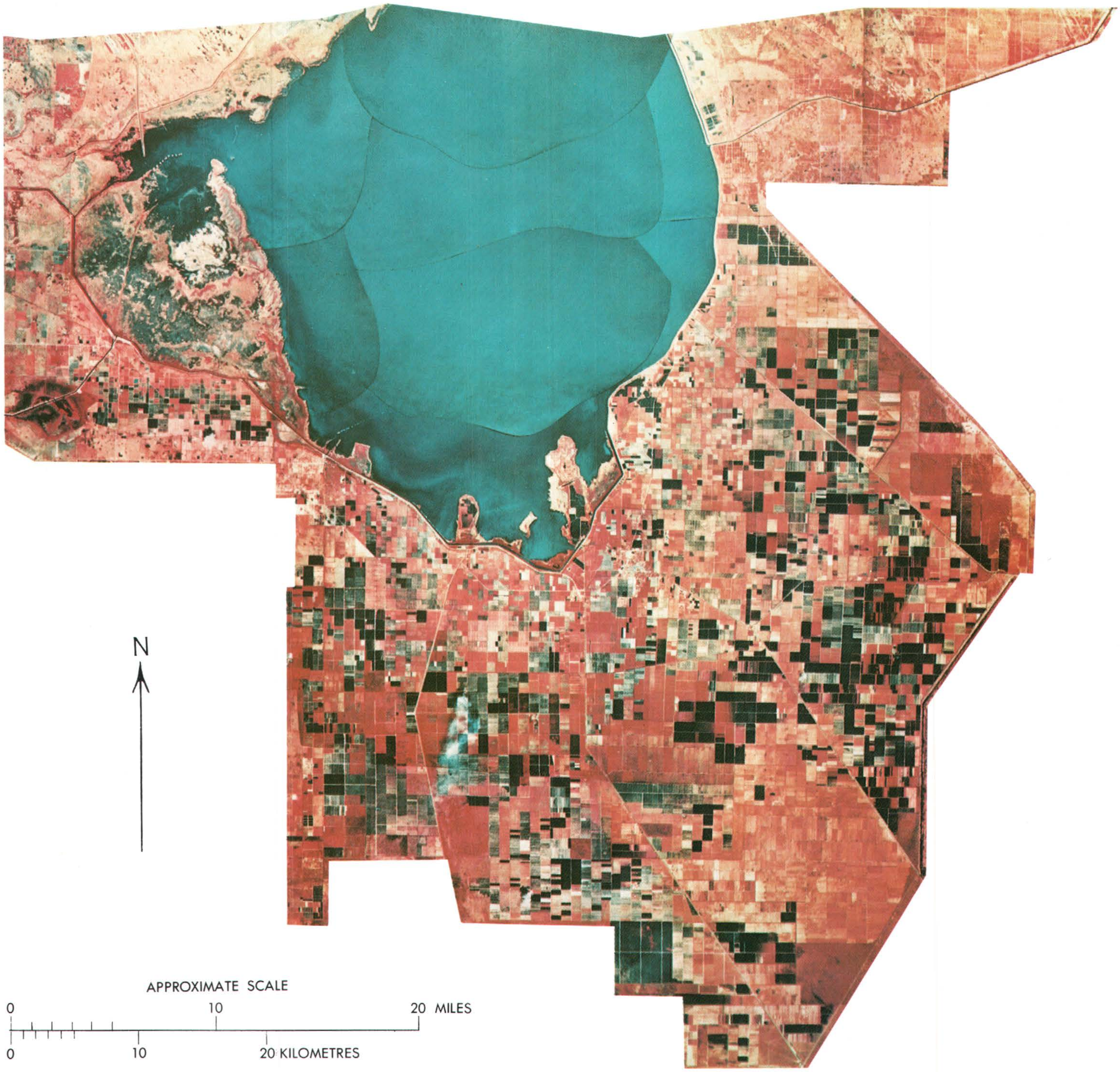

N
APPROXIMATE SCALE
0
10
20 MILES
0
10
20 KILOMETRES

FIGURE 19.—The urbanized Atlantic Coastal Ridge. ►

the Atlantic Coastal Ridge because the land is relatively high, most suited to development, and close to the marine transport that was essential to the original coastal settlements. Extension of the railroad to Miami at the turn of the century sparked a phenomenal growth. It should be noted that although there is also a coastal ridge on the west coast, the Everglades presented a formidable barrier between these two coastal areas.

The largest urban system (the Miami-Fort Lauderdale-West Palm Beach complex) is primarily along the narrow coastal ridge and extends from Palm Beach County to south Dade County. Through the years the flood-control and water-management practices have made some land west of the ridge available for development (fig. 19).

The modern urban systems have only been made possible by highly concentrated forms of energy. For example, industry, electrical power, and automotive engines all contribute to a very large energy consumption or metabolism in cities, about a hundred times higher than most other ecosystems (Lugo and others, 1971). Such a highly concentrated power density in urban areas may lead to serious ecological problems, however, and the resultant effect is greater dependence on fossil-fuel sources:

> Many of the problems of cities may come from the high power flows and local, high densities of power concentration. The intensity of these power flows tends to be destructive of the lower-powered ecological systems in contact with these higher powered areas. Just as a natural ecosystem is diminished when some of the inputs required for its main energy reactions are limited, so the cities can be limited by restrictions on the amount and concentration of the critical inputs. The water crisis in south Florida comes about because development of power plants and other fuel usages increases urban development generally, so that water becomes the limiting factor. In effect, water, as a critical limiting requirement to overall energy flows, becomes the energy releasing source. Energies of other types can be used to develop special water sources, but if such special sources are developed, the system's energy costs are then higher than in some other cities with which there is industrial competition. The system without an abundant life support from nature is not economically competitive. The possibility exists that south Florida is already near that optimum at which the input of the power sources and the inputs of the natural environment such as air, water, waste sink capacity, recycling capacities, and recreation capacities, are at their maximum balanced combination. (Lugo and others, 1971.)

Urbanization has reached its present level of development because of low-cost energy sources. Continued growth or even maintenance of the present system depends on such sources. If energy costs increase, as present trends indicate, the quality of urban life can be expected to deteriorate.

Air pollution is one indicator of a deterioration in environmental quality. Air in south Florida becomes polluted when certain meteorologic conditions, particularly temperature inversions, occur simultaneously with high amounts of gasoline-engine exhaust and smoke from Everglades fires, dump fires, and burning sugarcane near Lake Okeechobee. These inversions occur when the air temperature increases with height above the ground. This condition creates a stable layer of air that tends to trap pollutants (Gerrish, 1973). Incidents of air pollution tend to increase in frequency in south Florida in the dry season when fires become common. In addition to the specific incidents of air pollution, the general air quality has deteriorated over the last 10 years, as indicated by the increase in haze. The deterioration is due primarily to the increase in vehicular traffic and expanding industry.

Recent studies have shown that unstable conditions from low-level inversions occur frequently, not only inland but at the coast practically every night (Gerrish, 1973). Low-level inversions form punctually at night. They are quite strong and persist for about 14 hours. Inversions are generally stronger with east winds, a fact that suggests that the temperature of the upper air is increased by the heat plume from densely urban parts of Miami and that urbanization creates poor dispersion conditions downwind from the heat islands (Gerrish, 1973).


LAKE OKEECHOBEE
GULF OF MEXICO
FLORIDA BAY
ATLANTIC OCEAN

South Florida's hydrologic systems

Importance of water to south Florida

Water is the major controlling factor and a common denominator for all ecologic systems of south Florida. The sole source of freshwater for south Florida is its rainfall, 1,270 to 1,524 mm (50 to 60 in) each year, most of which occurs from June through October. Rainfall recharges shallow aquifers and provides surface runoff by slow sheet flow to the ocean through the Everglades and the Big Cypress Swamp. The natural plant and animal communities are mostly adapted to and depend on wetland conditions and have adjusted to the cyclic nature of the rainfall.

Man has degraded the ecosystem by manipulating the water systems through increased ground-water withdrawals along the urban coastal areas and by canal drainage from the interior to the coast. Drainage by canals has upset the natural flow system by accelerating the runoff and has shortened the periods of inundation and sheet flow in the wetlands. Since recharge to the shallow aquifers occurs in the wetlands, the accelerated runoff from there has reduced the quantities of water available for recharge. Consequences of the drainage were seawater intrusion in the coastal parts of the shallow aquifers and biological alteration in the interior areas. In addition, water-quality deterioration in the canal systems resulted from increased runoff from agricultural and urban lands.

Regional water management since the early 1960's has tended to slow down the rate of change in the interior, but increased demands for water in the rapidly expanding urban areas have continued. The problem becomes one of acceptable distribution of water supply where people demands and environmental demands are satisfied to the extent that the stresses upon each are minimized.

Aquifers

Nearly all municipal water supplies of south Florida are withdrawn from shallow aquifers, generally from wells less than 75 m (250 ft) deep. The most productive and widespread of the shallow aquifers are the Biscayne aquifer of southeast Florida and the shallow aquifer of southwest Florida (fig. 20).

Important also, but of lower yield, are the coastal aquifer, which extends northward from Palm Beach County, and local aquifers scattered through the remaining area, particularly those in Lee County that supply potable water to coastal urban areas (fig. 21). The Floridan aquifer, at greater depth, is capable of large yields of brackish and saline water by artesian flow, but because the water is not potable, the Floridan aquifer is not in general use as a source of water supply in south Florida.

The Biscayne aquifer, a highly permeable, unconfined, shallow aquifer more than 60 m (200 ft) thick in east Broward County, wedges out 56 to 64 km (35 to 40 mi) to the west in the Everglades (Klein and others, 1973). The principal water-yielding beds in the aquifer are solution-riddled limestones. The permeability of the aquifer is highest in south Dade County and decreases to the north and inland. Coastal parts of the aquifer are affected by seawater intrusion. Superimposed upon the aquifer is the system of levees, canals, and conservation areas (fig. 1) of the Central and Southern Florida Flood Control District (FCD) utilized for water control and water management. The responsibilities of the FCD include operating the system to prevent flooding in developed areas during the rainy season, insuring that adequate supplies of good quality water are available to meet increasing domestic and agricultural needs and providing adequate water supply to the eastern part of Everglades National Park.

The shallow aquifer of southwest Florida is as important to the urban lower Gulf coast as the Biscayne aquifer is to southeast Florida (Klein and others, 1973). The shallow aquifer also is unconfined and is thickest, about 39 m (130 ft), along the west coast. It thins to about 24 m (80 ft) in central Collier County and wedges out near the east edge of the county. The area of greatest potential for water supplies is central and west-central Collier County where the limestone beds in the aquifer are thickest, most extensive, and highly permeable. Permeability of the aquifer decreases within 16 km (10 mi) of the Gulf because of increasing content of fine sand and marl. Canals dug during the 1960's for urban development have accelerated freshwater runoff in the west part of the county (McCoy, 1972). Southward sheet flow occurs in the east half of the county during most of rainy season and for a few months after the rainy

FIGURE 20.—Generalized subsurface section showing aquifers of south Florida.

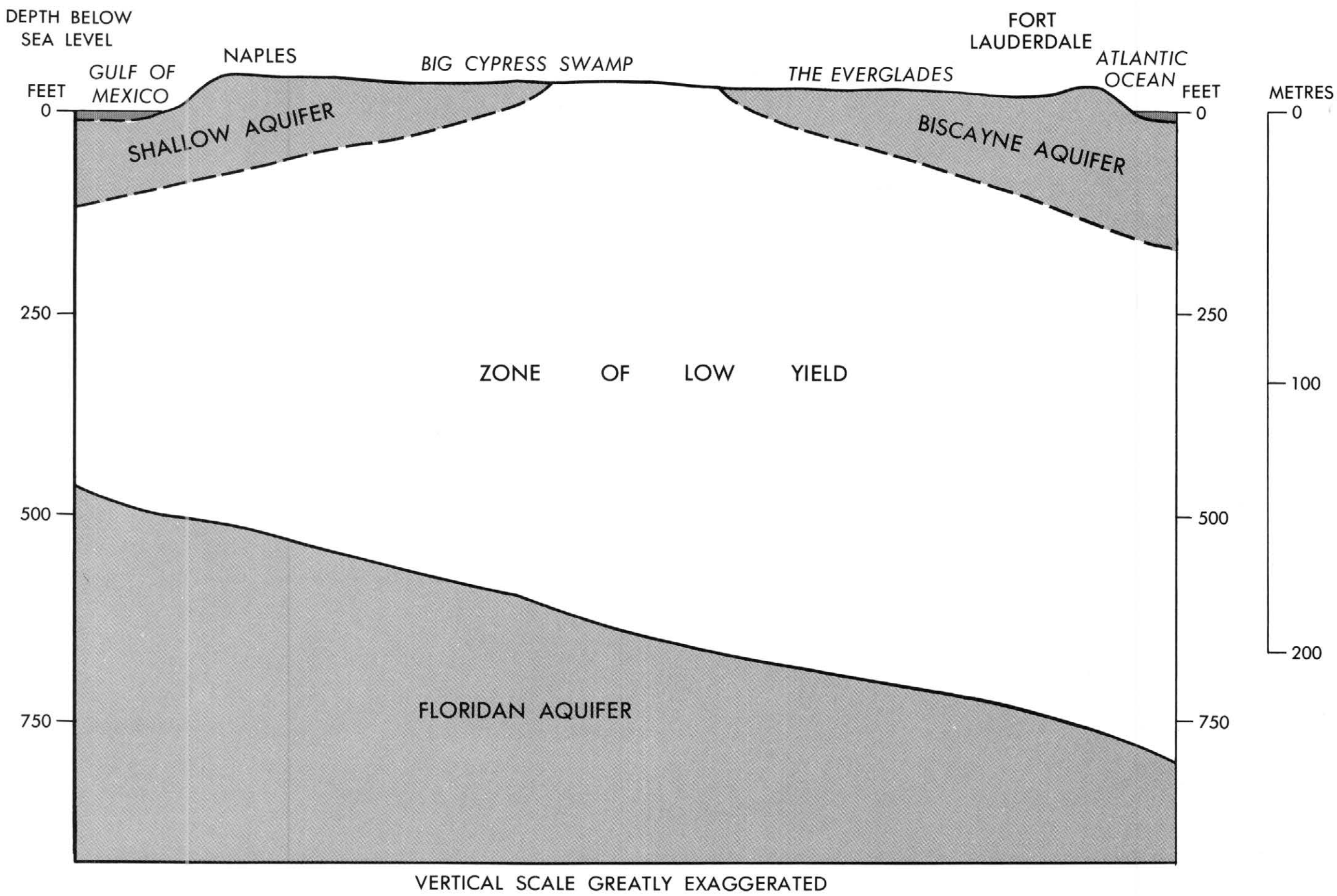
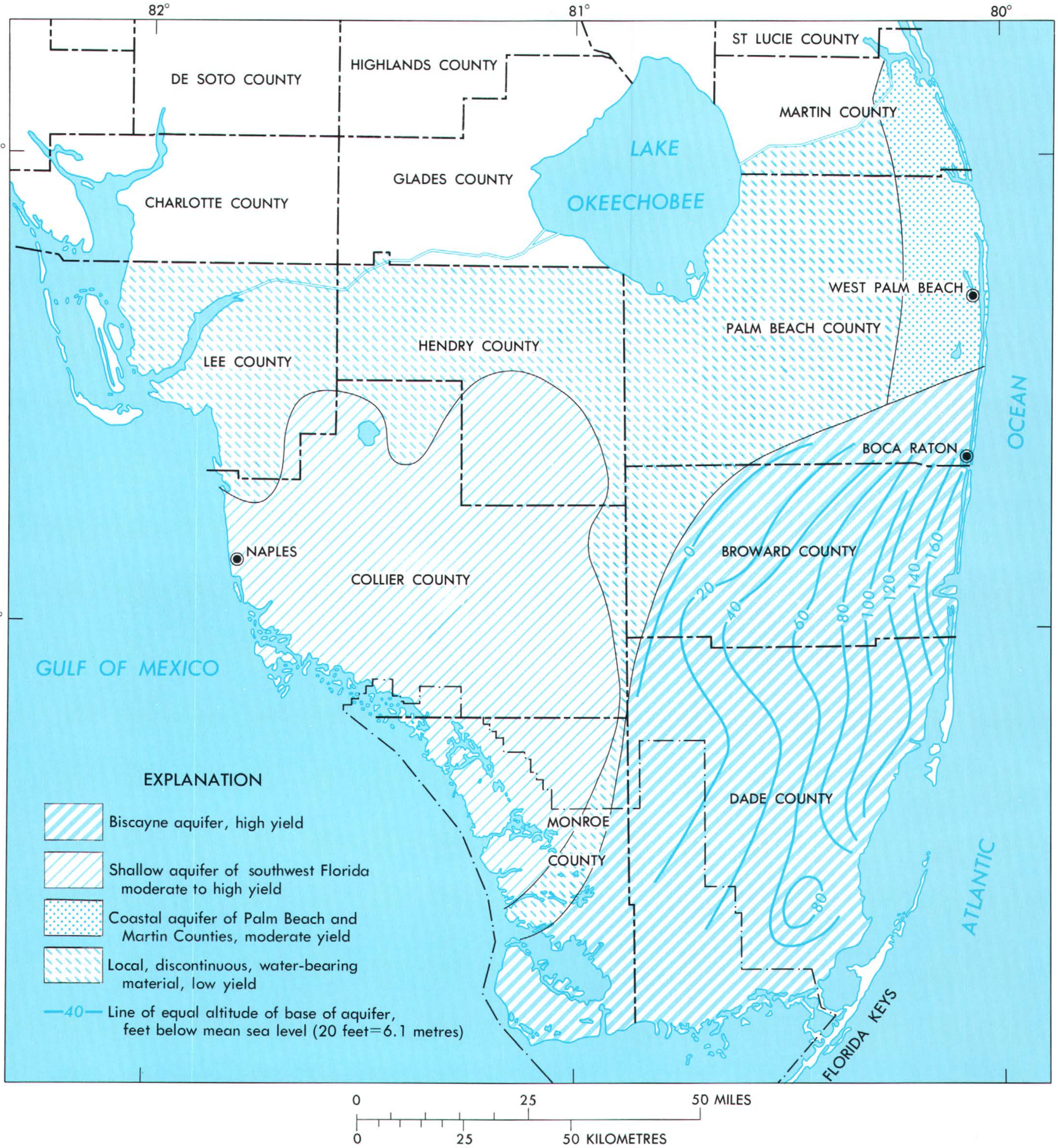


FIGURE 21.—Principal freshwater aquifers of south Florida.



season. Major losses from the aquifer are by evapotranspiration and by canal flow in the west part. Municipal and irrigation uses are minimal.

