Wetlands and Wildlife, the Everglades Perspective

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Abstract: The Everglades is a vast wetland that historically covered 10,000 km^2 in southern Florida. A strongly seasonal rainfall regime results in a seasonal fluctuation of surface water levels. Recent studies have demonstrated how plant and animal populations are dependent on this seasonal hydrology and how because of their dependence, populations and communities have been adversely affected by changes in the ecosystem over the past 50 years. Changes are of two types: loss of marsh owing to drainage, accounting for reduction of 65% of the marsh area; and alteration of the hydrology in remnant marshes. Loss of marsh area has adversely affected most characteristic plant and animal populations. The more subtle hydrologic changes have adversely affected some species and positively affected others, in some cases partially compensating for area losses. Most of the remaining Everglades is encompassed in five shallow reservoirs, only the downstream tail being within Everglades National Park. Water management procedures have changed the pattern of water level fluctuation in various parts of the Everglades, particularly affecting plants and such aquatic animals as wood storks, alligators, and fishes. In the core Everglades of Everglades National Park, unseasonable surface water discharge has resulted in higher-than-historic dry season water levels and unpredictable high water flows. Loss of marsh area, changes in system function, and necessity of using the Everglades for human services constrains management options. Most of the Everglades must be actively managed by structural and semistructural means for water supply and flood control as well as to supply appropriate surface water discharges to the downstream natural area zone in Everglades National Park. Hydrologic change has led to impacts that are as drastic, if more subtle, than those due to drainage. Nonetheless, conservation of the still vast Everglades is possible but requires active manipulative management for specified goals that must differ in the several management zones.

FRESHWATER WETLANDS AND WILDLIFE, 1989, CONF-8603101, DOE Symposium Series No. 61, R. R. Sharitz and J. W. Gibbons (Eds.), USDOE Office of Scientific and Technical Information, Oak Ridge, Tennessee.

INTRODUCTION

The Everglades, probably the best known and most publicly appreciated North American wetland, historically occupied much of the southern third of the well-watered Florida peninsula (Fig. 1), which juts past the warming waters of the Gulf Stream toward the tropics (Kushlan, 1988). In the past, the Everglades was ecologically integrated during its annual rainy season by the slow flow of water over its land surface. This flow has been interrupted by levees and canals and is controlled by political and management decisions superimposed on the natural ecosystem.