Except for West Palm Beach, all coastal communities north of the vicinity of Boca Raton obtain water supplies from an unconfined shallow aquifer. The aquifer is about 75 m (250 ft) thick near the coast and becomes thinner to the west. The aquifer probably is hydraulically connected with the Biscayne aquifer to the south, but its hydrogeologic properties differ in that its permeability is less than that of the Biscayne aquifer and that it is composed predominantly of sand rather than limestone.

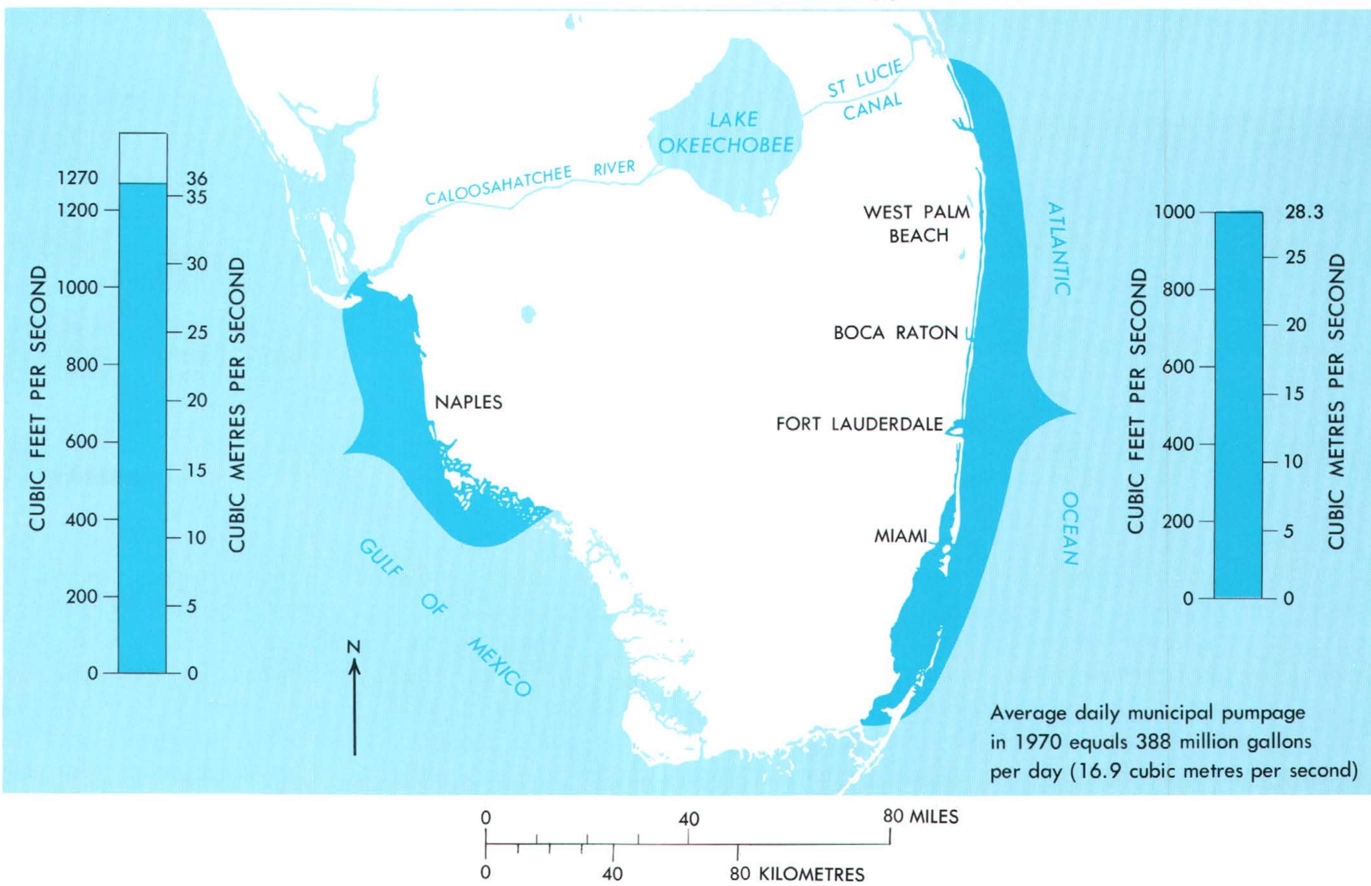
About 60 percent of the annual rainfall in south Florida is lost by evapotranspiration; the remainder infiltrates shallow aquifers, runs off as surface flow, or is used by man. During the wet season and for several weeks afterward, much of the surface flow is in the form of sheet flow in the Everglades and Big Cypress Swamp. Because the land surface is virtually flat, sheet flow is slow, leaving extensive areas inundated for long periods. Canals and levees for flood control and water management have greatly altered surface flows in southeast and southwest Florida coastal areas, so that part of the water that originally flowed southward through the interior is now being diverted eastward and westward. Even during extremely dry years, the quantities of water discharged to the ocean greatly exceed the quantities currently pumped for municipal purposes (fig. 22).

Change in water balance in southeast Florida

After several decades of urban and agricultural growth—with the attendant environmental changes—southeast Florida's residents have come to recognize that man and his environment are inseparable and that only through prudent, long-range land-use planning and water management can he attain an acceptable balance between development and environmental preservation. Until such plans are formulated and implemented, it is important that planning and water-management agencies use caution in their decisions involving growth that may effect further environmental changes, particularly those decisions affecting water resources, because of the reliance of the environment and urban growth upon southeast Florida's finite water supply.

The surface-water systems and interconnected aquifers of southeast Florida contain large quantities

FIGURE 22.—Dry-year outflows of freshwater in south Florida.



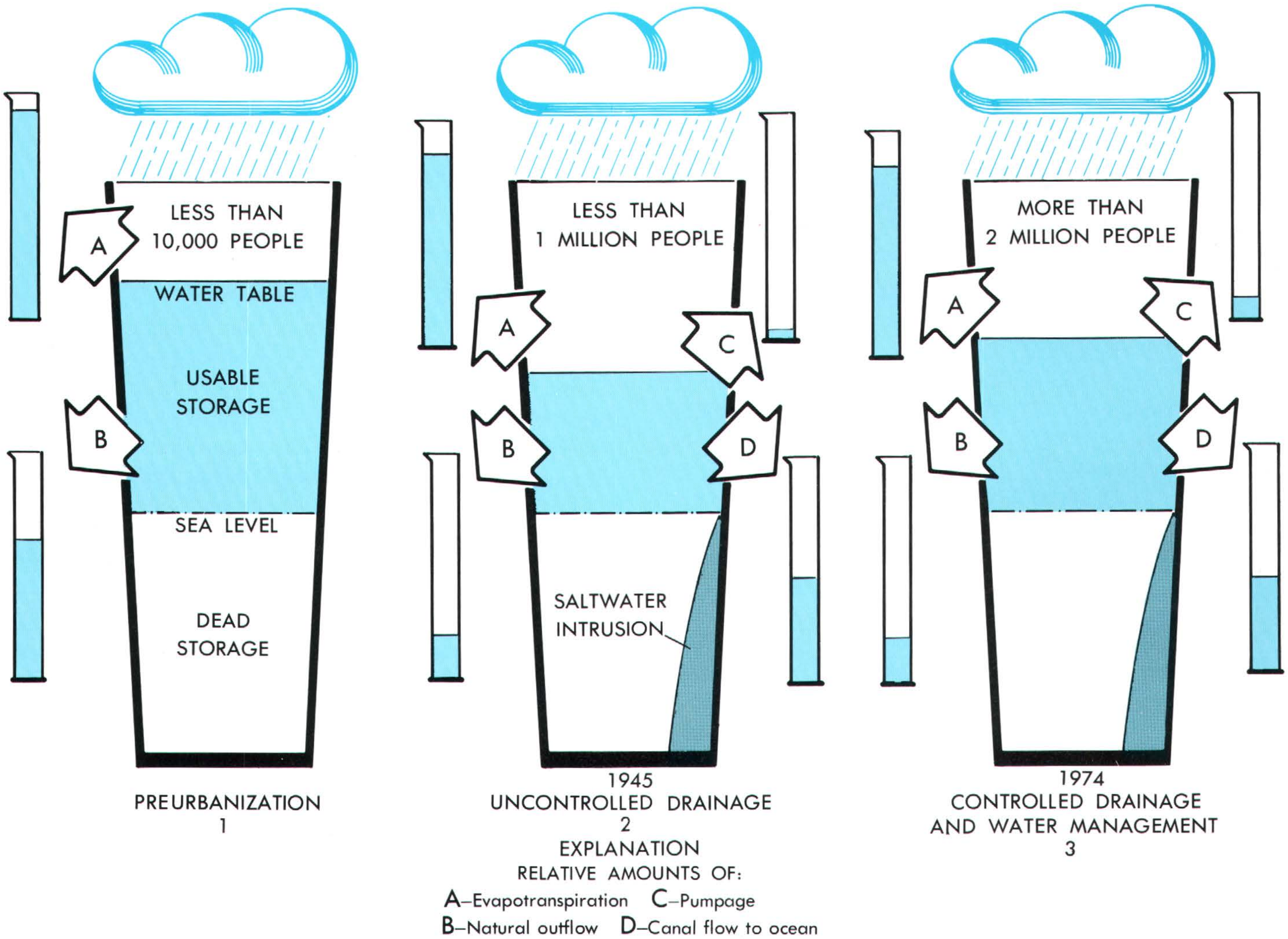


FIGURE 23.—Schematic diagram showing changes in the water balance in southeast Florida through 1974.

of freshwater in storage, but a major part should be considered to be dead storage—freshwater that occurs below sea level that ordinarily is not available for use. The remainder is usable freshwater stored above sea level in lakes, sloughs, canals, surface reservoirs (conservation areas), and shallow aquifers. The usable storage annually is increased by 1,270 to 1,524 mm (50 to 60 in) of rainfall and is reduced by evapotranspiration, outflow to the ocean, and pumping. In southeast Florida, usable storage available in the system at the end of the dry season is increasingly important because it is this storage that must sustain future increasing demands and retard seawater intrusion. This quantity frequently is governed by the amount of rainfall late in the rainy season because much of the early season rainfall is discharged through canals to the ocean to reduce the possibility of flooding in urban areas. The schematic diagrams in figure 23 furnish an insight to the water balance in southeast Florida. They indicate the progressive relative changes in the disposition of the annual rainfall brought about by step-by-step modifications of the hydrologic system, such as drainage and flood control, water management, and urban and agricultural expansion.

Before drainage was begun, south Florida was characterized by vast inland wetlands of long-period inundation and coastal ground-water levels that were perennially higher than those recorded in 1974. The preurbanization condition from the standpoint of the water balance is simulated in figure 23. Usable storage was maximum, and most of the annual loss of freshwater was by evapotranspiration and by continuous ground-water outflow along the coast that provided a narrow nearshore brackish-water habitat for biologic productivity. The major surface flow to the ocean was by slow southward sheet flow primarily through the Everglades to Florida Bay and the Gulf of Mexico and, during heavy rainfall, through the transverse glades that dissected the coastal ridge. Seawater intrusion was limited to the near-coastal zone only because of the generally high water levels. During years of deficient rainfall, parts of the interior wetlands became dry, fires occurred, and seawater intruded some of the coastal lowland areas. Burned peat beds are reminders of past droughts.

Sixty years of man's encroachment upon the south Florida environment caused irreversible changes in and heavy stress on the hydrologic systems, particularly in the southeast. By the mid-1940's, large coastal and interior wetland areas were drained by canals to reclaim land for urbanization and agriculture. Before 1946 the Everglades would virtually go dry before the end of the dry seasons, freshwater outflow of canals would cease, and, during prolonged drought, seawater would move inland along canal channels and infiltrate into and contaminate adjacent parts of the Biscayne aquifer, the only source of fresh ground water. At the end of the dry season of 1945, seawater intrusion had affected large segments of the aquifer along coastal Dade County, and several of Miami's municipal supply wells yielded salty water. Water levels in south Dade County and in what is now the eastern part of Everglades National Park were as low as 0.6 m (2 ft) below sea level (Parker and others, 1955). The water balance for the 1945 condition is shown as the uncontrolled-drainage condition in figure 23.

The irreversible effects of the decline of interior water levels included the drying out and aeration of Everglades peat and the resulting transition from the formation of peat to the destruction of peat (Stephens, 1969). Since drainage began in the early 1900's until 1953, nearly 1.8 m (6 ft) of peat and muck soil were lost by oxidation, compaction, wind erosion, and burning in the upper Everglades near Lake Okeechobee. An additional 0.3 m (1 ft) was lost from 1954 to 1968. Stephens (1969) estimated that if depletion continues at its current rate, by 1990 much of the organic soil in the upper Everglades will be too shallow to support economically viable agricultural production.

Uncontrolled drainage in southeast Florida was halted in 1946 by the installation of control structures (barriers) near the outlets of most drainage canals. These structures mitigated the recurring problems of seawater intrusion and excessively low water levels. During the rainy season the controls are opened to release water for flood prevention in the urban and agricultural areas, and during dry seasons they are closed to prevent overdrainage and to retard seawater intrusion. Canal flows have been controlled since 1946, and regional water management in southeast Florida was begun with storage of water in Conservation Area 3 after 1962. Water control in the 1950's and management in the 1960's reduced canal outflows from the Everglades (Leach and others, 1972) but increased losses from the coastal ridge area where flood prevention was necessary in the rapidly expanding urban areas.

The sum effects on the water balance over the years caused by land reclamation, urbanization, increased water demand, water control, and water management in southeast Florida through 1973 are shown as controlled-drainage and water-management condition in figure 23. The most notable difference between the condition of uncontrolled drainage and that of controlled drainage and water management was the increase in usable storage under the controlled and managed situation. Although water use increased many fold, the increase in usable storage was a direct result of the regulation of canal flows to the ocean. Such flow regulation and water-management practices by the FCD enabled flows to the Everglades National Park to be maintained at rates deemed by park officials to be the minimum to reproduce an approximation of historic discharge there and to be adequate to control water levels in the growing urban areas to prevent flooding.

The total daily flow to the ocean of the major canals of the lower east coast ranges from 28 m^3/s (1,000 ft^3/s) (2.5 million m^3 or 650 million gallons per day) during an extremely dry year, to more than 193 m^3/s (6,800 ft^3/s) (16.6 million m^3 or 4.4 billion gallons per day) during a wet year. For an average year, the daily flow is about 72 m^3/s (2,550 ft^3/s) (6.4 million m^3 or 1.7 billion gallons per day). These flows to the ocean are considered necessary by the FCD to prevent flooding in urban and agricultural areas. They represent also the quantities of water that are potentially salvageable to satisfy future demands.

Hydrologic changes in southwest Florida

Before 1960 the hydrologic regimen of the Big Cypress Swamp watershed in southwest Florida remained relatively unaltered, except for minor changes brought on by shallow borrow canals used in road construction. Not until the 1960's did major changes begin in the west part of the watershed as a result of two primary canal systems, the Golden Gate Canal system and the Faka Union Canal system (fig. 1). Their purpose was to lower ground-water levels, make the land suitable for urbanization, and reduce flooding.

In a 195-km^2 (75-mi^2) area immediately inland from Naples, water levels were lowered 0.6 m (2 ft) or more over a span of 4 or 5 years as a result of construction of the Golden Gate Canal network (Klein, 1972). Before that area was drained, it was inundated during most of the rainy season and for 2 or 3 months

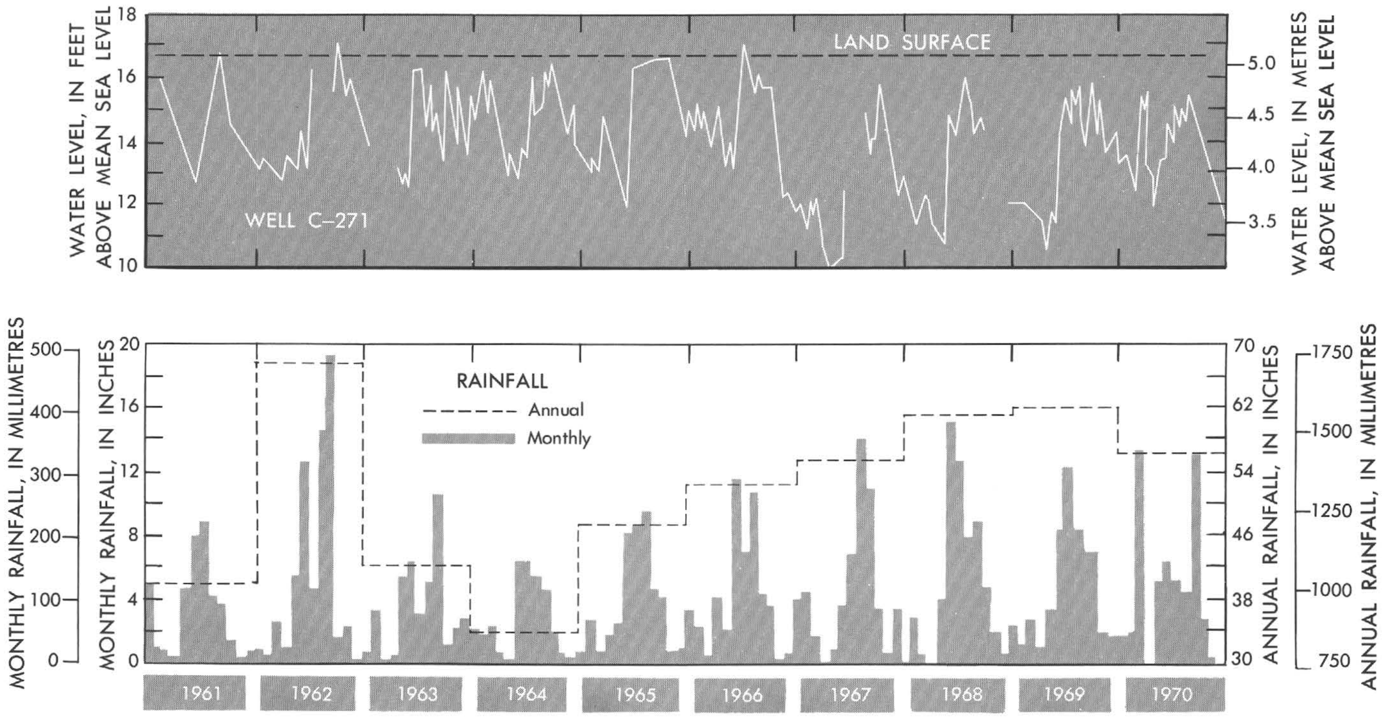


FIGURE 24.—Hydrograph of a well in the western Big Cypress Swamp, 1961–70, compared to rainfall for the same period.

afterward. Farther inland, to the east and southeast, the Faka Union Canal network, still under construction, has also lowered water levels (Carter and others, 1973), but the total areal extent and amount of lowering there cannot be evaluated until canal construction and water-control installations are completed. An indication of the change in water level and in the range in water-level fluctuations in the inland part of the Golden Gate Canal drainage area is shown by hydrograph in figure 24 (Klein and others, 1973). Levels have been lowered, as a result of increased movement of water from the interior toward the coast through the canals.