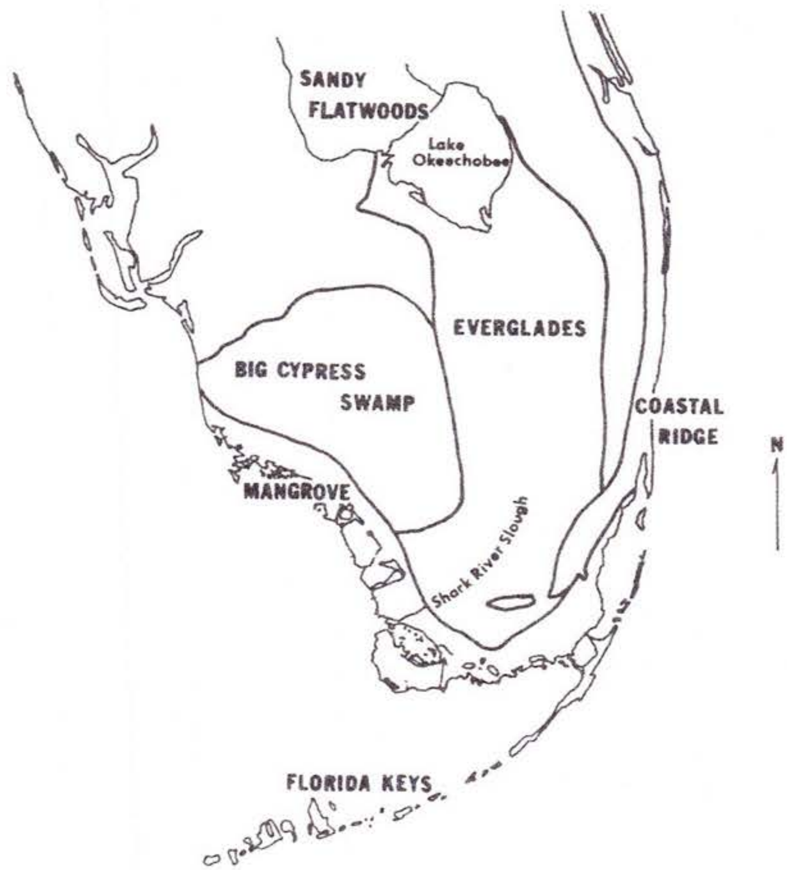

Fig. 1 Natural features of southern Florida.

In this paper, I discuss the current status of and prognosis for the Everglades in the hope that this perspective may be of some value in wetland conservation and management elsewhere. I begin by discussing briefly the ecological relationships that constrain management, aspects of which are covered in more detail elsewhere in this volume (Kushlan). I then describe the history of alteration and the current situation with respect to the interrelationships of biology and management.

A PRECIS ON EVERGLADES ECOLOGY

Historically the 10,000 km^2 of the Everglades wetlands occupied an elongated basin 65 km wide and 160 km long extending from Lake Okeechobee to the southwestern edge of the Florida peninsula (Fig. 1). To the north, the Everglades headed in intermittent high water outflow from the lake, although most water in the Everglades was derived from in situ rainfall. Peat deposits and thick emergent vegetation inhibited flow except at high water levels. Under flow conditions, water moved across the ground surface following a shallow gradient of 3.6 cm/km (Parker et al., 1955). High-water depths were about 0.33 to 0.66 m. At these conditions, water was exchanged with the slightly more elevated Big Cypress Swamp to the west, with higher marshes to the east (from which it passed through and under a limestone and sand ridge along the east coast), and with the Taylor Slough, a predominant southward drainage feature. Elsewhere, little water moved southward under usual conditions because of natural levees inland of the southern coastal mangrove swamps. At its southwestern outflow, Everglades water moved through an estuarine mangrove swamp via a network of streams that quickly coalesce into several short rivers exiting into the Gulf of Mexico. Because of the shallow and leaky berms of the Everglades basin, high water levels seldom exceeded the norms, and then for only short periods following hurricanes.

Precipitation is highly seasonal with an average of 75% of the annual rainfall occurring in the summer and fall (Fig. 2). The wet-dry rainfall cycle causes a seasonal fluctuation of surface water that plays a dominant role in the ecology of the Everglades. At the beginning of the rainy season in late May or June, a rapid increase in water depths begins that peaks in autumn. Water levels fall in late winter and spring to a low point in May. Throughout normal dry seasons the peat soil remains damp, but standing surface water is absent from all but the deeper sloughs and ponds for a period of weeks or months depending on elevation. Several types of Everglades marsh communities have annual inundation periods of 5 to 10 months (Schomer and Drew, 1982). Marsh organisms must be able to cope with alternating flood and drought, processes that along with fire (Wade et al., 1980), are the dominating forces in fluctuating water wetlands (Kushlan, this volume).

Sawgrass marsh is the predominant plant community in the Everglades, once covering 800,000 ha (Stephens, 1974) and accounting for about 70% of the remaining Everglades (Loveless, 1959a). Sawgrass *(Cladium jamaicense)* is particularly adapted to fluctuating water conditions. It grows on sites inundated for less than 80% of the time and dies out under conditions of prolonged flooding. On the other hand, sawgrass can withstand short-term submergence of its leaves for as many as 6 weeks. Thus while it can withstand flooding, it requires periodic dry conditions. Without such dry periods, there would be no sawgrass marsh in the Everglades.

Inundation depths and duration (hydroperiod) are correlated with the occurrence of various plants and their recognizable communities, which often can be found to vary along hydrologic gradients (Loveless, 1959a; Pesnell and Brown, 1977). Most marsh plants can neither germinate nor survive as seedlings under water, and most adult aquatic plants cannot long survive complete exposure and drying of the soil. The dynamics of plant community

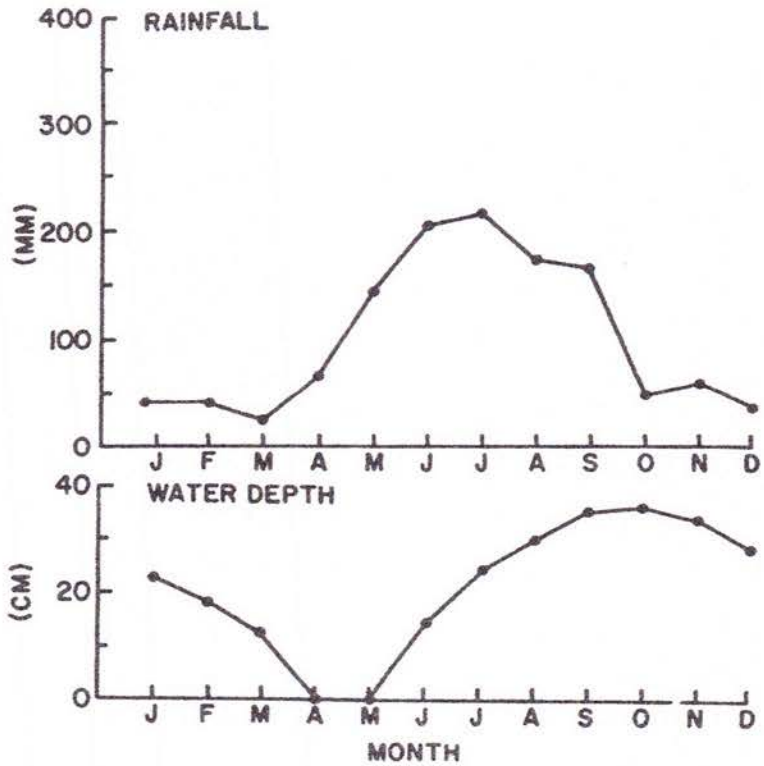

Fig. 2 Average rainfall and water level fluctuations in the Everglades (source: NOAA and U. S. Geological Survey).

development involve a seasonal fluctuation between inundation for most of the year and short-term exposure in the dry season.

However, because the inundation tolerances of various species broadly overlap, the occurrence of recognizable plant associations at a specific site also reflects the site-specific history of disturbance (especially by fire), patterns of initial colonization, and competitive relationships. Maidencane *(Panicum hemitomon)*, for example, grows in water inundated for relatively long periods, 78% or more of the time, overlapping the requirements of sawgrass. Such deeper water species can colonize exposed soil better than can the slow-spreading sawgrass. Once established, however, the taller sawgrass can overtop the maidencane. Sawgrass also has a competitive advantage because of its low nutrient requirements (Steward and Ornes, 1975), a principal reason for its dominance of Everglades vegetation. Under conditions of nutrient enrichment, cattail (*Typha* spp.) outcompetes sawgrass. Thus vegetational shifts within the Everglades may be due to several interacting factors and are reflective of dynamic vegetative mosaic.

Water level fluctuations also affect the periphyton community that covers nearly all of the substrate and floating plants in the open Everglades marsh. A large portion of the carbon and oxygen production is due to the algal components of this community (Browder, 1982; Swift, 1984). Long hydroperiods favor the dominance of desmids and diatoms whereas shorter hydroperiods favor a periphyton dominated by blue-green algae, which are less favored as food by higher organisms.

Recent studies have demonstrated the dominating role of fluctuating water levels in the ecology of the characteristic animal populations of the Everglades (Loveless, 1959b; Kahl, 1964; Kushlan, 1974a, 1974b, 1975, 1976a, 1976b, 1976c, 1977, 1979a, 1980, 1986a, 1986b, 1987; Kushlan and Kushlan, 1979, 1980; Kushlan and Frohring, 1986; Kushlan and Jacobsen, in preparation; Kushlan et al., 1975; Schortemeyer, 1980; Dineen, 1984; Sykes, 1979, 1983a, 1983b, 1984). It is worthwhile to review some of these findings.