The original plan for development in southwest Florida called for controlled drainage, but the original plan in southeast Florida was one of uncontrolled drainage. In the southwest, canal flows are controlled by a series of weirs that reduced the possibility of saltwater intrusion. The weirs are set at progressively higher elevations inland, thereby stepping up water levels to simulate the predrainage hydraulic gradients but at lower elevations. According to McCoy (1972), the problem of seawater intrusion along the coastal areas is not magnified because water levels are not lowered excessively, as they were in southeast Florida. Maintaining water levels as high as possible is of utmost importance in the southwest Florida area because no provisions have been made for establishment of water conservation areas to store excess water for later distribution during the dry seasons, as has been done in the southeast.

Hydrologic information obtained in the Naples area at the end of the 1973–74 dry season showed that record low rainfall and prolonged pumping of municipal wells at high rates caused ground-water levels to be critically low and thus that any increase in withdrawal rates there could cause problems of seawater intrusion. These low levels and the projected increase in water demand emphasize the importance of keeping water levels high in the western part of the Big Cypress Swamp. Planning and water-supply agencies expect to develop water supplies to satisfy future urban demands from this part of the swamp.

The Golden Gate Canal system and the Faka Union Canal system are cut into the highly permeable limestone of the shallow aquifer. Because of the high permeability, ground water drains rapidly to the canals and thereby lowers the annual peak water levels. Wherever ponding occurs within those drainage areas during the rainy season, it is likely to be local and short lived. Thus, the pattern of slow, prolonged southward sheet flow of freshwater through the west part of the Big Cypress to the Gulf estuaries has been changed to one of accelerated and shortened-period runoff, primarily through the canal systems. Accelerated flow through canal systems tends to increase the opportunity for transport of pollutants and water of poor quality to the estuaries. In the eastern half of the Big Cypress Swamp, no drainage works have been constructed with outlets to the ocean, and therefore inundation occurs soon after the rainy season starts and continues for several weeks to months into the dry season. Natural surface flows of freshwater from the eastern Big Cypress area sustain estuarine conditions in the northwest part of Everglades National Park.

Water-quantity problems in southwest Florida

The prime water-supply problems of southwest Florida are related to urban growth and environmental protection. Large quantities of potable water will have to be made available to satisfy the increasing demands, if urban growth in the Naples and Fort Myers areas continues as expected. Freshwater supplies near the coast are being overtaxed as conditions in Naples and Fort Myers during the 1973–74 dry season indicated. Heavy withdrawals superimposed upon low water levels during the prolonged drought caused saltwater to move inland from the Gulf toward the Naples municipal well field. The water-supply situation was even more difficult in Fort Myers where saltwater migrated upstream above control structure S–79 on the Caloosahatchee River where the intake for the city's supplemental supply pipeline is located. For more than 2 months the chloride concentration of the river water at that point exceeded 250 mg/l.

Successive recurrence of low-water conditions comparable to those of 1973–74 could cause permanent damage to the water resources of the Naples area unless additional supplies are made available in the near future. Degradation of water quality in the aquifer beneath Naples could come from seawater intrusion along the Gulf side or migration of mineralized ground water from the area of poor quality water inland from Naples, as indicated by McCoy (1972). The remote interior area, beginning about 24 km (15 mi) east from Naples, is underlain by a highly permeable section of the shallow aquifer that is probably capable of satisfying the future municipal water demands for west Collier County, if pollution of the aquifer can be prevented and if high-water levels can be sustained (Klein, 1972). Future urbanization of that area will be a potential source of pollution from urban runoff. Provision for preventing the direct runoff from urban areas into the Golden Gate Canal and Faka Union Canal systems will minimize the problem of ground-water pollution also, since water from the lower controlled reaches of canals infiltrates the aquifer during part of the year.

The recent lowering of water levels by the Golden Gate Canal and Faka Union Canal systems should accelerate urban and agricultural growth in west Collier County, and this growth in turn will increase the demand on the water resources. Most of the urban water may be used consumptively because sewage systems may be obliged to dispose of effluents into environments other than local canals. Increased withdrawals of ground water will progressively lower water levels each dry season, unless measures are taken to progressively reduce the discharge of freshwater from the canal systems.

During the dry year from October 1970 to September 1971, the combined mean discharge of the Golden Gate Canal and the Faka Union Canal was more than 17 m^3/s (600 ft^3/s) or nearly 1.5 million m^3 (400 million gallons) per day. This quantity is about equal to the aggregate daily pumpage of the cities along the heavily populated lower east coast for the dry season of 1974. If the elevations of weirs throughout the drainage systems were to be raised 0.3 to 0.6 m (1 to 2 ft), the reduction in runoff would salvage for potential use a large part of the flow to the sea. The resulting rise in water levels would tend to reduce damage to the environment and the possibility of seawater intrusion and would probably reinundate some of the sloughs that became dry as a result of drainage. The possibility of environmental changes in the Fakahatchee Strand, and in the Corkscrew Marsh northeast of Naples, would be reduced because diversion of freshwater toward canals would be reduced.

The water-supply problems of Fort Myers and coastal Lee County are about as serious as those of coastal Collier County, but the environmental consequences of drainage and urbanization are not as great as those in the Big Cypress Swamp. The prime problem in Fort Myers is the impaired quality of the water from the Caloosahatchee River that is used to supplement water supplies during the dry seasons. The salinity of the river depends upon the amount of freshwater released from Lake Okeechobee. During dry seasons, when releases are minimal, the lower controlled reach of the river becomes contaminated by saltwater during boat lockages at structure S–79 (Boggess, 1970). During prolonged dry seasons, the chloride concentration of the water at the pipeline intake exceeds the limit for public supplies. No improvement in the quality of the supplemental water can be expected until measures are taken to provide sustained freshwater flows from Lake Okeechobee and to restrict or reduce boat lockages during the dry season.

Preliminary hydrogeologic information shows the occurrence of permeable layers containing freshwater in the shallow aquifer in the east part of Lee County. Those aquifers may be capable of supplying the water for the future demands not only of Fort Myers but also of other coastal communities in the county whose supplies are being overdeveloped and are threatened by saltwater contamination. The extent and the potential yield of the inland parts of the shallow aquifer were undergoing evaluation in 1974.

Water-resource limits in southeast Florida

Low water levels and the resultant inland advance of saltwater in the Biscayne aquifer in parts of south Dade County during the prolonged droughts of 1970–71 and 1973–74 were direct signals of impending water shortages within the FCD system and tended to confirm predictions by the U.S. Army Corps of Engineers (1968) that water deficits would occur about 1976. The deficits are most pronounced and occur earliest each year in Dade County, particularly south Dade County, because that is the terminus of the hydrologic system of the FCD and the most difficult area to replenish from the water-storage areas. These shortages result not only in low (below-sea-level) water levels and seawater intrusion but also in stress or change in biologic communities.

The capacity for storing water within the already developed areas of coastal southeast Florida cannot be increased appreciably because of the commitment to agricultural and urban flood protection by the water-management agencies. During much of the rainy season and for varying periods afterward, primary canals are permitted to discharge freshwater to minimize the possibility of flooding in urban areas and in nearshore and inland agricultural areas. Therefore the parts of the system where development has taken place can no longer return to the high water levels that occurred before development, and these parts must rely increasingly upon ground-water inflow and releases from undeveloped inland areas and water-storage areas for water-supply replenishment to satisfy projected demands. As a consequence, water shortages occur during years of subnormal rainfall because of the deficiency of water stored in the conservation areas and Lake Okeechobee. As urban demands increase, the shortages will become increasingly acute, even during years of normal rainfall, unless a reduction in flows to the ocean can be effected by more stringent water-management practices.

The prime objective of land-use planning is to establish an optimum rate and extent of urban and agricultural growth to minimize environmental degradation. Because of the heavy reliance of the ecosystems of south Florida upon the water resources, any additional permanent diversion of freshwater from the interior wetlands could further disrupt existing plant and animal communities there. These diversions could be effected by extending drainage works inland from their 1974 limits or by steadily increasing pumping and the consumptive use of water. Diversions by either method would increase the eastward losses from the water conservation areas and would reduce the extent and annual period of inundation there and in Everglades National Park, which receives much water from the conservation areas.

If growth continues with no implementation of water-management practices beyond those now in operation, water levels will continue to decline gradually throughout southeast Florida, attended by a corresponding incremental increase in the number of coastal areas affected by seawater intrusion, which can result in other environmental disruptions. These hydrologic conditions are shown in the sketch for the year 2000 (fig. 25) in which the usable storage has virtually been depleted. Since many of the large municipalities are served by wells near the coast, some wells will inevitably be affected by seawater intrusion, and new wells will have to be drilled inland. A large-scale shift of pumping from the coast to the interior would accelerate the diversion of water from the wetlands.

If, however, ordinances were enacted aimed toward protecting the remainder of the natural freshwater environment by prohibiting further water diversions from the wetlands (and if growth continues), then water supplies to satisfy future demands would have to come from the salvage, through implementation of more stringent water-management practices, of much of the storm water presently flowing to the sea during rainy seasons. These quantities of water, such as those that were excess in 1974, would then become the potential supplies to satisfy future demands of southeast Florida.

The quantity of freshwater discharged through the primary canal system of southeast Florida varies widely from year to year. As indicated, the total average outflow rate to the ocean of 14 major canals ranges from about 30 m^3/s (1,000 ft^3/s) to more than 192 m^3/s (6,800 ft^3/s). The average outflow rate for an average rainfall year is 72 m^3/s (2,550 ft^3/s). In considering the freshwater flow to the ocean as potential future water supplies, it would not be feasible to salvage all the discharge. Part must be discharged for flood protection in the urban coastal areas, but this part contains most of the pollution from urban runoff. Part of the excess rain that falls inland from the densely urbanized coast, however, can be salvaged by back-

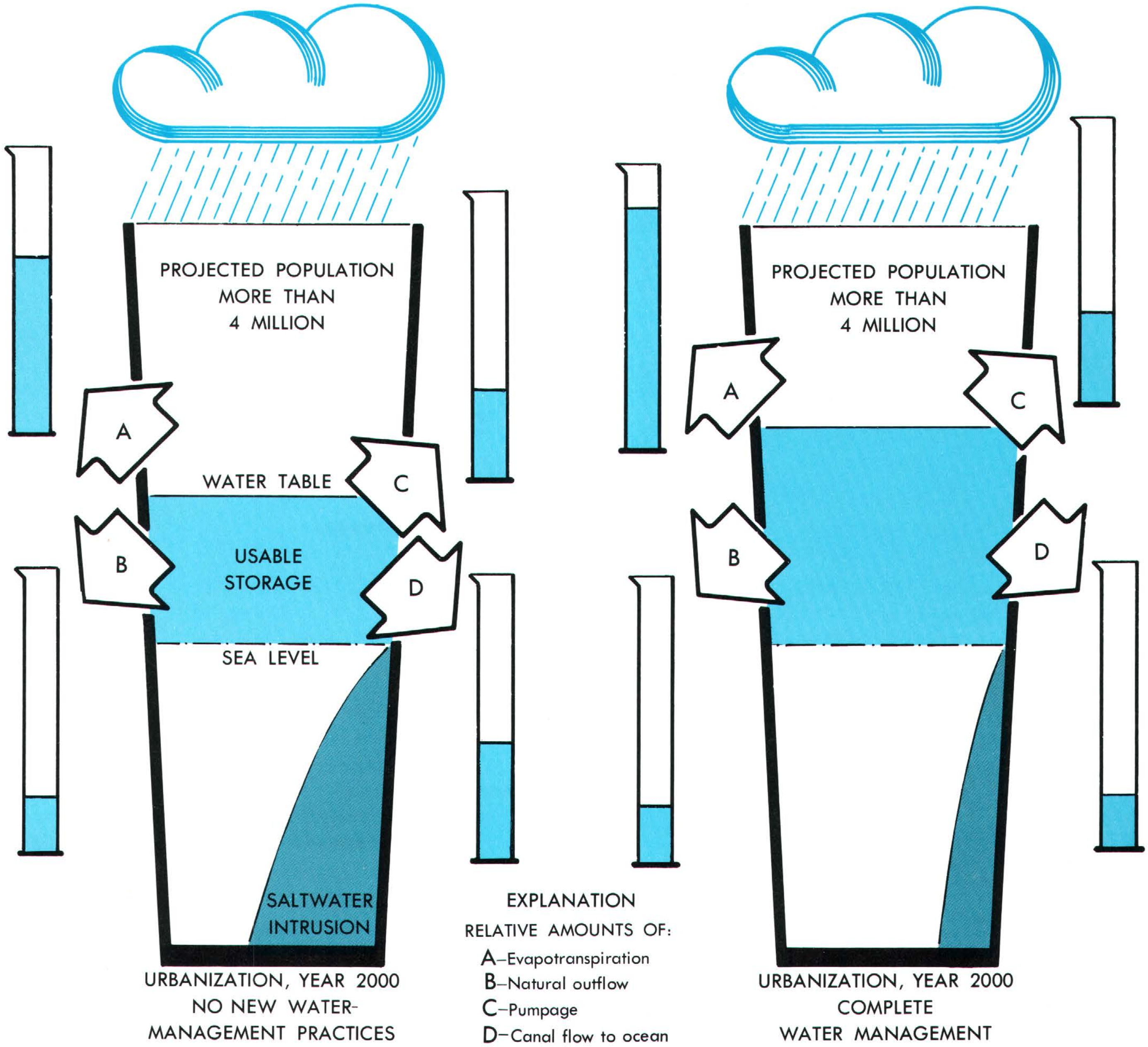


FIGURE 25.—Schematic diagram showing water balance in southeast Florida in year 2000.

pumping it into the conservation areas. The quantity backpumped might be 50 percent or more of the present seaward flow to the ocean. During the driest years this would be at least 1.2 million m^3/day (325 million gallons/day) that would be available for use during the dry season. The water balance for southeast Florida under such water-management practices as backpumping and raising the level of Lake Okeechobee is shown in figure 25 (year 2000).

Implementation of plans for backpumping and increasing storage in Lake Okeechobee (by raising levels) not only would make more freshwater available, but it would also make the operational system more flexible. An increase in storage capability of Lake Okeechobee would minimize the need for frequent release of freshwater to the ocean through the St. Lucie Canal and the Caloosahatchee River, as is presently required for protection against hurricane damage, and would thereby enhance the possibility of storing surplus water needed to alleviate the effects of prolonged drought. Backpumping facilities and practices and the ability to move water through the management system would tend to compensate for nonuniform rainfall patterns in southeast Florida and to make possible the movement of water from areas of surplus to areas of shortage. Some of the environmental implications of backpumping are discussed further under the section on "Water Quality."

Water quality

The effects of water quality on man

Contamination of water affects man directly as a health hazard or aesthetic degradation and indirectly as damage to the aquatic environment.

Waterborne diseases—such as typhoid, dysentery, salmonellosis, infectious hepatitis, and eye, ear, and nose infections—constitute a threat in south Florida from inadequately treated drinking water or from contact water sports in unsafe areas. A typhoid epidemic, with more than 100 cases, occurred at a migrant-labor camp in south Dade County in early 1973. The epidemic was apparently caused by contamination of drinking water by sewage. County health departments in south Florida warn that virtually all inland waters, including waterways, canals, ponds, and lakes, are subject to periodic contamination and hence are unsafe for drinking and contact water sports (Klein and others, 1973).

Shellfish concentrate some pathogenic organisms to levels many times greater than those found in the surrounding water. The Florida Division of Health prohibits commercial shellfishing for direct marketing along the entire east coast of south Florida and along parts of the Gulf coast.

The presence of toxic and exotic chemicals in water is another cause of concern for public health authorities. Little is known, however, of the effects of low levels of toxic chemicals in drinking water on health. The increasing numbers and amounts of exotic chemicals released to the environment by industry and agriculture also are cause for concern.

The aesthetic quality of water is also subject to impairment. Many canals in south Florida are visually offensive because of aquatic plants and floating debris and garbage. Dead and dying aquatic plants putrify canals, bays, and coastal areas.

Water is enriched by runoff or by an influx of excessive amounts of nutrients. Excessive amounts of nutrients usually accelerate eutrophication of a body of water. Overenrichment results in prolific growth of algae and other plants and in the ultimate deterioration of water quality. In south Florida, many canals are overenriched, as indicated by excessive blooms of algae and luxuriant growths of water hyacinths and other aquatic plants.

Man has altered and degraded the quality of water over much of south Florida (Crowder, 1974h; Klein and others, 1973). The degree of degradation varies from area to area, but the greatest is along the east coast and the least in the Big Cypress Swamp. Water in the Everglades and Lake Okeechobee has undergone moderate degradation.

Before man began to drain and then develop land in south Florida, water quality depended almost entirely on natural factors such as geology, climate, seawater intrusion, and the life processes of plants, animals, and bacteria. Historical information indicates that quality was good (Tebeau, 1973), probably much the same as it is now in the undeveloped parts of the Big Cypress Swamp (Klein and others, 1973). For this reason, the Big Cypress Swamp can be used as an index of past water quality in south Florida. The drained (western) part of the Big Cypress Swamp, however, is showing early signs of water-quality degradation.