The composition, abundance, and degree of concentration of the Everglades fish community depends on the annual pattern of water depth fluctuation (Kushlan and Lodge, 1974; Kushlan, 1976a, 1980; Dineen, 1984; Loftus and Kushlan, 1988). The fish community averages about ten fish per square meter in the relatively deep water of the core Everglades and fewer in marshes of shorter hydroperiod. Under the usual fluctuating conditions, the fish community in the marsh is dominated numerically by small fishes, especially the mosquitofish *(Gambusia affinis)* which can account for 60% of the fishes present. Larger fishes, such as sunfish, gar, and bullheads, are rare in the fluctuating marsh but occur in deeper water especially in ponds and deep water lily marshes. Under typically fluctuating conditions, the larger fishes suffer high mortality as the marshes dry, but both they and smaller species persist in the ponds and adjacent deep marshes and are able to repopulate the marsh following a dry period. Densities are restored in the marsh within a few months of inundation. There is no evidence of long-distance movements by fishes, and recolonization appears to be a localized phenomenon. Growth and maturity occur rapidly with some species reproducing within 1 month (Haake and Dean, 1983) and so may produce as many as 5 to 10 generations per wet season. The fish community is dynamic and requires only one skipped dry season for the community to change from one dominated by small species to one more characteristic of permanently flooded lake-like conditions. Conversely, a single dry season resets the community.

The degree of concentration of aquatic organisms is critical to predator populations. The number of fish per square meter is inversely related to water depth as water levels decrease seasonally. When water levels fall, standing surface water becomes shallower, affecting initially the higher elevations in the marsh. As these begin to dry, some of the fishes and other mobile aquatic organisms concentrate in the remaining pools. Maximum fish density occurs in the marsh when water reaches a depth of 25 to 30 cm. Thereafter density decreases until the marsh dries completely. Fishes simultaneously become concentrated in the deeper water ponds within the marsh. Reduction of fish populations by predatory activities, especially of birds, can increase the probability that the remaining fish can survive through the dry season. Some aquatic organisms, notably crayfish *(Procambarus alleni)*, do not concentrate but rather burrow in the marsh as waters recede.

The reproductive cycles of certain birds allow them to take advantage of the abundant patches of food available in the marsh and its ponds to obtain food for young. In some species the relationships between water level fluctuations and nesting biology are crucial to nesting success (Kahl, 1964; Kushlan, 1976c, 1977, 1979a, 1986b, this volume; Kushlan et al., 1975). The wood stork *(Mycteria americana)* depends on a specific rate of falling water, which concentrates the fishes and thus provides a food source so the storks can initiate and successfully complete nesting. The white ibis *(Eudocimus albus)* chooses to nest near drying marsh patches where its food, crayfish and aquatic insects, is available. In the latter case, the falling water depths open foraging areas but do not concentrate the prey.

The snail kite *(Rostrhamus sociabilis)* (Sykes, 1983a, 1983b, 1984) and the Cape Sable seaside sparrow *(Ammodramus maritimus)* (Werner and Woolfenden, 1983; Kushlan and Bass, 1983) exemplify converse relationships to water depths. The snail kite depends almost entirely on a single species of aquatic snail *(Pomacea paludosa)*, which achieves its highest populations in deeper water ponds and marshes (Kushlan, 1975). The nomadic kites found such scattered patches of snails by moving among marshes and lake edges throughout the state using those that had remained flooded for some period. The sparrow occupies higher marshes along the edge of the Everglades characterized by relatively short hydroperiods and recurrent fire.

The American alligator *(Alligator mississippiensis)* (Kushlan, 1974a; Kushlan and Jacobsen, in preparation; Jacobsen and Kushlan, 1986) may be considered the dominant animal in the Everglades. The primary alligator habitat in southern Florida is the central core Everglades marsh. Alligators also occurred in lesser numbers in higher marshes and in mangrove swamps but only seasonally in the latter since they cannot tolerate saline water. The nesting success of the alligator in the Everglades depends on the pattern of water level fluctuation during the wet season. The alligator places its eggs in a mound constructed from available marsh vegetation at the beginning of the rainy season. Development takes place as water levels rise, which may put the eggs at risk to flooding. However, the height at which the eggs are positioned above the marsh bottom depends on water levels at the time of nesting. The water levels at the time of nest construction have a statistically predictable relationship with the maximum water levels later in the wet season, which cause nest flooding. Thus the alligator relies on the predictability of the pattern of water level rises during the Everglades wet season.