Water quality of the Big Cypress Swamp

The concentration of dissolved solids is a general indicator of water quality. Natural concentrations of dissolved solids in the surface water of Big Cypress Swamp average about 250 mg/l and mainly reflect the composition of the geologic formations and the amount of freshwater (from direct rainfall on the Big Cypress Swamp) available for dilution (Klein and others, 1973). The limestone is soft and easily dissolved, and the water is therefore naturally high in dissolved solids and hardness. Water hardness, generally a function of calcium and magnesium content, averages 175 mg/l in the Big Cypress Swamp. Water whose hardness exceeds 180 mg/l is considered to be very hard.

The natural processes of plants and animals help to determine the concentration of dissolved oxygen in water. Dissolved oxygen is necessary for plants and animals to flourish and for bacteria to break down organic materials. In the Big Cypress Swamp, dissolved oxygen concentrations are sometimes naturally low because of the dense forest cover, which reduces penetration of sunlight. On occasion, fish deaths are caused by low concentrations of dissolved oxygen in the waters of the Big Cypress Swamp (Klein and others, 1973.)

Several nutrient elements are essential for life. Among the most important and most publicized are phosphorus and nitrogen. When they are abundant in water, they may cause excessive growth of aquatic plants, which can degrade the recreational and esthetic values. Concentrations of phosphorus and nitrogen (as nitrate) are low in the Big Cypress Swamp compared with other areas in south Florida: average values are 0.03 mg/l as phosphorus and 0.10 mg/l as nitrogen (Klein and others, 1973).

Although the quality of the water in much of the Big Cypress Swamp is considered to be little changed from the natural state, agricultural development and drainage in the northern and western parts have disrupted natural cycles, modified the hydrology of the watershed, accelerated the rate of soil oxidation and erosion, and added pollutants to canals and estuaries (Horvath, 1973).

Nutrients transported from drained parts of the Big Cypress Swamp to the estuaries exceed those transported by overland sheet flow in the undrained parts. The Faka Union Canal transports to the estuaries almost 5 times as much Kjeldahl nitrogen (ammonia and organic nitrogen), 10 times as much total phosphorus, and 7 times as much organic carbon as the Fakahatchee Strand transports by sheet flow (Carter and others, 1973). Heavy metals are also transported to the estuaries by canals that extend to agricultural land in the north. The heavy metals derived from agricultural areas are concentrated in fine-grained (less than 20 μ) sediments, particularly organic sediments (Mattraw, 1973). These sediments are readily transported when canal flow is high and are deposited in the estuaries where organic detritus fom mangrove trees is thereby enriched in heavy metals. Because mangrove detritus is a major food source, its enrichment may provide a pathway for the metals to enter into the estuarine and marine food chains (Mathis, 1973).

Chokoloskee Bay, which receives heavy metals from the Barron River Canal, has greater loads of these metals in its waters and sediments than more remote bays and estuaries to the south that do not receive canal flows (Horvath, 1973; Mattraw, 1973). Concentrations of lead in the waters of Chokoloskee Bay are greater than concentrations to the south, and the maximum concentration has exceeded the maximum value recommended by Federal water-quality criteria. Manganese, iron, cobalt, copper, zinc, and cadmium in Chokoloskee Bay are also above natural levels but are not sufficient to cause acute ecological effects (Mattraw, 1973). Long-term chronic effects, however, remain a possibility.

Water quality of Lake Okeechobee

Water quality in Lake Okeechobee has been degraded by large-scale inflow from streams draining agricultural land on the north side of the lake and from backpumping from canals in the Everglades agricultural areas to the south (Klein and others, 1973). Agricultural wastes are washed from farmlands into canals during heavy runoff. During high-water periods, excess water is often backpumped from the Everglades agricultural area into Lake Okeechobee to prevent crop damage. The average concentration of dissolved solids of the inflow from the north and from the Everglades agricultural area is higher than anywhere else in south Florida, excluding the saltwater areas, and at times it is more than three times the average in the Big Cypress Swamp. The relatively high concentration of dissolved solids is partly the result of irrigating with highly mineralized water (Klein and others, 1973).

Water-quality and biologic data collected in 1969 and 1970 indicate that Lake Okeechobee was in an early eutrophic condition then. The rate of eutrophication is of major concern because the lake is the primary surface reservoir in southeast Florida. Overenrichment could seriously impair its water quality and, thereby, affect downstream water users. The study by Joyner (1971) showed that the growth of algae increased greatly between January and July 1970. The dominant species also changed from a green alga, indicative of early eutrophic conditions, to a blue-green alga, indicative of late eutrophic conditions. The dominant algal species changed after a period of abnormally heavy rainfall and inflow from tributaries to the lake. Inflow was also increased at this time by channel improvement and accelerated inflow to the lake from its major tributary, the Kissimmee River. After channelization of the Kissimmee River, water flow through the marshes was reduced. The concentrations of blue-green algae later subsided (Joyner, 1974) but have generally remained above the levels recorded earlier by Joyner (1971).

Water quality of the Everglades

Water quality in the Everglades, which includes the water conservation areas and most of Everglades National Park, has not been extensively affected by land-use changes. However, water quality has changed where water from flood-prone farming areas has been routed to the Everglades or backpumped from flood-prone urban areas to increase water storage. For example, dissolved solids and chloride have increased in water originating or passing through the Everglades agricultural area. This is illustrated by the steady rise in chloride concentration from 10 to 70 mg/l since 1959 at monitoring station P–33 in an area of Everglades National Park (fig. 26) that receives direct runoff from Conservation Area 3 primarily by Levee–67 canal. For comparison, water sampled from station P–34, which is farther west and remote from water-control works, has remained unchanged in chloride concentration since 1959 (Klein and others, 1973).

Although concentrations of nitrate and phosphorus generally are low in water in the Everglades, they may become excessive during droughts when most of the marshlands dry up and aquatic biota are forced to the deeper water of ponds to survive. Wastes and breakdown products from these organisms accumulate and cause concentrations of oxygen to decrease and con-

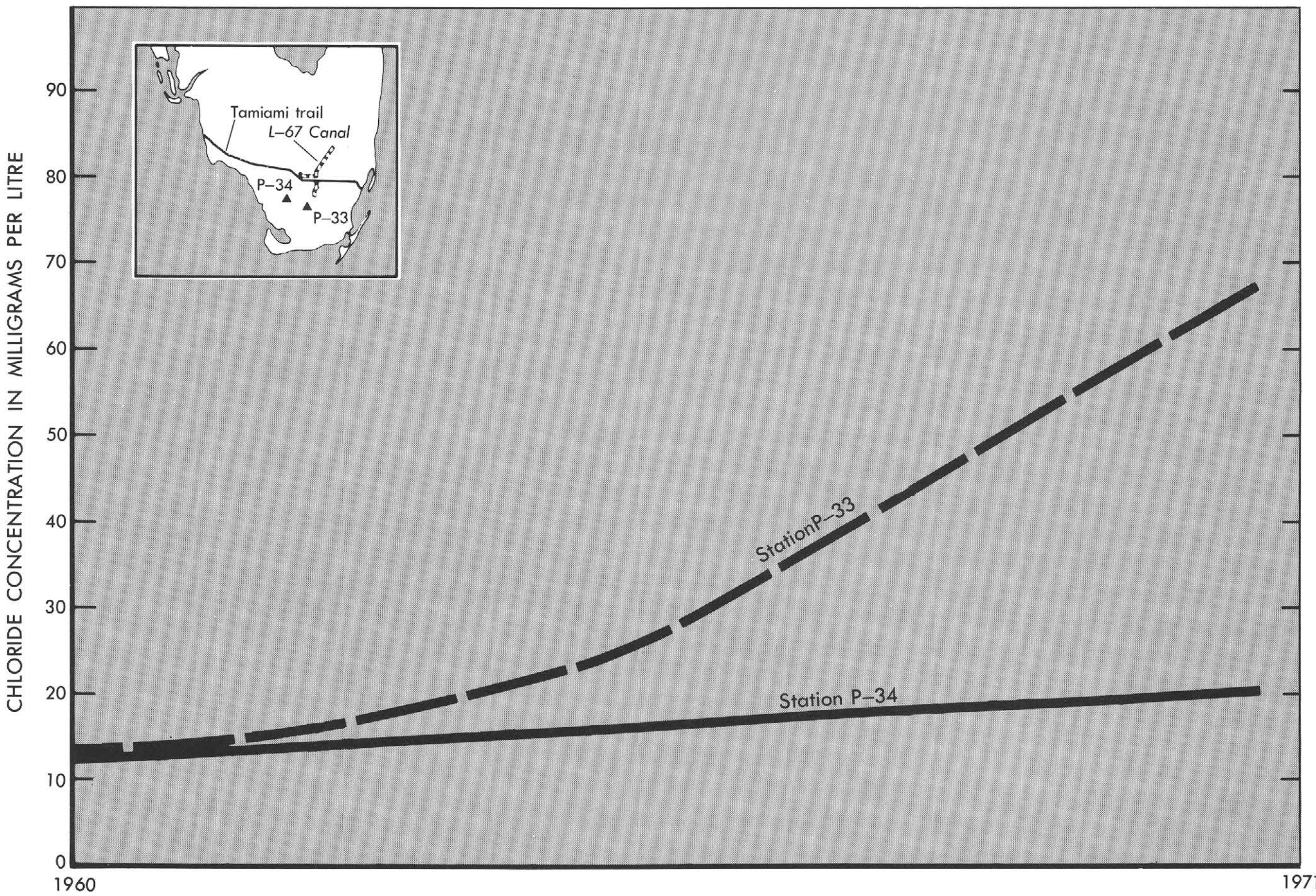


FIGURE 26.—Chloride concentration of water at two stations in Everglades National Park.

centrations of nitrate and phosphorus to increase in the water. Under anaerobic conditions, nitrogen and phosphorus compounds may be released from the sediment into the water. Evaporation also causes increased concentrations of these and other elements in the water. Nitrate concentrations are also increased in the Everglades by water distributed from the Everglades agricultural area.

Plans to backpump nutrient-rich water from the eastern urban region into the conservation areas (Crowder, 1974h) have raised some concern. The extent to which these nutrients, and possibly other compounds, would alter the water quality and the biota is unknown although aquatic plants and sediments would remove some nutrients. Studies indicate that sawgrass, the dominant emergent marsh plant of the conservation areas, has only a limited capacity for removing nutrients from water (Steward and Ornes, 1973b, c). Controlled tests showed that 1 ha of sawgrass uses 1.8 kg of phosphorus in 1 year's growth. At this utilization rate, 890,000 ha (2.2 million acres) of sawgrass would be required to remove the phosphorus contained in the waste water being discharged into inland canals each year (Steward and Ornes, 1973a). The total area of the three conservation areas, however, is only 348,000 ha (860,000 acres). It is unlikely, therefore, that sawgrass could efficiently renovate backpumped waste water of high nutrient content (Steward and Ornes, 1973a). In addition, water to be pumped into the conservation areas would not be distributed evenly through the areas. In Conservation Areas 1 and 3, the water presently stays chiefly within the peripheral canals. In Conservation Area 2, however, canal water does move into the interior marshes.

The marsh system in general appears to have a limited capacity for assimilating nutrients. Application of phosphorus at a continuous rate of 2.5 kg/ha per week on Everglades test plots caused stress after 3 weeks and extensive biological change and disruption after 8 weeks (Ornes and Steward, 1973). The changes in the composition of the plant community are evidence of the effects that could occur from an increased supply of nutrients into the Everglades ecosystem. Another study, however, has shown that inorganic forms of nitrogen and phosphorus are removed from canal water soon after it moves into the Everglades marshes (Gleason, 1974).

Data collected from many areas in south Florida indicate that pesticide concentrations in water are generally low. This fact is not surprising because most pesticides are insoluble in water and are absorbed readily on sediments. In the sediments of canals or marshes, high concentrations have been found (Klein and others, 1973; Carter and others, 1973). For instance, some soil samples underlying marshes in the Everglades had concentrations of the DDT family (DDT, DDD, and DDE) as much as 1,000 times greater than the concentrations found in water (Klein and others, 1973). Concentrations of the DDT family tend to become higher and accumulate in the higher orders of the Everglades food chain (Klein and others, 1973; Carter and others, 1973; Feltz and Culbertson, 1972). In the Everglades National Park, however, concentrations of the DDT family, dieldrin, and polychlorinated biphenyls (PCB's) in the upper food chain are mostly below the concentrations known to produce either acute or chronic effects (Ogden and others, 1974).

A study of pesticides at 10 sites in the Everglades showed that concentrations of the DDT family in bottom sediments and fish were much more prevalent at sites near agricultural areas than elsewhere. Concentrations of the DDT family in sediment at sites influenced by agriculture averaged 53 μg/kg (micrograms per kilogram) whereas those more remote averaged 31 μg/kg. The difference was most pronounced in fish samples. The average DDT concentration near agricultural areas was 340 μg/kg whereas in more remote areas it was 70 μg/kg (McPherson, 1973b). The data not only show that concentrations of DDT are higher in areas influenced by agricultural activities but also that DDT is more concentrated in organisms in the higher orders of the food chain (Klein and others, 1973).

For comparison, average concentrations of the DDT family in sediment and fish samples collected adjacent to Miami International Airport, an urban-industrial complex, were intermediate between average concentrations in agricultural areas and nonagricultural areas. Average concentrations of the DDT family in sediment and fish near the airport were 34 and 160 μg/kg, respectively (Freiberger and McPherson, 1972).

The toxic effects of pesticides on humans and wildlife are not absolutely clear at this time. It is known that most pesticides are persistent (that is, they are not easily degradable) and that they accumulate in the fatty tissues of both humans and wildlife. A human being may easily accumulate and retain pesticides in his tissues by consuming fish or meat from animals that have accumulated pesticides in their systems.

Much of the information on the effects of pesticides comes from the study of birds. Some species of falcons, hawks, and eagles have laid thin-shelled eggs, probably because of intake of pesticides of the DDT family. Experimental evidence shows that DDE, a metabolite of DDT, reduces the birds' ability to produce calcium for eggshells, thereby causing premature breakage and consequently limited offspring. Concentrations as low as 10,000 μg/kg in bird eggs might result in impaired reproductive success in some species. The highest concentration of DDE in bird eggs found in this study, however, was slightly over 1,000 μg/kg detected in osprey eggs (Ogden and others, 1974).

Water quality of the east coast urban and agricultural area

The east coast area, where degradation of water quality has been most noticeable in recent years, includes the urban-industrial and the eastern agricultural areas. Most degradation has been in urban canals, especially during periods of low flow when many urban canals are covered with algae and scum and are choked with aquatic weeds. These conditions have been brought about through the discharge of improperly treated nutrient-laden sewage into canals. Average concentrations of nitrate and phosphorus in the water of urban canals were 6 to 15 times greater than that of the Big Cypress Swamp. Water in one urban canal contained 125 times the average phosphorus content of Big Cypress Swamp water (Klein and others, 1973). Recent directives from the Environmental Protection Agency and ordinances passed by local governments are designed to reduce discharges of waste water to inland canals. Enforcement is difficult, however, because adequate facilities are not yet available for ocean or outfalls other than inland canals.

Rapidly expanding urbanization has increased the average dissolved-solids concentrations of canal waters to about 400 mg/l, or about 50 percent higher than that of the waters of the Big Cypress Swamp. The increase is mainly the result of storm runoff into canals from parking lots, streets, and construction sites. Included in the materials carried in the runoff may be debris, oil and grease, pesticides, and toxic metals (Klein and others, 1973).

Data indicate that concentrations of toxic metals are clearly most prevalent in urban-industrial areas. Lead and arsenic have been found in water and sediment in concentrations above recommended limits. These and other toxic metals extensively used in manufacturing are included in waste products discharged into waterways, from which they may enter the ground-water system and the public water supply (Klein and others, 1973).

An ample supply of dissolved oxygen is most important for water of good quality, especially in urban areas where much of the oxygen is used in the decomposition of sewage. In polluted canals with a luxuriant growth of plants, the dissolved-oxygen content is high during daylight. During the night, however, the dissolved-oxygen content may approach zero as the oxygen is depleted to oxidize sewage. Thus many urban canals lack popular sport fish such as bass and are inhabited, instead, by gar and mullet, which are able to tolerate low levels of dissolved oxygen (Klein and others, 1973).

In recent years, PCB's have been detected in increasing concentrations in water, sediments, and fish in south Florida (Klein and others, 1973). These compounds have about the same toxic effects on wildlife as pesticides, but in addition, it is believed that PCB's have distinct toxic effects on humans, namely on the skin and the liver. Common uses of PCB's include ballasts for fluorescent light fixtures, insulation of electrical wiring, adhesives, formulation for epoxy paints, and carbonless reproducing paper.

Although traces of PCB's have been found in the Everglades and the Big Cypress Swamp areas (Carter and others, 1973), they are most prevalent in the industrial areas. A fish sample from a canal at Miami International Airport contained PCB's in a concentration of 1,000 μg/kg (Freiberger and McPherson, 1972). Attention should be given to the fact that PCB's can enter the ground-water system in urban areas and eventually find their way into the drinking-water supply.

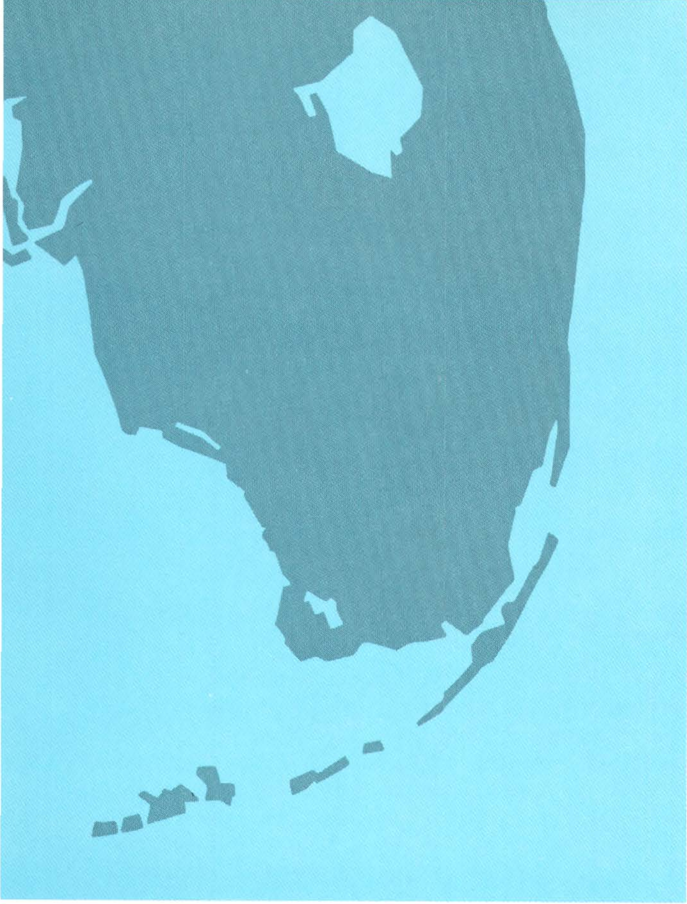
Ground-water quality

Generally, ground water is less susceptible to pollution than surface water because it is filtered as it moves through sediments. The prime threat to ground-water quality in south Florida in past years has been that of seawater intrusion in coastal areas and near heavily pumped municipal wells. Seawater intrusion, however, can be and has been generally controlled in recent years by providing sufficient freshwater to maintain adequately high water levels near the coast.