Deer *(Odocoileus virginianus)* that occur in the Everglades are distinguished by their small size and aquatic habits (Loveless, 1959b). They wade through water that can be shoulder deep to obtain forage, particularly water lilies, various emergent herbaceous plants, and woody swamp plants, especially willows. They require higher exposed ground when not foraging and for fawning.

Water flow through the Everglades marsh also has important effects in the downstream estuary (Odum et al., 1982). Recent studies have demonstrated that high discharge into the estuary during the fall period of high water levels is correlated with estuarine functioning. Browder (1985) found that the amount of water during the rainy season in the lower Everglades correlated with shrimp harvest, presumably owing to enhanced production and survival in the estuaries. Thayer et al. (1987) found that spawning, density, and biomass standing stock of fishes in the mangroves were maximum in fall during the period of historically high water flows. Conversely, Browder found that dry season discharge is not positively correlated with shrimp harvest.

In summary, the Everglades is a shallow marshland characterized by seasonal fluctuation of water levels leading to a dry season of weeks to months in extent depending on marsh elevation. In any segment of the Everglades marsh, the extent and timing of water level fluctuation depend on two factors: local rainfall and surface water inflow from higher areas. Water depths are restricted by rapid overspill of the basin during periods of exceptional rainfall. At lower stages, surface water moves through the shallow marsh very slowly because it is blocked by the dense plant stands. Aquatic plants depend on periodic exposure for establishment; and sawgrass marsh, the most widespread plant community, has a 10-month period of inundation. Competitive relationships among plants involve hydrological conditions in combination with nutrients levels and disturbance history. Animal species have varying adaptations to patterns of water-level fluctuation; most of the characteristic species require seasonal dry periods. The nomadic kite requires prolonged inundation. The downstream estuary appears to depend on high wet season inflows from the marsh.

HISTORIC CHANGES AND PRESENT CONDITIONS

Thirty percent of the land area of Florida was once covered by wetlands. Reclamation began in southern Florida in the late 1800s at Lake Okeechobee and along the coasts (Blake, 1980), but these early efforts had little effect on the core of the Everglades marsh. Canal building in the Everglades began in 1907 and continued for the next 2 decades. Four canals were dug in the Everglades, and Lake Okeechobee was surrounded by levees. Although these canals penetrated well inland, they were too shallow to affect significantly the interior marsh. After the collapse in 1928 of the drainage district responsible for its construction, the existing drainage system deteriorated further. The limited effect of these canals on floodwaters led to the establishment of another water control district in 1949, which began the process of dyking and isolating the virtually undrainable core Everglades marsh from reclaimed lands to the north and east, a process that was not completed until 1967. Thus effective management of Everglades water is a recent phenomenon of the past 20 years.

The present alteration of the Everglades marsh may be attributed to two related factors. The fundamental cause of its ecological degradation was dewatering of a substantial portion of its more elevated periphery and northern reaches. A second factor was alteration of the natural patterns of water level fluctuations in the remaining marsh.

With respect to drainage, by the 1980s 65% of the original Everglades marsh had been irretrievably drained, mostly for agricultural development. Because the northern reaches of the Everglades served as a flow-way only during high water levels, its loss probably did not greatly affect water conditions in core Everglades marshes much further south. Additional land was reclaimed east of the Everglades, between the central core of the basin and higher ground along the coast. This represented a loss primarily of wet prairie and sparse sawgrass marshes. Over 80% of these marshes has been drained in one area (Birnhak and Crowder, 1974).