Rapid urbanization of the lower east coast and growth of agricultural areas pose additional threats of ground-water pollution—those of contamination by manmade liquid and solid wastes and by fertilizers and pesticides. Ground water in the section of the Biscayne aquifer beneath the densely populated urban parts of southeast Florida contains nutrients and coliform bacteria at shallow depth as a result of effluent from thousands of septic tanks and seepage from polluted canals. These pollutants presumably have built up over the 60 years of urbanization. Although septic tanks operate adequately in the southeast, they provide only partial water treatment. Because of the benefits of seasonal heavy rainfall and dilution, however, the level of pollution probably has been excessive only in some local areas. Septic tanks become inoperative because of lack of periodic maintenance. In such cases raw waste water seeps into the aquifer and causes local temporary pockets of pollution. The recent constraints on the use of septic tanks and the construction of sewage systems to service large urban sectors will further curtail the use of septic tanks in many areas and thereby reduce the potential pollution of the ground-water system. These sewage systems will utilize ocean outfalls rather than outfalls to inland canals, as was the case for many years. Furthermore, within the past 2 years, the deep part of the Floridan (artesian) aquifer, at a depth of about 900 m (3,000 ft), has been locally used as a reservoir for waste-water discharge.

Solid-waste disposal in dumps poses another but less widespread source of pollution of shallow aquifers by contributing leachates from garbage and trash. Many materials in dumps are toxic and nonbiodegradable. Preliminary data from widely scattered study sites in southeast Florida indicate that local pollution plumes exist downgradient from the dump sites but primarily in the shallow parts of the aquifer. Polluted ground water near dumps also contains coliform bacteria and nutrients because sludge from many septic tanks and small sewage-treatment plants is disposed at some dumps. Traces of toxic metals have also been found in the shallow ground water beneath the dumps. Because of the high permeability of the aquifer, contaminants can move readily to wells in downgradient areas.

Numerous deep wells under high artesian pressure, drilled to the Floridan aquifer many years ago, have been a source of brackish-water contamination of shallow aquifers in Lee and Hendry Counties and to a lesser extent in Collier County. The wells were not cased deeply enough or the casings have corroded, and brackish water under pressure from the Floridan aquifer moves upward along open well bores or through corroded sections and seeps outward to contaminate large parts of shallow aquifers (Klein and others, 1964; Sproul and others, 1972). Such contamination can be controlled by a program of plugging of the leaking wells. Other areas of brackish-water contamination are inland from Naples (McCoy, 1972) and south of Lake Okeechobee (Parker and others, 1955). These sources of contamination are the natural upward leakage of artesian water from the Floridan aquifer through partly permeable confining layers or open well bores or incompletely flushed residual saltwater remaining from ancient inundations by the sea.



A final word

South Florida is at a crossroad in the environmental path, and a decision is necessary as to which branch to take. One branch could be labeled development and another preservation. The former would represent full-scale development of the area for man's use without thought for environmental consequences; the latter would refer to no further development and to an effort to restore the pristine environment.

As for most activities, there is a middle branch leading away from the crossroad which represents a harmonizing of man's demands and nature's needs. By developing and utilizing a thorough knowledge of the south Florida environmental system and of the flow of energy through that system, planning and development that balances society's desires against environmental values can occur and permit full use and enjoyment of south Florida's unique natural resources without destroying those resources.

References

[Citations of the 51 reports summarized by this paper are accompanied by abstracts. Those reports are available from the U.S. Department of Commerce, National Technical Information Service, Springfield, VA 22161, by PB number]

Ager, L. A., 1970, Annual report, Lake Okeechobee Project 1969–70, Fisherman census: Tallahassee, Fla., Florida Game and Fresh Water Fish Comm.

Adams, C. A., Oesterling, M. J., Snedaker, S. C., and Seaman, W., 1973, The role of mangrove ecosystems—Quantitative dietary analyses for selected dominant fishes in the Ten Thousand Islands, Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 747.

The stomach contents of 710 *Bairdiella chrysura,* 256 *Cynoscion nebulosus,* 479 *Eucinostomus gula,* 316 *Lagodon rhomboides,* and 868 *Anchoa mitchilli* of the mangrove estuarine areas in south Florida's Ten Thousand Islands were analyzed gravimetrically. Ontogeny of food habits, such as percentage composition of food related to age and growth (i.e., size class) and milligrams of food per kilogram of fish body weight, were determined. Analyses were made on specimens from Fahka Union Bay, an estuarine embayment receiving freshwater runoff from upland real estate developments, and Fahkahatchee Bay, a relatively undisturbed area. The items eaten by these fishes show that variation in food types occurs among fish species and, to a lesser degree, among habitats. Data indicate that, for certain species, the intake of food material (milligrams of food per kilogram of fish weight) may be related to osmoregulatory adjustments for salinity differences between these two bays.

Alexander, T. R., and Crook, A. G., 1973, Recent and long-term vegetation changes and patterns in south Florida: U.S. Natl. Park Service PB–231 939.

This preliminary report includes methods, ecological history, and 10 completed samples of how data and maps for quadrats will be presented in the final report. Quadrats (sections) will number 100 and will be representative of the entire ecosystem. Vegetation change has been both major and minor. Agriculture, logging, and fire have had the greatest role, augmented by drainage. Examples are: the change from graminoid glade vegetation to a closed canopy of woody species on abandoned farmland and the the invasion of cypress forests by maple and pine. In the saltwater-freshwater ecotone, mangroves have invaded inland, and freshwater species have been killed. For example, the cabbage palm population has been reduced. Coastal erosion has locally reduced mangrove forests. In the Conservation Areas, tree islands have been damaged by fire and flooding and even destroyed, and graminoid communities have adjusted to varying water depths. The latter are hard to document. Great changes in community structure have occurred where exotic plants have invaded and gone through a population explosion. *Melaleuca, Schinus,* and *Casuarina* are the greatest threat. No part of the study area is free from this threat to native communities. A bibliography is included.

Armbruster, J. T., 1972, Land use in the Big Cypress area, southern Florida: Florida Dept. Nat. Resources, Bur. Geology, Map Series no. 50, 1:250,000.

Bayley, S., and Odum, H. T., 1971, Simulation of a model of sawgrass marsh with peat, fire, water, and phosphorus: U. S. Natl. Park Service PB–231 668.

The energy circuit language is used to model and guide parameterization of the south Florida sawgrass marsh ecosystem. Included in the model are processes describing grass growth, water-level oscillations, rainfall, transpiration, phosphorus uptake, fire, peat deposition, and controlled inputs of surface water containing nutrients. Coefficients were estimated by using data from published sources, and the model was simulated on an analog computer. The responses of the sawgrass system under varying initial conditions and inputs are evaluated and discussed. The simulation suggests that high inputs of phosphorus lead to increased water loss (via transpiration) and larger fires as a result of larger accumulations of biomass. (Originally included as an appendix in "Models for Planning and Research for the South Florida Environmental Study.")

Birnhak, B. I., 1974, An examination of the influence of freshwater canal discharge on salinity in selected southeastern Florida estuaries: U.S. Bur. Sport Fisheries and Wildlife PB–231 610.

Monthly determinations of surface- and bottom-water salinity were made within the canal (or stream) estuary complexes of six southeastern Florida coastal zones (St. Lucie River and Estuary, Loxahatchee River and Estuary, West Palm Beach Canal and Estuary, Hillsboro Canal and Hillsboro River Estuary, New River Canal and Estuary, and Miami River-Biscayne Bay Estuary) by means of a refractometer. Salinity data were arrayed against freshwater discharge volume and local rainfall to explore relationships among these parameters. Since rainfall during most of the sampling period (June 1971–May 1972) was atypically light, conclusions drawn from the sample data are tentative. Results to date (1) confirm the requirement for maintaining minimum freshwater canal discharges to inhibit extreme inland penetration of saline water during dry periods; (2) demonstrate the significance of these discharges in maintaining desired brackish salinity values in all zones studied except the Hillsboro Canal Estuary and Biscayne Bay, where oceanic influences in these shallow open lagoons overwhelm the relatively minor freshwater discharge of the Miami Canal; and (3) point to the need for further study to determine optimum canal discharge regimens for estuarine fish and wildlife management, particularly in the St. Lucie River, Loxahatchee River, West Palm Beach Canal, and the estuarine zones associated with them.

Birnhak, B. I., and Crowder, J. P., 1974, An evaluation of the extent of vegetative habitat alteration in south Florida 1943–1970: U.S. Bur. Sport Fisheries and Wildlife PB–231 621.

The extent of vegetative habitat alteration in seven south Florida counties was estimated. The acreage historically occupied by each of 13 vegetative habitat types was determined by planimetry of a base map prepared by J. H. Davis, Jr., in 1943. Land areas currently occupied by urban and agricultural development were identified from recent land-use maps prepared by the Florida Coastal Coordinating Committee and the Florida Department of Transportation. The remaining amounts (in acres) of each type of habitat were determined by outlining upon the base map all acreage now converted to agricultural or urban usage, planimetering the area of each habitat type lost to development, and subtracting the amount of lost habitat from that which was historically present. The data were arrayed in both county and regional summaries to show the total acreage and percentage of each vegetative habitat type lost to each form of development and the total remaining acreage of each. A "naive extrapolation" of past trends in land use was performed to show the astonishing rate at which wild lands are being developed in the region and to demonstrate the need for constraints on population growth and land use in order to conserve supportive natural systems.

Boggess, D. H., 1970, The magnitude and extent of salt-water contamination in the Caloosahatchee River between LaBelle and Olga, Florida: Florida Dept. Nat. Resources, Bur. Geology, Inf. Circ. 62.

Brown, Mark, and Genova, Grant, 1974, Energy indices in the urban pattern: Gainesville, Fla., Univ. of Fla., Center for Wetlands.

Carter, M. R., Burns, L. A., Cavinder, T. R., Dugger, K. R., Fore, P. L., Hicks, D. B., Revells, H. L., and Schmidt, T. W., 1973, Ecosystems analysis of the Big Cypress Swamp and estuaries: U.S. Environmental Protection Agency PB–231 070.

The U.S. Environmental Protection Agency (EPA) conducted a 2-year study to obtain necessary biologic and hydrologic information for objective planning of wise use of south Florida's land, water, wildlife, and fisheries resources. Field investigations during 1971–72 intensively examined the details of biotic community interactions with hydrologic conditions of disturbed and relatively unaffected regions of the Big Cypress Swamp and contiguous tidal wetlands and estuaries. Process studies and experimental manipulation models were formulated for the various components of the ecosystem. Study results demonstrate the total dependence of the south Florida ecosystem on the hydroperiod. Canal drainage of upland wetlands, which include cypress swamps and wet-prairies, effected a 10-fold decrease in primary productivity. Drainage also effected a thinning of the forest canopy and induced a reduction in the rate of forest litter decomposition, resulting in a build-up of litter as increased fuel sources for destructive wildfires. Canal drainage of uplands also affected the estuaries, resulting in changes in the benthic plant communities, increased nutrients, increased metals in sediments, and a change in the abundance and diversity of fishes. For the first time, tidal streams were proven to be a major nursery area for young snook.

Craighead, F. C., 1964, Land, mangroves and hurricanes: Fairchild Tropical Garden Bull., v. 19, p. 5–32.

——— 1971, The trees of south Florida, *v. 1 of* The natural environments and their succession: Coral Gables, Fla., Univ. of Miami Press, 212 p.

Crowder, J. P., 1974a, Exotic pest plants of south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 619.

From existing literature, personal experience and observation, and consultation with experts, the origins, modes of introduction, growth habits, and ecological impacts of seven species of naturalized exotic pest plants of south Florida (*Melaleuca quinquenervia, Schinus terebinthifolius, Casuarina glauca, Casuarina equisetifolia, Eichhornia crassipes, Hydrilla verticillata,* and *Alternanthera philoxeroides*) are described. The adaptability of *Melaleuca quinquenervia* to a wide range of soil and moisture conditions and its tendency to reproduce to stress (fire, mechanical damage) confer advantages upon this species that apparently encourage it to spread at the expense of native plants, in many instances displacing indigenous vegetation of value to wildlife. *Schinus* and *Casuarina* likewise displace native vegetation without providing significant wildlife habitat. The rampant spread of the aquatic species (*Eichhornia, Hydrilla, Alternanthera*) is documented, and their impact on water quality is described, especially as it relates to eutrophication. Possibilities and recommendations for biological and mechanical control are summarized. Biological controls of massive aquatic weed infestations in conjunction with preliminary mechanical harvest are suggested as an approach combining weed removal and nutrient reduction of overenriched waters.

——— 1974b, Native reptiles and amphibians of south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 632.

The 74 native species of reptiles and amphibians of south Florida (Lake Okeechobee southward) are listed. Their distributions among six major habitats (xeric, mesic, alternohygric, hygric, halohygric, and edificarian-ruderal) are noted, with reference to the habitat classification schemes of other workers. Destruction of habitat is identified as the predominant factor in the declines of the region's reptile and amphibian species. Seven declining species of reptiles and amphibians are identified, and specific problems related to depletion of these species are discussed.

——— 1974c, Some perspectives on the status of aquatic wading birds in south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 216.

Relationships between wading birds, water levels, and other biota of the south Florida wetlands ecosystem are discussed. Data from other studies are consolidated to present information on wading birds in the Everglades National Park and the remainder of Florida south of Lake Okeechobee. A total of 35,000 breeding pairs of wading birds (excluding 22,500 pairs of cattle egrets) are all that is left of a once larger population of about 2.5 million in 1870. The effects of wetlands drainage on nesting success and broader implications of feeding and other ecological relationships of wading birds are discussed, with emphasis on population size, feeding efficiency, predator-prey relationships, and stress. Particular emphasis is placed on wood storks, white ibis, and cattle egrets. Recommendations for preserving these birds are presented with a discussion of artificial feeding habitat.

——— 1974d, The biological impact of residential real estate development in the south Florida coastal wetlands: U.S. Bur. Sport Fisheries and Wildlife PB–231 672.

The effects of dredging, filling, and canalizing in the coastal shallow waters and wetlands of south Florida are summarized and analyzed. A brief history is provided of the evolution of statutory control over construction in coastal waters. Recent stringent regulation of submerged land dredging and filling has generated an increase in interior, or so-called "upland," canal construction. Whether of the bayfill or upland type, canals and associated fills may adversely affect fish and wildlife habitat by direct destruction of wetlands, degradation of water quality, and habitat oversimplification. Maintenance dredging of existing residential canal systems creates recurrent problems in disposal of spoil materials. Recommendations are made for minimizing future adverse impact on wetlands, with emphasis on water dependency and navigation needs as essential criteria. Central joint-use facilities are cited as an alternative to individual house lot access to waterways. Means of utilizing tidal flushing are explored, and the general preference of riprap surfaces over conventional bulkheads is emphasized.

——— 1974e, The effects of drainage and associated development in the Big Cypress Swamp: U.S. Bur. Sport Fisheries and Wildlife PB–231 612.

The major adverse environmental impacts of development in the Big Cypress Swamp are described. Nutrient overenrichment of waters receiving runoff from agricultural and urban areas is expected to reduce species diversity and ecosystem stability. Increases in water-borne pesticides are also expected to accompany development and could elevate levels significantly above the present relatively low concentrations in water, soils, and animal tissues in the Big Cypress. Major alterations to surface-water flows will disturb the critical periodicity of water delivery to the estuarine zones, produce surface-water depth fluctuations out of phase with the seasonally heavy feeding requirements of aquatic wading birds, and precipitate massive redistributions of the dominant vegetative communities, with selection in favor of the less aquatic types. Drainage that causes a pulsing of freshwater flows to the sea will intermittently reduce salinity to abnormally low levels in the gulf coast estuarine zone of the watershed and will increase the transport of silt and chemical pollutants to these valuable waters. The basic threat to the Big Cypress is identified as the piecemeal and uncoordinated development of relatively small projects that will cumulatively have severe impacts on the area's biological resources. Establishment of the proposed Big Cypress National Freshwater Reserve is cited as a means of preventing loss or degradation of these resources in the Big Cypress and in the northwestern estuarine area of Everglades National Park.

——— 1974f, The exotic vertebrates of south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 214.

Species of introduced exotic vertebrates of south Florida (Lake Okeechobee southward) are identified and described. The principal factors responsible for their introductions are explored, and recommendations are made for alleviation of current problems caused by exotics and for prevention of further harmful introductions. Major problems were determined to be (1) the rapid spread of exotic tropical fishes, principally cichlids and the walking catfish (*Clarias batrachus*), and their displacement of native sunfishes, (2) the presence of a number of exotic psittacine birds with potential for depredations of fruit and grain crops, and (3) three species of giant herptiles (knight anole, marine toad, and Cuban tree frog) that prey upon their smaller native counterparts.

———1974g, The freshwater fishes and fisheries of south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 631.

The freshwater sport and commercial finfishes and fisheries are described. Everglades sport fishery dynamics are summarized, with emphasis on the functions of canals and natural depressions as dry-season refuges for remnant stocks. Deleterious effects of unnaturally prolonged flooding and associated detrital accumulations are described. The marsh dependency of largemouth bass, bluegill, and redear sunfishes is considered, with attention given to the potentially deleterious effects of raising the Lake Okeechobee water regulation schedule. The impact of accelerated lake eutrophication (by excess input of nutrients from the developed lake watershed) is assessed through a survey of recent water-quality problems in the lake. Data suggest that the approximate trophic status of the lake lies well within the eutrophic category. Available data on sport-fisherman use are presented for Lake Okeechobee, the Everglades Conservation Areas, and the Big Cypress Watershed. The channel catfish commercial fishery of Lake Okeechobee is described, and a recommendation is made for increased harvest of commercial and sport fishes from the lake as a method of nutrient removal. Selected data from recent Everglades and Lake Okeechobee fish population and biomass studies are summarized for potential incorporation into a systems model.