Superimposed upon the loss of higher marshes are flood control and water supply management within the remaining marsh. Much of the change in the remnant core Everglades marsh can be attributed to its use for water storage and the periodic release of water for flood control. This has been accomplished by the enclosure of all but the southern tail of the core Everglades in shallow reservoirs called water conservation areas (Fig. 3). One of these, Conservation Area 1, is managed as the Loxahatchee National Wildlife Refuge; the others are managed by local and state agencies. The southernmost compartments are Everglades National Park, including only 6% of the original Everglades marsh, and the adjacent undeveloped high marsh to the east, recently named the East Everglades. The water conservation areas are intended to provide flood control for the developed east coast, supply municipal and agricultural water requirements, prevent the intrusion of salt water into the aquifer, supply water to the southern Everglades, and conserve fish and wildlife habitat in the conservation areas. Presently about 3500 km^2 of Everglades marsh is encompassed by the five interconnecting water conservation area pools holding a maximum regulation storage of over 1,600,000 acre-feet of water.

As late as the early 1960s, the flow of surface water in the core remnant Everglades was relatively unimpeded. But enclosure caused substantial changes in water patterns. The eastern (north-south) levees of the water conservation areas, for example, blocked the typical overflow of water eastward, thereby increasing the amount of water in the remaining Everglades marsh and directing it southward (Leach et al., 1972). The western (north-south) levees of Conservation Area 3 kept Everglades water from flowing southwestward into the southern Big Cypress Swamp during high water periods. Transverse (east-west) levees interrupted southward-flowing water, which piled up deeply flooding the marsh in the southern ends of the conservation areas. Conversely, surface water flowed off the higher ground in the northern ends of the water conservation areas leaving them drier than normal. All of these factors contributed to the current situation in which as much or more water than would naturally be the case is confined to a substantially reduced marsh area, from which outflow is possible only by groundwater infiltration and by discharge south into Everglades National Park.

The southern transverse levees also caused considerable disruption of the natural southward flow of water into Everglades National Park. The eastern segment of surface flow, comprising a majority of flow under most water conditions, was completely blocked. The western segment of surface flow, immediately north of the park, also was blocked by closure of the newly installed gated structures in late 1962. These remained closed for 2 years except for a few short politically inspired openings. However, in 1970 federal law guaranteed that certain amounts of water would be delivered to Everglades National Park in flows that, at minimum, were to approximate median monthly amounts as extracted from available historic records. The National Park Service agreed to accept any additional water that might be available. The result was that extra water was discharged into the park whenever upstream stages exceeded regulation flood conditions for the reservoirs. Thus the immediate water flows that would have been triggered by rainfall events were delayed until appropriate for water management purposes in the water conservation areas.