———1974h, Water management—The key to fish and wildlife values in south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 653.

Some probable effects of continued population growth and development in south Florida upon water quality, quantity, and distribution are described. Rampant urbanization, escalating demands for domestic and agricultural water, and the orthodox technological responses to water-supply problems are factors that presage a continuing decline in the quality of the region's aquatic habitats. Particular emphasis is placed upon the problems of cultural eutrophication and hydroperiod alteration. The upstream and downstream effects of backpumping urban and agricultural runoff to interior water-storage basins are considered, and a recommendation is made against additional vertical storage of water in the Everglades wetlands.

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Evink, G. L., 1973, The role of mangrove ecosystems—Biomass and diversity of benthic macroinvertebrates of Fahka Union and Fahkahatchee Bays, Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 749.

Quantitative samples were taken to establish the biomass and diversity of benthic macroinvertebrates in the area of Fahka Union and Fahkahatchee Bays in south Florida. A series of 37 samples was completed during the period February to December 1972. Major taxonomic groups collected were Crustacea, Mollusca, Polychaeta, and Echinodermata. Biomass of macrobenthos in Fahkahatchee Bay ranged from 3.1 to 6.1 g/m^2; macrobenthos in Fahka Union Bay ranged from 4.0 to 6.4 g/m^2. Analysis of biomass data revealed no significant difference in the biomasses of the bays. Analysis of species occurring in the two bays showed that the bays have similar species, with a small difference in species diversity.

Feltz, H. R., and Culbertson, J. K., 1972, Sampling procedures and problems in determining pesticide residues in the hydrologic environment: Pesticide Monitoring Jour., v. 6, no. 3, p. 171–178.

Finn, M. A., 1966, Humans, plants and animals in Florida, Fahkahatchee Strand: Natl. Parks Mag., v. 40, p. 10–13.

Florida University Bureau of Economic and Business Research, 1973, Projections of population, employment, and income, selected Florida counties, 1975, 1980, 1990, 2000: U.S. Bur. Outdoor Recreation PB–231 683.

This report contains projections of (1) population, by age and by sex, (2) employment, by specified categories, and (3) family income for selected Florida counties for 1975, 1980, 1990, and 2000. Control data for total population and employment were derived from regional and county estimates made under the OBERS program, a joint program of the Office of Business Economics and the Economic Research Service. The value of the projections in this report is their usefulness as a series of baseline reference points. Supporting data for the Bureau of Outdoor Recreation's report, "An Analysis of Outdoor Recreation Resources, Impacts, and Potentials in South Florida," was prepared as part of the South Florida Environmental Study.

Forthman, C. A., 1973, The effects of prescribed burning on sawgrass, *Cladium jamaicensis* Crantz, in south Florida: U.S. Natl. Park Service PB–231 603.

Burning under prescribed conditions did not kill sawgrass culms, nor did it result in changes in the density or successional stage of the stands. The leaves of sawgrass were shorter and less rigid in the first post-burn year. Growth rates increased for about one month after burns and showed seasonal increases in April through June. The spring burn recovered more quickly than the fall burns. Certain nutrients, especially PO_4, increased in the water around sawgrass after burns.

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Freiberger, H. J., and McPherson, B. F., 1972, Water quality at Miami International Airport: U.S. Geol. Survey open-file rept., 50 p.

Gerrish, H. P., 1973, Low-level temperature inversions in the Miami, Florida area: U.S. Natl. Park Service PB–231 630.

The 268-foot AT&T Pennsuco Radio Tower was instrumented at the 5-, 105-, and 205-foot levels to investigate low-level temperature inversions in the vicinity of Site 14, the recommended location for the new Florida Regional Jetport. Data collected during the period February 22 to April 30, 1973, revealed that relatively strong ground-based inversions formed there nightly for an average duration of 14 hours. Generally, the inversions were stronger with east winds, which suggests temperature enhancement aloft by the heat plume from urban Miami. It is concluded, therefore, that urbanization creates poor dispersion conditions downwind from the heat island. Daytime inversions were observed for periods of one or two hours in association with troughs aloft, cold frontal passages, and sea-breeze fronts. The mean low-level temperature profile at rural Site 14 was that of an inversion. These results vividly show that low-level temperature inversions are quite pronounced in south Florida and, therefore, should be given paramount consideration in all air-quality planning.

Gleason, P. J., 1974, Chemical quality of water in Conservation Area 2A and associated canals: Florida Flood Control Tech. Pub. no. 74–1, 72 p.

Hagenbuck, W. W., Thompson, Richard, and Rodgers, D. P., 1974, A preliminary investigation of the effects of water levels on vegetative communities of Loxahatchee National Wildlife Refuge, Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 611.

The relation between water-level fluctuation and plant-community distribution on the 145,635-acre Loxahatchee National Wildlife Refuge was explored by means of ground transects and aerial photograph interpretation. Inundation curves for 15 plant species were prepared from data at 2,715 stations located primarily within seven 100-acre plots. The 15 species were grouped into four distinct communities based on similarities in inundation curves. Sampling data were extrapolated to estimate proportions of the study area occupied by each community and to predict changes that would accompany proposed adjustments in the water-regulation schedule. Aerial photographs of study plots were used to quantify the area of the four community types in each year of record (1948, 1952, 1962, and 1968). Changes in plant community distribution over the 20-year period were strongly correlated with water-level manipulations. Based on the demonstrated relation between seasonal water-level fluctuation and plant-community distribution, a 14- to 17-foot (mean sea level) water-regulation schedule was superior to the proposed 17- to 15-foot schedule in maintaining plant-community equilibria favorable to refuge management objectives.

Harriss, R. C., 1973, Distribution of pesticides in a south Florida watershed: U.S. Natl. Park Service PB–231 684.

In almost all cases, the total organochlorine pesticides content of the 40 samples of soils and of canal and estuarine bottom sediments from the lower southwest Florida coast were below the detection limit of the analytical method used.

Hoffmeister, J. E., 1974, Land from the sea, the geologic story of south Florida: Coral Gables, Fla., Univ. of Miami Press, 143 p.

Hofstetter, R. H., 1973, Effects of fire in the ecosystems of southern Florida—An ecological study of the effects of fire on the wet prairies, sawgrass glades and pineland communities: U.S. Natl. Park Service PB-231 940.

The role of fire in the major ecosystems of southern Florida is being studied in a continuing project. Results and recommendations are preliminary. Natural fires are caused by lightning and are common in the summer wet season. Man-caused fires now dominate and are characteristic of the later dry season. The latter are unnatural and more destructive. This destructiveness is promoted by altered hydrologic conditions. Vegetation, insects, spiders, small mammals, birds, biogeochemical cycles, and microclimate are coordinated in permanent plots and are being studied relative to fire and succession. Many of Robertson's plots, established in the Everglades National Park in 1960, are incorporated. The pinelands are the most threatened system in southern Florida. Without fire, succession leads to hardwood hammocks. Fire checks this succession. Species dependent on a shrub layer are reduced in diversity. No direct kill of birds or mammals by fire has been observed. Recommendations for incendiary fires, prescribed burning for fire abatement, and ecosystem management are presented. (Includes appendix "Seasonal Rhythms of Soil Arthropods in Miami Rock Ridge Pinelands" by Earl D. McCoy.)

Horvath, G. J., 1973, The influence of Big Cypress land development on the distribution of heavy metals in the Everglades estuaries: U.S. Natl. Park Service PB-231 941.

The distribution, chemical fractionation, and flux rates of heavy metals were investigated in the Big Cypress Swamp and the Everglades National Park. The study area included canals draining developed land and estuaries receiving runoff from both developed areas and natural wetlands. In the Barron River Canal, metals were present mainly in the dissolved ionic form, with the exception of iron and zinc, which occurred mostly in the dissolved organically complexed and particulate fractions. Dissolved metal concentrations in canals adjacent to actively cultivated fields were 2 to 6 times higher than those in canals draining uncultivated land. The degree of contamination was higher during the rainy season. The flux rates of heavy metals during high-flow conditions were generally twice as high as those during low flow. Iron had the highest flux rate under both flow conditions, followed by manganese, lead, cobalt, and zinc. Dissolved iron concentrations decreased sharply over the salinity gradient, while the concentrations of other metals showed a net increase. Concentration levels of heavy metals in Chokoloskee Bay were 1.5 to 3 times higher than those present in other Everglades estuaries receiving natural drainage. The degree of enrichment increased during the wet season.

Houde, E. D., 1971, Survey of the literature relating to sport and commercial fishes in south Florida: U.S. Natl. Marine Fisheries Service PB-231 669.

An annotated bibliography on literature relating to fish and fisheries in south Florida that has been published mostly in the period 1960–71 is included in this report. A total of 466 references is presented, plus 27 references on fish surveys done in the south Florida area. Twenty-eight journals were searched systematically for this report, and publications from many other sources are included.

Joyner, B. F., 1971, Appraisal of chemical and biological conditions of Lake Okeechobee, Florida, 1969–70: U.S. Geol. Survey open-file rept., 89 p.

——— 1974, Chemical and biological conditions of Lake Okeechobee, Florida, 1969–72: Florida Bur. Geology Rept. Inv. 71, 94 p.

Kersey, H. A., Jr., 1973, A history of the Seminole and Miccosukee Tribes, 1859–1970: U.S. Bur. Indian Affairs PB-233 052.

A brief history of the Seminole and Miccosukee Tribes, 1859–1970, was developed as a logical starting point for studying contemporary Indian society in Florida. It explores the way in which social, political, economic, religious, and other factors led to the development of a unique Indian lifestyle. Chapters focus on Indian cultural development during five distinct periods: (1) the end of the Third Seminole War to the establishment of missions and government agencies; (2) the era of Indian interaction with missionaries, traders, and government agents; (3) Indian reaction to education and Christian religion; (4) the establishment of Indian reservations in Florida; and (5) contemporary social, political, and economic development of the Seminole and Miccosukee Tribes. An extensive bibliography and footnotes are included with the report.

Klein, Howard, 1972, The shallow aquifer of southwest Florida: Florida Dept. Nat. Resources, Bur. Geology, Map Series no. 53.

Klein, Howard, Armbruster, J. T., McPherson, B. F., and Freiberger, H. J., 1973, Water and the south Florida environment: U.S. Geol. Survey PB-236 951.

Increasing population and the concomitant urban sprawl and industrial growth in south Florida have caused concern to agencies involved in land-use planning and water management as to the adequacy of water supplies, determination of water quality, and changes in environmental factors. This report describes the physical system, past and present, and the environmental problems that exist now and provides alternative solutions to these problems, with emphasis on alternatives that might be used to minimize deleterious effects on the environment of south Florida in years to come.

Klein, Howard, Schneider, W. J., McPherson, B. F., and Buchanan, T. J., 1970, Some hydrologic and biologic aspects of the Big Cypress Swamp drainage area, southern Florida: U.S. Geol. Survey open-file rept., 94 p.

Klein, Howard, Schroeder, M. C., and Lichtler, W. F., 1964, Geology and ground-water resources of Glades and Hendry Counties, Florida: Florida Div. Geology Rept. Inv. 37, 101 p.

Kurz, Herman, 1942, Florida dunes and scrub, vegetation and geology: Florida Geol. Survey Bull. 23, p. 154.

Leach, S. D., Klein, Howard, and Hampton, E. R., 1972, Hydrologic effects of water control and management of southeastern Florida: Florida Div. Geology Rept. Inv. 60, 115 p.

Leopold, L. B., and others, 1969, Environmental impact of the Big Cypress Swamp Jetport: U.S. Dept. of the Interior, 155 p.

Lindall, W. N., Jr., 1973, Alterations of estuaries of south Florida—A threat to its fish resources: Marine Fisheries Rev., v. 35, no. 10, p. 26–33.

Lindall, W. N., Jr., Hall, J. R., Fable, W. A., and Collins, L. A., 1973, A survey of fishes and commercial invertebrates of the nearshore and estuarine zone between Cape Romano and Cape Sable, Florida: U.S. Natl. Marine Fisheries Service PB–235 215.

Fishes and commercial invertebrates of the nearshore and estuarine zone between Cape Romano and Cape Sable, Florida, were sampled quarterly (May 1971–February 1972) with beach seine and otter trawl. One-hundred and fourteen species of fish (31,982 individuals) and six species of commercial invertebrates (2,864 individuals) were collected at 35 stations located in inland waters and to 10 miles in the Gulf of Mexico. Catches were decidedly higher at nearshore and inland stations than at stations located 5 and 10 miles offshore. Twenty-four species of fish not listed in previous studies in the Everglades region were identified. A systematic account of all species is provided.

Little, J. A., Schneider, R. F., and Carroll, B. J., 1970, A synoptic survey of limnological characteristics of the Big Cypress Swamp, Florida: Washington, Federal Water Quality Admin., 94 p.

Loveless, C. M., 1959, A study of vegetation in the Florida Everglades: Ecology, v. 40, no. 1, 9 p.

Luer, C. A., 1964, Orchids of the Fahkahatchee: The Florida Orchidist, v. 4, no. 7, p. 191–195.

Lugo, A. E., Evink, G. L., Brinson, M. M., Broce, A., and Snedaker, S. C., 1973, The role of mangrove ecosystems—Diurnal rates of photosynthesis respiration and transpiration in mangrove forests of south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 743.

Measurements of CO_2 exchange and transpiration were made on the four south Florida mangrove-forest tree species (*Rhizophora mangle, Avicennia nitida, Laguncularia racemosa*, and *Conocarpus erecta*) at Rookery Bay, Florida. Mangrove species were studied by compartment (trunks, prop roots, pneumatophores, seedlings, and shade and sun leaves) during two study periods: August 1971 and January-February 1972. *R. mangle* leaves had higher net daytime photosynthesis rates and lower nighttime respiration rates than *A. nitida*. Sun leaves had higher net daytime photosynthesis, while shade leaves had higher nighttime respiration. Data obtained from the gas exchange studies suggest a metabolic basis for the zonation of the four mangrove species.

Lugo, A. E., Sell, M., and Snedaker, S. C., 1973, The role of mangrove ecosystems—Mangrove ecosystem analysis: U.S. Bur. Sport Fisheries and Wildlife PB–231 744.

A parameterized model of a mangrove ecosystem was simulated on an analog computer. The results suggest that: (1) maximum live-biomass accumulation is hurricane limited; (2) both in situ detrital accumulation and export are functions of tidal amplitude; (3) gross photosynthesis is sensitive to terrestrial nutrient inputs, and net production depends on the quantity of available nutrients; and (4) species zonation appears to be a function of nutrient availability as well as salinity gradients.

Lugo, A. E., and Snedaker, S. C., 1973, The role of mangrove ecosystems—Properties of a mangrove forest in south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 741.

A suite of parameters describing the physical environment and the structure and function of a mangrove ecosystem was evaluated. The resulting data were evaluated in terms of the dynamic properties of the ecosystem, with emphasis on auxillary energy sources, systems adaptions, and relationships with contiguous estuarine areas. Mangrove ecosystems are described as interface systems linking the terrestrial uplands with the coastal estuaries.

Lugo, A. E., Snedaker, S. C., Bayley, S., and Odum, H. T., 1971, Models for planning and research for the South Florida Environmental Study: U.S. Natl. Park Service PB–231 938.

The major subsystems of the south Florida regional ecosystem are described to focus attention on the critical problems and to set research priorities. The energy circuit language is used (as a substitute for differential equations) to identify the major stocks, flows, interactions and feedbacks, control mechanisms, and man-nature couplings characteristic of each of the 22 subsystems selected for evaluation. The models are based on the integrating role of energy in balances of man and nature and thus on energy as a common denominator for evaluating diverse kinds of data and information. The authors argue for an increased understanding of the behavior of whole ecological systems, of which man is one component, and for the evaluation of data for this purpose. The whole-systems research methodology is described.

Marshall, A. R., Hartwell, J. H., Anthony, D. S., Betz, J. V., Lugo, A. E., Veri, A. R., and Wilson, S. U., 1972, The Kissimmee-Okeechobee basin, A report to the Florida cabinet: Miami, Fla., Univ. of Miami [Florida] Center for Urban Studies, 64 p.

Martens, J. H. C., 1931, Beaches of Florida: Florida Geol. Survey 21st-22d Ann. Rept., p. 71–119.

Mathis, J. M., 1973, Mangrove decomposition—A pathway for heavy metal enrichment in Everglade estuaries: U.S. Natl. Park Service PB–231 738.

Red mangrove decomposition was studied as a natural pathway for heavy metal enrichment in estuaries of south Florida. Red mangrove leaves, major constituents of the highly organic suspended detritus of the estuaries, were analyzed in several decomposition stages for heavy metal concentration. Analysis revealed a 3- to 200-fold enrichment of Fe, Mn, Cu, and Cd in the detritus compared to living leaves. This enrichment process is thought to be primarily due to absorption, complexion, and concentration of dissolved metals by the mangrove detritus and its associated microbiota. Comparisons between the Barron River estuary, which receives its drainage from agriculturally developed areas, and the Shark and Broad River estuaries, which receive drainage from undeveloped areas, revealed a significantly higher concentration of Cu and Cd in Barron River leaves and a higher concentration of Mn, Fe, and Cu in Barron River detritus than in the leaves and detritus of the uncontaminated estuaries. This increase in heavy metal concentrations is probably due to the metal-containing pesticides and fertilizers applied to farmlands drained by the Barron River estuary.

Mattraw, H. C., Jr., 1973, Cation exchange capacity and exchangeable metals in soils and sediments of a south Florida watershed: U.S. Natl. Park Service PB–233 526.

A study of exchangeable metal behavior was designed and tested for a disrupted Big Cypress watershed in south Florida. Essential considerations included isolation of an hydraulic equivalent fine fractions of soils and sediments and in situ measurements of sediment pH and eH. Measurements of cation exchange capacity (CEC) and exchangeable manganese, iron, cobalt, copper, zinc, cadmium, and lead for four identifiable environments were compared with field data and laboratory measurements of pH, the amount of fine material, and the organic content to elucidate control mechanisms on exchangeable metal content. Kruskal-Wallis analysis of variance on CEC-normalized estuarine sediments indicated a cultural enrichment of exchangeable cobalt, copper, zinc, and lead in Chokoloskee Bay. (35 references.)

McCoy, H. J., 1972, Hydrology of western Collier County, Florida: Florida Div. Geology Rept. Inv. 63, 32 p.

McPherson, B. F., 1973a, Vegetation map of southern parts of subareas A and C, Big Cypress Swamp, Florida: U.S. Geol. Survey Hydrol. Inv. Atlas HA–492, scale 1:125,000.

——— 1973b, Water quality in the conservation areas of the central and southern Florida Flood Control District, 1970–72: U.S. Geol. Survey open-file rept., 39 p.

Moore, S. A., Jr., 1973, Impact of pesticides on phytoplankton in Everglades estuaries: U.S. Natl. Park Service PB–231 618.

Six- and 24-hour bioassays were conducted to determine in situ the effect of selected organochlorine compounds on natural communities of estuarine phytoplankton. The effect of organochlorine concentration observed was to reduce phytoplankton utilization of bicarbonate, thereby also reducing photosynthetic production of organic material. Polychlorinated biphenyls (PCBs: Aroclor 1242 and Aroclor 1245) phytotoxicity occurred at PCB levels less than 5 μg PCB/l. P, P'-DDT phytotoxicity initiated at concentrations of 10 μg DDT/l. Phytotoxicity by dieldrin is inconclusive. No phytotoxicity was observed in one ecosystem. A typical dose-response toxicity was observed in a second ecosystem and indicated apparent dieldrin toxicity at 15 μg dieldrin/l. Nannoplankton and netplankton difference in Aroclor 1242 sensitivity was observed. Ten and 25 μg/l PCB did not inhibit nannoplankton, which contributed approximately 73 percent of the phytoplankton production. Netplankton production was inhibited by more than 50 percent in both the 10 and 25 μg/l PCB concentrations. Biochemical modes for organochlorine action are discussed in conjunction with difficulties in interpreting the effects of organochlorine compounds on phytoplankton. An objection to basing water-quality standards on organochlorine concentrations is raised.

National Academy of Sciences and Engineering, 1970, Environmental problems in south Florida: Washington, D.C., pt. 2, 76 p.

National Audubon Society, 1973, Status of colonies of large wading birds in south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 633.

Colonies of wood storks, *Mycteria americana*, and other wading birds were surveyed in south Florida, excluding Everglades National Park, and the locations of colonies during 1971 and 1972 were given. Populations of birds were estimated by direct aerial and ground counts. A total of 1,368 breeding pairs of wood storks were counted in 1971, of which 1,200 were found in Corkscrew Swamp. About 1,500 storks were fledged in 1971, but only 200 fledged in 1972. Most other large wading birds did not breed in 1971 because of drought; however, about 37,000 pairs (including 10,000 cattle egrets) nested in 1972. Comparison of these counts with counts made by previous workers indicates a drastic long-term decline in wading bird populations in south Florida, from about 2.5 million to 150,000 birds in the last 100 years. Recommendations are presented in an attempt to preserve wading bird populations from an increasing loss of habitat and food supply.

Nicholas, J. C., 1973, Land utilization in south Florida—A description of the historical development of urban and agricultural land use patterns: U.S. Bur. Indian Affairs PB–231 942.

This report consists of four studies designed to yield an overall view of the burgeoning growth of the south Florida region and the potential impact that these growth patterns might have on the Indian tribes residing in the region. The first report is "Land Utilization in South Florida: A Description of the Historical Development of Urban and Agricultural Land Use Patterns," prepared to provide the historical perspective needed in order to project south Florida to the year 2000. The remaining three reports constitute a projection trilogy concerned with population, employment, and land use. Four population series were employed in these studies: (1) Office of Business Economics projections, (2) the Jerome Pickard projection, (3) the naive extrapolation, and (4) the Florida Social Science Advisory Committee projection. The report "Population Projections for South Florida" details the various population series for the aggregate area and for the individual counties to the year 2000. The report "Employment Projections for South Florida" projected employment to the same date, with alternative levels of employment projected based upon the four population series. In each of the reports the relevant area of south Florida is taken as being the counties of Broward, Charlotte, Collier, Dade, Glades, Hendry, Lee, Martin, and Palm Beach.

Nicholas, J. C., and Kersey, H. A., Jr., 1973, Recommendations concerning employment, income, and educational opportunities for the Seminole and Miccosukee Tribes in Florida: U.S. Bur. Indian Affairs PB–231 943.

In this report, a research team concentrated on developing an estimate of present and future employment opportunities for the Indian tribes, as well as a general land-use forecast for the current reservation lands to the year 2000. A clear perception of future development in the south Florida region abutting their reservation lands, including the possible location of a jetport, and an assessment of both the problems and the potential economic gain that it poses, should greatly benefit the Seminole and Miccosukee people in planning for the future. A set of general educational recommendations has been prepared on how the tribes might best proceed in developing programs for their school-aged children, adult education, and vocational-technical training.

Odum, H. T., 1971, Environment, power, and society: New York, Wiley-Interscience, 331 p.

Ogden, J. C., Brown, R. A., and Salesky, Norman, 1973, Grazing by the echinoid *Diadema antillarum* Philippi—Formation of halos around West Indian patch reefs: Science, v. 182, no. 4113, p. 715.

Ogden, J. C., Robertson, W. B., Davis, G. E., and Schmidt, T. W., 1974, Pesticides, polychlorinated biphenyls and heavy metals in upper food chain levels, Everglades National Park and vicinity: U.S. Natl. Park Service PB–231 359.

A general concern over possible environmental pollution by manmade poisons prompted the extensive survey of chlorinated insecticides, polychlorinated biphenyls, and metals in upper trophic levels of material collected in and adjacent to the Everglades National Park. Collections were made between 1971 and 1973, and analyses were conducted by WARF, Inc., Madison, Wisconsin. The resulting analyses provide a baseline for future analyses and clues for particular poisons or particular species in need of more intensive study. These data revealed that DDT, DDE, DDD, dieldrin, and PCBs appear to exist in concentrations well below amounts known to have either acute or chronic effects. Less is known of the significance of the various metal concentrations reported here, although levels of mercury in freshwater vertebrates and arsenic in marine species are great enough to deserve more intensive study.

Ornes, W. H., and Steward, K. K., 1973, Effect of phosphorus and potassium on phytoplankton populations in field enclosures: U.S. Natl. Park Service PB–231 650.

In an enrichment experiment within a sawgrass community, phosphorus and potassium were added to field enclosures in amounts equivalent to what generally occurs in sewage effluent. This resulted in phytoplankton blooms and dynamic shifts in dominant phytoplankton genera. Also, the aquatic macrophytes *Chara* sp. and *Utricularia* sp. disappeared after 22 weeks of treatment. Both polluted and clean water phytoplankton genera appeared in the control and treated enclosures. The experiment results indicated a disrupted environment. Thus, more study should be conducted before utilizing the sawgrass marshes as living filters for wastewater.

OVERVIEW, 1969, Beyond the impasse—The Dade Jetport and south Florida environment: Washington, D.C., OVERVIEW, 1700 Pennsylvania Ave. NW., 47 p.

Parker, G. C., Ferguson, G. E., Love, S. K., and others, 1955, Water resources of southeastern Florida: U.S. Geol. Survey Water-Supply Paper 1255, 965 p.

Pool, D. J., 1973, The role of mangrove ecosystems—Mangrove leaf area indices: U.S. Bur. Sport Fisheries and Wildlife PB–231 745.

Leaf area index (LAI) on total leaf surface per unit ground area is one parameter that may be used to estimate the photosynthetic capacity of individual plants or entire ecosystems. Techniques used for determining LAI in south Florida mangrove ecosystems included: (1) planimetric method, (2) light table, (3) plumb-line method, (4) photographic records, (5) canopy closure, and (6) light transmittance. Leaf area of the mangrove communities measured ranged from 0.8 to 5.1 m^2/m^2. All sites had a canopy closure of over 95 percent with low light transmittance. Early successional ecosystems have leaf area indices lower than the older closed-canopy forests.

Pool, D. J., and Lugo, A. E., 1973, The role of mangrove ecosystems—Litter production in mangroves: U.S. Bur. Sport Fisheries and Wildlife PB–231 746.

Seventy 0.25-m^2 baskets were placed in three different types of mangrove forests in the Ten Thousand Islands and at one site at Rookery Bay in Naples, Florida. Results of litter-basket collections and separations are reported by component and by species. Total litter fall ranged from 1.4 g/m^2/day (estimated 511 g/m^2/ year) to 2.3 g/m^2/day (estimated 840 g/m^2/year). The total litter fall was composed of 75 to 85 percent leaves, 10 to 15 percent wood, and 4 to 5 percent miscellaneous (insect parts, grass, flowers, seeds, etc.). In 1972, the Rookery Bay site had the greatest daily rates of litter fall in the months of January, February, and March (2 to 5 g/m^2/day), with total litter fall remaining stable during the remainder of the year. High rates of litter fall are associated with low temperatures and seasonal storms.

Prochaska, F. S., and Cato, J. C., 1974, Landing, values and prices in commercial fisheries for the Florida Keys region: Gainesville, Florida Sea Grant Pub. SUSF–SG74–004, Univ. of Florida, 20 p.

Rodgers, D. P., 1974, Waterfowl in south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 655.

Recent waterfowl kill and survey data for south Florida are summarized. The harvest in the Everglades Region (an administrative region of the Game and Fresh Water Fish Commission) increased by 66 percent from the previous season, reflecting in part a 36-percent greater hunter effort in the former period. Aerial survey counts for the Loxahatchee National Wildlife Refuge, Conservation Areas 2 and 3, Lake Okeechobee, and the southwest Florida coast are presented. In the past, considerable fluctuation has occurred in the regional waterfowl populations. The present long-term trend is a reduction in numbers of most species, largely attributable to the general decline in North American waterfowl populations and the availability of select waterfowl habitat in central and northern Florida and in States farther north. Heavy airboat traffic in central south Florida areas disturbs some resting waterfowl and displaces them to Central and South America and the West Indies.

Rodgers, D. P., and Crowder, J. P., 1974, Threatened wildlife of south Florida: U.S. Bur. Sport Fisheries and Wildlife PB–231 654.

The 34 endangered or otherwise threatened wildlife species (as classified by the Department of the Interior) of south Florida are identified and described. The listing includes 23 species or subspecies of birds, 6 of mammals, and 3 of reptiles. Eleven of these are found exclusively in Florida; several others are found only in Florida within the United States portion of their ranges. Thirteen are officially classified by the Secretary of the Interior as endangered species, entitled to protection under provisions of Federal endangered species legislation. Direct physical alteration or destruction of habitat (including drainage of wetlands), depredations by market hunters, and pesticides are identified as principal factors in population declines of the region's threatened species. Problems peculiar to each species are considered in detail. Recommendations are made for the protection and enhancement of surviving populations.

Schemnitz, S. D., 1972, Populations of bear, panther, alligator, and deer in the Florida Everglades: U.S. Bur. Sport Fisheries and Wildlife PB–231 620.

The population status of the Florida black bear, the white-tailed deer, and two endangered wildlife species, the American alligator and the Florida panther, were studied in the Everglades Region of Florida. Questionnaires were distributed to field personnel of the Florida Game and Fresh Water Fish Commission and the Florida Department of Natural Resources to obtain information on population levels of bear and panther. Individuals who reported panthers were interviewed. Records of panther and bear at the Everglades National Park were examined. Nocturnal and diurnal alligator counts along canals were made. Aerial deer counts, pre- and post-hunting season sex ratio changes, and deer harvest information were used to estimate deer populations. Black bear and panther population estimates were 145 and 92, respectively. Most of these animals occur in Collier County. The estimated deer population of the Everglades Region (4.5 million acres) is about 20,000. The calculated 1971–72 legal deer harvest from the Everglades Wildlife Management Area (800,-000 acres) was 900. With increased protection from poaching in recent years, alligator populations have increased, despite the loss of more than 1.5 million acres of habitat. This habitat destruction is largely attributable to agricultural, residential, commercial, and industrial development.

Schemnitz, S. D., and Schortemeyer, J. D., 1972, The influence of vehicles on Florida Everglades vegetation: U.S. Bur. Sport Fisheries and Wildlife PB–231 613.

The influence of off-road recreational vehicles (airboats and half-tracks) on Everglades vegetation and soils was measured intensively on six fenced plots. Pre- and post-treatment measurements of vegetation heights and biomass were made. Treatments selected at random consisted of single and repeat runs of vehicles on marked transects.

Soil depth and compaction were also measured. Post-treatment recuperation of vegetation was more rapid on wet prairie and muck burn plots than on sawgrass plots and more rapid on wet plots than on dry ones. Half-track damage to vegetation was more severe than airboat traffic damage. Recovery of vegetation after 4 or 5 months averaged 59 percent for airboat traffic and 48 percent for half-tracks on the basis of height changes. There was no significant difference in soil compaction or in the variety of plant species in vehicle treatment areas and undisturbed control transects. Soil moisture readings were greater in half-track ruts than in adjacent controls. Water temperatures in half-track ruts were higher than temperatures in nearby water shaded by sawgrass. Examination of older half-track trails of known age showed contrasting results. One trail network in Conservation Area 3 was essentially erased after 9 months of regrowth. Track trails in the Everglades National Park were more persistent.

Seaman, W., Adams, C. A., and Snedaker, S. C., 1973, The role of mangrove ecosystems—Biomass determinations in shallow estuaries—Technique evaluation and preliminary data: U.S. Bur. Sport Fisheries and Wildlife PB–231 748.

A new type of portable drop net was developed and used to quantitatively harvest fishes from 16-m^2 sample areas in shallow estuaries. The technique is shown to be suitable for sedentary benthic and vegetation-inhabiting fishes, including eels, gobies, erreids, syngathids, juvenile pinfish, sciaenids, and flat fishes. The technique and preliminary results are evaluated and compared with reports in the literature describing techniques to estimate fish biomass.

Snedaker, S. C., and Pool, D. J., 1973, The role of mangrove ecosystems—Mangrove forest types and biomass: U.S. Bur. Sport Fisheries and Wildlife PB–231 742.

Five physiognomic types of mangrove forests are identified on the basis of local topography, coastal position, and relationship to terrestrial runoff and tidal flushing. Estimates of biomass, by compartment, are reported for an overwash forest, a fringe forest, a riverine forest, a single-tree island, and white mangroves (*Laguncularia racemosa*) colonizing dredge-spoil banks. Forest biomass (dry weight, above ground) ranges from 11 to 25 kg m^{-2}. Standing stock detritus contributes up to 39 percent of the total biomass and is related to storm damage.

Sproul, C. R., Boggess, D. H., and Woodward, H. J., 1972, Saline-water intrusion from deep aquifer sources in the McGregor Isles area of Lee County, Florida: Florida Div. Geology Inf. Circ. 75, 30 p.

Starck, W. A., II, 1968, A list of fishes of Alligator Reef, Florida, with comments on the nature of the Florida reef fish fauna: Undersea Biology, v. 1, no. 1, p. 1–40.

Stephens, J. C., 1969, Peat and muck drainage problems: Am. Soc. Civil Engineers Proc., Jour. Irrigation and Drainage Div., v. 95, p. 285–305.

Steward, K. K., and Ornes, W. H., 1973a, Assessing the capability of the Everglades marsh environment for renovating wastewater: U.S. Natl. Park Service PB–231 652.

Everglades vegetation was enriched with simulated effluents in order to determine the feasibility of recycling wastewater through the marshes. Weekly application of nutrients increased assimilation of nutrients by the plants but did not increase growth. This indicated that growth was not limited by lack of nutrients. Only 12 percent of the applied nutrients was assimilated into the vegetation. Of the amount remaining, 3 percent was used to produce algal blooms, 43 percent settled to the bottom, 5 percent remained dissolved in the water, and 37 percent was unaccounted for. The dense algal blooms, which were maintained throughout the experiment, were believed to have been responsible for the disappearance of several floral components of the ecosystem. Because of the low capacity for nutrient assimilation and because of potential alterations in species composition, it appeared unlikely that the marsh system could be used to renovate wastewater.

——— 1973b, Investigations into the mineral nutrition of sawgrass using experimental culture techniques: U.S. Natl. Park Service PB–231 609.

Sawgrass (*Cladium jamaicensis* Crantz) seedlings were grown in virgin soil in a greenhouse to determine the mineral-nutrient status of plants in the field, as well as their response to nutrient enrichment. Additions of small quantities of phosphorus produced significant increases in dry weight, shoot length, and vegetative reproduction of new plants. Growth responses of seedlings were highly related to P levels in tissues. There appeared to be an optimum P level in tissue, however, as higher levels inhibited dry-matter production, shoot elongation, and new shoot production. This was a significant finding, indicating that serious consequences may result from discharging nutrient-rich waters into Everglades marshes. Critical P concentration was determined to be higher in seedlings than in sawgrass plants from the field. It was concluded that experimentally determined critical nutrient levels do not adequately diagnose the nutrient status of plants in the field.

——— 1973c, The autecology of sawgrass (*Mariscus jamaicensis)* in the Florida Everglades: U.S. Natl. Park Service PB–231 608.

Investigations were conducted in 1971 and 1972 to characterize typical stands of sawgrass (*Cladium jamaicensis* Crantz), the dominant plant species in the southern Everglades. The mature stands exhibited little seasonal variation within the parameters of standing crop, plant density, and concentration of most inorganic nutrients. Plant nutrient requirements were determined to be low, since the tissue levels of nutrients were low as compared to those of other species of Everglades macrophytes. Levels of available nutrients in soil were variable and had no seasonal pattern. Most nutrients were in adequate supply. Waters in the marsh contained on an average 3, 10, and 8 percent of the N, P, and K, respectively, contained in a comparable area of sawgrass standing crop. Concentration of most nutrients in plants regrowing after fires was high during early growth stages but decreased to levels found in older plants after 3 to 5 months. After 18 months' growth, burned stands of sawgrass had produced only 38 percent of the standing crop contained in mature stands prior to burning. The apparent low nutrient requirements of sawgrass may partially explain the dominance of this plant in the marsh community.

Tebeau, C. W., 1973, Past environment from historical sources: U.S. Natl. Park Service PB–231 711.

In the year 1900, peninsular Florida south of Polk and Orange Counties was the home of only 43,344 people, just under 8 percent of the State's total, and over a third of them lived in Key West. The region, aptly described as one huge refuge for wildlife and plant life, was as yet largely unexploited and undisturbed. Though it had been explored, mapped, and described during the Second Seminole War, 1835–42, the reports were not generally known. The interior remained a mystery until it began to be "rediscovered" and widely reported about 1870 by hunters, naturalists, and surveyors who described what was there and what was happening to it. Gatherers of hides and feathers and sportsmen were killing ruthlessly. Settlers and developers were clearing and burning and draining and lowering the water table and thereby altering the environment. Some species were disappearing, and others were threatened. The Everglades National Park became a refuge for the surviving remnant, but man's activities threatened them even there.