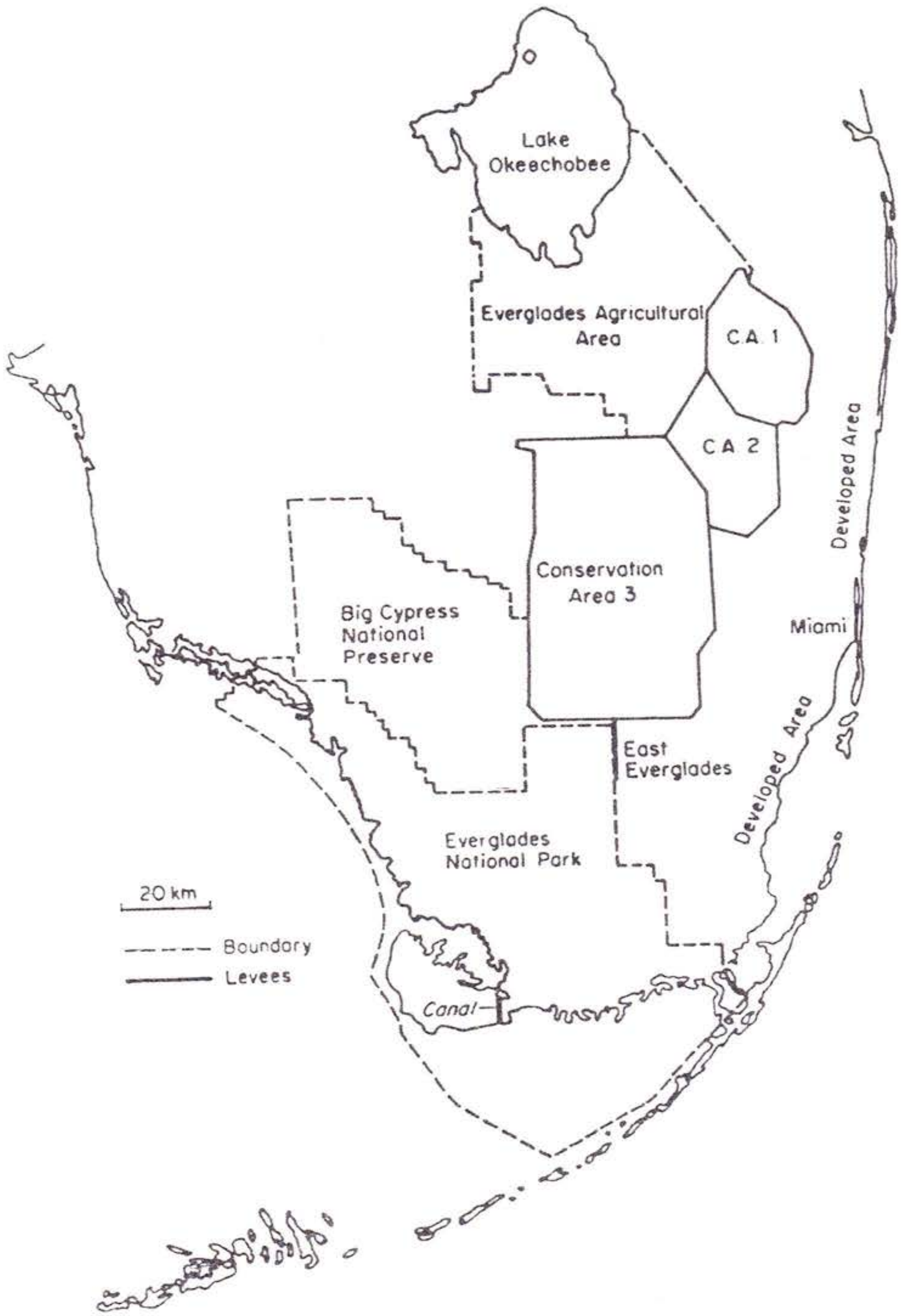

Fig. 3 Political features of southern Florida.

A naturally dry year in 1971 served to reinforce the public misconception that the Everglades was threatened by man-caused droughts (Ward, 1972), rather than by the actual condition of unseasonal flooding. In fact, no drought-related effects are noticeable in the core of the southern Everglades of Everglades National Park since institution of the water delivery schedule. The excess water in the now-reduced Everglades and its unnaturally timed release has led to changes in the patterns of water level fluctuation both north and south of the transverse levees, resulting in the extensive system disruptions documented in the Everglades in the past 20 years. Along the higher marshland peripheral to the core Everglades, drainage has decreased the hydroperiod since the institution of water management in 1968. Thus parts of the Everglades are overly flooded and others are drier than natural conditions.

Recent studies have documented how alteration of water levels has markedly affected plant communities. In the flooded southern parts of the water conservation areas, sawgrass marsh and higher tree island communities were replaced by deeper water habitats such as water lily sloughs (McPherson, 1973). Certain plant species nearly disappeared owing to extended hydroperiods in the Conservation Area 2 marsh (Worth, 1983). The upstream part of these same areas experienced losses of marsh vegetation to shrubby swamp trees accompanied by deep burning fires as hydroperiods were decreased. In the southern Everglades, changes were more subtle. From 1940 to the mid-1960s, the area covered by sawgrass marsh increased at the expense of spikerush flag marsh while at the same time inundation periods of both communities increased (Kolipinski and Higer, 1969).