U.S. Army, Corps of Engineers, 1968, Water resources for central and southern Florida: Survey Rev. Rept. on Central and Southern Florida Project, 74 p.

U.S. Bureau of Outdoor Recreation, Southeast Region, 1973, An analysis of outdoor recreation resources, impacts, and potentials in south Florida: PB–231 760.

This report describes briefly the 11 physiographic provinces of south Florida, relating to the recreational potentials and problems of the area. The socioeconomic climate in terms of projections of population, employment and income for target years, and the relationship of these factors to outdoor recreation are analyzed for the study area. State, county, and local recreation programs are noted, analyzing in depth local recreation programs. This report identifies program functions and enabling legislation most likely to enhance or increase outdoor recreation opportunity where most people live—in the urban environment. A complete inventory of public park and open space areas in south Florida at the various levels of government has been assembled. A recreation utilization system that denotes land classes and capacity standards was adopted in order to catalog inventory data. Totals indicate the amount of specified types of recreation facilities available for each county within the study area. A detailed analysis of study-area-resident recreation participation rates is given. This report reviews regionally significant natural resources remaining south of Lake Okeechobee, their recreational values, impacts, and actions needed to preserve them.

U.S. Department of the Interior, 1974, United States list of endangered fauna: Washington, 22 p.

Vernon, R. O., 1947, Cypress domes: Science, v. 105, no. 2717, p. 97–99.

Voss, G. L., Bayer, F. M., and Robins, C. R., 1969, The marine ecology of Biscayne National Monument—A report to the National Park Service: Miami, Fla., Univ. of Miami [Florida] Rosenstiel School of Marine and Atmosphere Sciences, 128 p.

Wetterqvist, O. F., and others, 1972, Identification and evaluation of coastal resource patterns in Florida: Florida Coastal Coordinating Council, 83 p.

Appendices

I.—An introduction to systems ecology and ecological modeling

The living biological community and the nonliving physical environment work together in nature to function as an ecological system (ecosystem). Each type of system usually has a particular combination of environmental factors that allows it to be separated from other ecosystem types, such as forests, beaches, and cities. In every system the component parts work together or interact in the way that is necessary for the perpetuation of the system. Any ecosystem evaluation must incorporate means for recognizing the differences inherent in each system type, and at the same time it should pick out those threads that tie all those different systems together into a functioning unit of man and nature.

In evaluating ecosystems, we will consciously or subconsciously construct conceptual models (visual diagrams) to aid in placing the component parts into a functioning arrangement. The selection and arrangement of the component parts are often by intuitive reasoning. For example, in a freshwater-marsh system, water, light, and vegetation are obviously important parts. Intuitively we know that alteration of the flow of water or amount of light will affect the marsh vegetation although we do not know to what degree. Also, we know that the flow of water, for example, is affected by other factors such as man's diversion of water for public water supply. As more factors are included in the model and as quantitative data are incorporated, intuition falls short of effecting a solution. We must then make use of a more sophisticated treatment. One possibility is the use of a mathematical model. Another is to make use of a model that employs symbols rather than numerical parameters to represent the real-world system. Such a model, which uses pictures of familiar forms, objects, or figures, is easy to understand and simple to apply.

A simple example of how these symbols are used to represent a system is illustrated in figure 27 where a human dwelling is diagrammed in two different ways. Figure 27*A* shows a house with food, building material, and fuel oil being brought into the house for consumption. Figure 27*B* translates this picture language into an energy-flow diagram. We see that by using the energy-flow diagram we can equate dissimilar components of the system under study and provide a better understanding of the whole system.

In south Florida one is confronted with a set of complex problems, all interrelated in some fashion. It became evident that systems analysis with a regional modeling approach would be valuable to illuminate the main environmental issues and to predict changes in the system under specific types of potential development. The modeling approach used by Lugo and others [1] is well adapted for obtaining a broad overview as well as for predicting changes in south Florida because it incorporates the following features:

1. The common denominator used to compare system components is the energy value expressed in potential energy.
2. A symbolic systems language permits rapid visual identification and understanding of models both conceptually and mathematically. This language is analogous to analog computer diagrams and is easily used in simulation studies.
3. A broad view of a large regional system is possible in which the important major pathways vital to the region can be evaluated. The forcing functions (such as energy from the sun or from fossil fuels) outside the system under study can be seen as they enter, drive, and leave the system.
4. Smaller subsystems or ecosystems making up the larger systems may be identified and evaluated in greater detail if necessary.
5. Computer simulations of conceptual models can be checked for accuracy with data from the real world. After this validation the model can be used to predict future trends.

[1] Lugo, A. E., Snedaker, S. C., Bayley, S., and Odum, H. T., 1971, Models for planning research for the South Florida Environmental Study: U.S. Natl. Park Service, available from U.S. Dept. of Commerce, Natl. Tech. Info. Service, Springfield, Va. 22151 as PB-231 938.

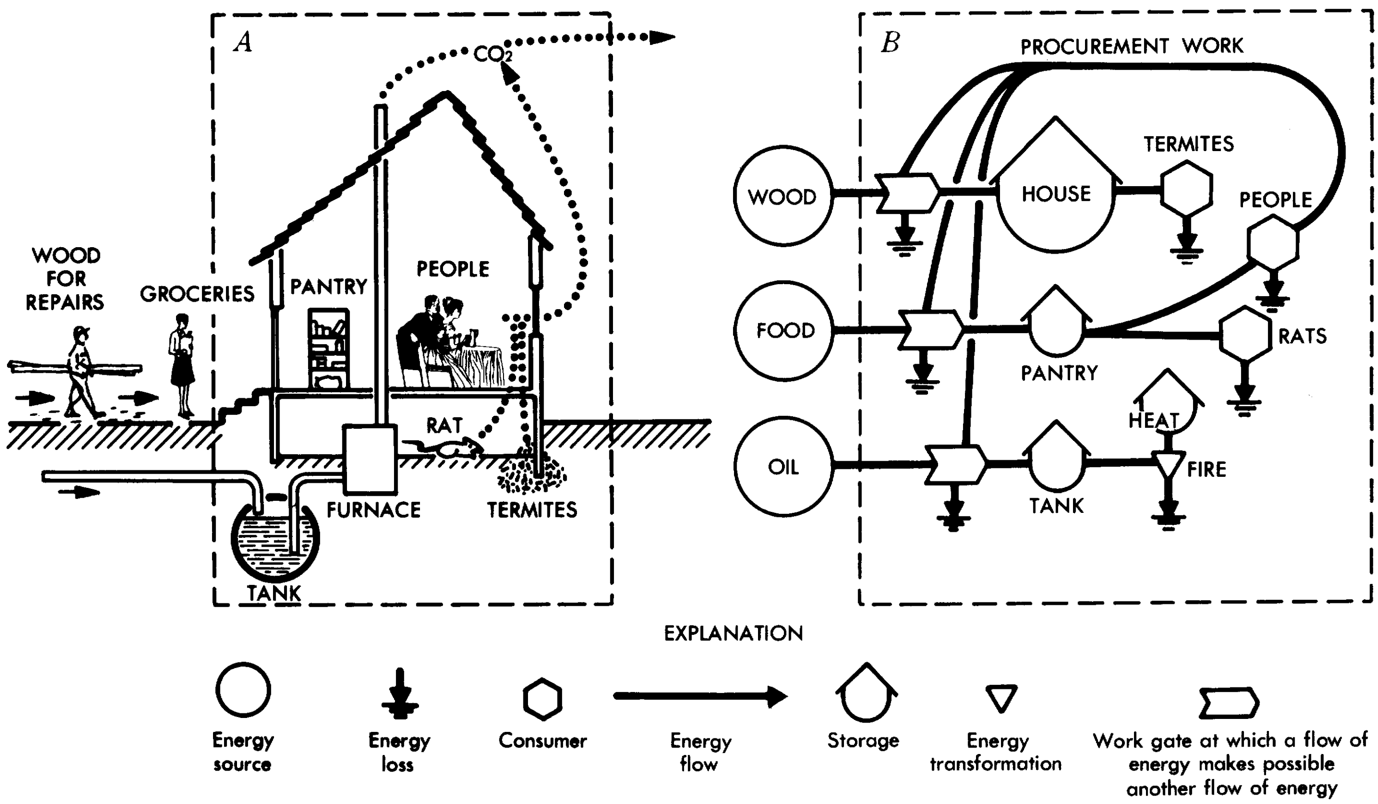

FIGURE 27.—Diagrammatic illustrations of energy flow.

6. Predictions can be applied to resource management in an effort to aid decisionmakers in the planning process.

Using this approach, systems ecology incorporates the use of diagrams of systems in an "energy language" where the component parts of the system are connected by lines that represent the flow of potential energy from one energy storage compartment in the system to another. This conceptual model can be made large or small, depending upon the particular system, but always the view taken is large enough to include all important features of the system, including the driving functions from outside the system.[2]

As systems are studied, and as the energy sources and pathways are drawn into a model, the whole becomes greater than the sum of its parts. This is because the whole system includes not only the parts but the interaction between the parts. An analogy is a box of parts needed to assemble a tricycle. When the pedals are attached to the wheels, then both pedal and wheel bear a functional relationship that did not exist in the unconnected box of parts. The same is true for ecosystems. The parts are intricately related, and changes in one part frequently produce unsuspected changes in others. Systems ecology strives to identify these important interactions and allows an investigation into them by the use of the computer simulation.

By using systems ecology in south Florida, data needs have been illuminated, south Florida systems have been studied, and recommendations for future resource management have been generated based on the energy denominator.[3]

[2] Lugo and others, op. cit.
[3] Brown, Mark, and Genova, Grant, 1974, Energy indices in the urban pattern: Gainesville, Fla., Univ. of Florida Center for Wetlands.

II.—Scientific names of plants and animals mentioned in report

PLANTS

Common Name	Scientific Name
arrowhead	*Sagittaria lancifolia*
Australian pine	*Casuarina* spp.
baycedar	*Suriana maritima*
beachberry	*Scaevola plumieri*
beakrush	*Rhynchospora tracyi*
beardgrass	*Andropogon* spp.
black mangrove	*Avicennia germinans*
black rush	*Juncus roemerianus*
bladderwort	*Utricularia* spp.
Brazilian pepper	*Schinus terebinthfolius*
bustic	*Dipholis salicifolia*
buttonwood	*Conocarpus erecta*
cabbage palm	*Sabal palmetto*
cajeput	*Melaleuca quinquenervia*
carpetgrass	*Axonopus* spp.
cattail	*Typha* spp.
coco plum	*Chrysobalanus icaco*
cypress	*Taxodium* spp.
coontie	*Zamia pumila*
cordgrass	*Spartina* spp.
dahoon	*Ilex cassine*
duckweed	*Lemna* spp.
fire flag	*Thalia geniculata*
fringe rush	*Fimbristylis castanea*
gallberry	*Ilex glabra*
glasswort	*Salicornia perennis*
gumbo limbo	*Bursera simaruba*
holly	*Ilex* spp.
hydrilla	*Hydrilla verticillata*
live oak	*Quercus virginiana*
laurel oak	*Quercus laurifolia*
maidencane	*Panicum hemitomon*
manateegrass	*Syringodium filiformis*
marlberry	*Ardisia escallonioides*
myrsine	*Myrsine guianensis*
niads	*Najas* sp.
panicgrass	*Panicum* sp.
paurotis palm	*Paurotis wrightii*
pickerelweed	*Pontederia lanceolata*
pigeon plum	*Coccoloba diversifolia*
pine	*Pinus* sp.
poisonwood	*Metopium toxiferum*
pond-apple	*Annona glabra*
pop ash	*Fraxinus caroliniana*
railroadvine	*Ipomoea pes-caprae*
redbay	*Persea borbonia*
red mangrove	*Rhizophora mangle*
red maple	*Acer rubrum*

Plants—Continued

Common Name	Scientific Name
rosemary bushes	*Ceratiola ericoides*
running oak	*Quercus pumila*
rusty lyonia	*Lyonia ferruginea*
saltwort	*Batis maritima*
samphire	*Philoxerus vermicularis*
sand pine	*Pinus clausa*
sand spurs	*Cenchrus* sp.
satinleaf	*Chrysophyllum oliviforme*
sawgrass	*Cladium jamaicensis*
saw palmetto	*Serenoa repens*
sea blite	*Suaeda linearis*
sea daisy	*Borrichia frutescens*
seagrape	*Coccoloba uvifera*
sea purslane	*Sesuvium portulacastrum*
sea-lavender	*Tournefortia gnaphalodes*
sea oats	*Uniola paniculata*
shiny blueberry	*Vaccinium myrsinites*
silver palm	*Coccothrinax argentata*
slash pine	*Pinus elliottii*
spikerush	*Eleocharis cellulosa*
staggerbush	*Lyonia fruticosa*
strangler fig	*Ficus aurea*
sweetbay	*Magnolia virginiana*
tetrazygia	*Tetrazygia bicolor*
turtlegrass	*Thalassia testudinum*
varnishleaf	*Dodonaea viscosa*
water dropwort	*Oxypolis filiformis*
waterhemp	*Amaranthus cannabinus*
water hyacinth	*Eichhornia crassipes*
waterlettuce	*Pistia stratiotes*
water rush	*Rhynchospora inundata*
wax myrtle	*Myrica cerifera*
white mangrove	*Laguncularia racemosa*
wild coffee	*Psychotria undata*
wild tamarind	*Lysiloma latisiliqua*
willow	*Salix caroliniana*
wiregrass	*Aristida* spp.

Animals

Invertebrates

Common Name	Scientific Name
black-spined sea urchin	*Diadema antillarum*
blue crab	*Callinectes sapidus*
brain coral	*Maeandra* spp.
crab spider	Thomisidae
cobweb weavers	Theridiidae
commercial shrimp	*Penaeus* spp.
crayfish	*Procambarus* sp.
freshwater prawn	*Palaemonetes paludosus*
honeycomb worms	Sabellariidae
jumping spiders	Salticidae
lobster	*Panulirus argus*

Animals—Continued

Invertebrates—Continued

Common Name	Scientific Name
orb weavers	Arancdae
oysters	*Crassostrea virginica*
pink shrimp	*Penaeus* spp.
staghorn coral	*Acropora* spp.
star coral	*Montastrea annularis*
stone crab	*Menippe mercenaria*

Fish

Common Name	Scientific Name
catfish	*Ictalurus* spp.
dolphin	*Coryphaena hippurus*
gar	*Lepisosteus platyrhincus*
gray snapper	*Lutjanus griseus*
grouper	*Mycteroperca* spp.
grunt	*Haemulon* spp.
pike killifish	*Belonesox belizarus*
flag fish	*Jordanella floridae*
Florida pompano	*Trachinotus* sp.
largemouth bass	*Micropterus salmoides*
least killifish	*Heterandria formosa*
mackerel	*Scomberomorus* spp.
mosquito fish	*Gambusia affinis*
mudfish	*Amia calva*
mullet	*Mugil* spp.
red drum (channel bass)	*Sciaenops ocellatus*
red snapper	*Lutjanus* spp.
sailfin molly	*Poecilia latipinna*
sea trout	*Cynoscion* spp.
sheepshead minnow	*Cyprinodon variegatus*
snook	*Centropomus* spp.
spanish mackerel	*Scomberomorus maculatus*
sunfish	*Lepomis* spp.
tarpon	*Tarpon atlanticus*
walking catfish	*Clarias batrachus*

Amphibians

Common Name	Scientific Name
Cuban tree frog	*Hyla septentrionalis*
marine toad	*Bufo marinus*

Reptiles

Common Name	Scientific Name
alligator	*Alligator mississippiensis*
Florida pine snake	*Pituophis melanoleucas mugitus*
indigo snake	*Drymarchon corais couperi*

Animals—Continued

Reptiles—Continued

Common Name	Scientific Name
knight anole	*Anolis equestris equestris*
snapping turtle	*Chelydra serpentina*
soft-shelled turtle	*Trionyx ferox*
water snakes	*Natrix* spp.

Birds

Common Name	Scientific Name
anhinga	*Anhinga anhinga*
Audubon's caracara	*Polyborus cheriway audubonii*
blue heron	*Ardea herodias*
bobwhite quail	*Colinis virginianus*
coot	*Fulica americana*
Florida burrowing owl	*Speotyto cunicularia floridana*
Florida duck	*Anas platyrhynchos fulvigula*
Florida grasshopper sparrow	*Ammodramus savannarum floridanus*
green heron	*Butorides virescens*
great egret	*Casmerodius albus*
kingfisher	*Megaceryle alcyon*
Louisiana heron	*Hydranassa tricolor*
mourning dove	*Zenaidura macroura carolenensis*
southern bald eagle	*Haliaeetus leucocephalus leucocephalus*
southern red-cockaded woodpecker	*Dendrocopus borealis*
turkey	*Meleagris gallopavo*
wood duck	*Aix sponsa*
wood ibis	*Mycteria americana*

Mammals

Common Name	Scientific Name
armadillo	*Dasypus novemcinctus*
bear	*Ursus americanus*
coastal dolphin	*Tursiops* sp.
deer	*Odocoileus virginianus*
opossum	*Didelphis virginiana*
otter	*Lontra canadensis*
panther	*Felis concolor*
racoon	*Procyon lotor*
squirrel	*Sciurus* spp.

U.S. DEPARTMENT OF THE INTERIOR

Thomas S. Kleppe, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

International System (SI) and English Equivalents

International System Units (SI)		*English Equivalent Units*
millimetre (mm)	=	0.039 inch (in)
centimetre (cm)	=	0.39 inch (in)
metres (m)	=	3.28 feet (ft)
kilometre (km)	=	0.62 mile (mi)
hectare (ha)	=	2.47 acres
square kilometre (km^2)	=	0.386 square mile (mi^2)
cubic metre per second (m^3/s)	=	35.3 cubic feet per second (ft^3/s)
cubic metre per day (m^3/day)	=	264.2 gallons per day (gal/day)
kilogram (kg)	=	2.2 pounds (lb)
degrees Celsius (°C) (temperature)	=	[(1.8 × °C) + 32] degrees Fahrenheit (°F)

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