Water management has altered water quality in the Everglades (Klein et al., 1975; Waller, 1982). Waters in Conservation Area 2, for example, have increased in mineral content because 57% of the surface water in the interior marsh is derived from canal inflow that has been mineralized by contact with the limestone bedrock (Waller, 1982). The ionic composition of waters flowing into the southern Everglades has similarly been altered by canal deliveries of water and sediment affected by agricultural runoff. Chloride, sodium, magnesium, color, and iron have increased since 1959 (Waller, 1982), resulting in a change in conductivity extending the length of the core southern Everglades marsh (Flora and Rosendahl, 1982).

Under natural conditions most of the nutrients of the Everglades were derived from rainfall rather than from upland runoff or bedrock, and even under current conditions 78% of the nitrogen and 90% of the phosphorus entering the conservation areas are from rainfall, and 74% and 96%, respectively, are retained within the marsh (Waller, 1975). Additional nutrient-loaded water can enter the Everglades, owing to agricultural drainage, in excess of what occurred naturally. Although sawgrass has low nutrient requirements and can accumulate phosphorus in concentrations beyond its requirements (Alexander, 1971), there is a limit to the capacity of sawgrass and periphyton communities to take up the additional nutrients, which are then passed through in surface flow (Steward and Ornes, 1975; Davis, in preparation; Swift and Nicholas, in preparation). The result of nutrient enrichment is a shift in the emergent community from sawgrass to cattail and a shift from a diatom-desmid dominated periphyton to a blue-green algae dominated periphyton and eventually under lowered oxygen conditions a reducing bacterial epiphytic community. Such changes have occurred near water inflows and canals in the water conservation areas and to a lesser extent in the southern Everglades.

Effects on the fish community have been geographically and temporally variable because of its resiliency and exceedingly fast turnover. There is no evidence that fish populations have decreased in the core Everglades where fish abundance and composition depend on time since the previous dry season (Kushlan, 1976a). The normal fish community of the Everglades, dominated by small species, requires the maintenance of seasonally fluctuating water conditions. Where high water conditions are stabilized, substantial changes occur, altering the fish community to one that resembles a lake community dominated by large predatory fishes (Kushlan, 1976a).

There is no simple relationship between overall fish abundance and bird predation in that the total size of the fish population poses no limit to supporting wading bird populations. However, seasonal concentration and presentation of these prey by falling water levels are required to make them available to the birds. Even the wood stork, which consumes the largest fish, eats prey that average only 3.5 cm long, a size attainable within a single growing season. Thus rapid growth and fast turnover mean that Everglades fishes represent annual crops that reflect current and immediately antecedent water conditions in the nearby area.

Maintenance of high water levels and slow recession rates in the Everglades has adversely affected several species of wading birds, particularly the wood stork. This species has experienced repeated nesting failure over the past 20 years because of excessive seasonal flooding of its feeding marshes. As a result, the southern Everglades wood stork population has decreased by 75% from 1967 to 1982 (Kushlan and Frohring, 1986). We have no evidence of a substantial decrease of wood storks or of other wading birds in southern Florida prior to the recent period of water management. Nonetheless, the decrease in the wood stork population may be directly attributable to failure of the marsh to dry appropriately.

Other species of herons and ibises now nest in extremely small numbers or not at all in the southern Everglades of Everglades National Park. Each of these species has differing water depth and prey requirements that apparently are not being satisfied under the present water management system. The white ibis, for example, a nomadic species that once was the most abundant species of wading bird, consumes crayfish and depends only on the marsh drying to a specific water depth for effective foraging. That this species has in large part abandoned the southern Everglades further suggests the inadequacy of the drying conditions rather than an inadequacy in the food base per se.

Sykes (1979, 1983a, 1983b, 1984) demonstrated that past decreases in the Florida population of the snail kite were the result of drainage projects that destroyed much of its marsh habitat throughout Florida and were also the result of modifications of the wetlands that remained. Under natural conditions within the broad expanse and scattered distribution of Florida's marshes, the kite in most years located marshes suitable for foraging sites. Recent management of the core Everglades and Lake Okeechobee, which provided long-term high water levels, has benefited the kite population which has increased over the past 20 years. The stabilization of some of the Everglades marshes therefore compensated for the loss of habitat elsewhere in Florida.

Drainage of peripheral marshes has had salutary effects on some marsh species that prefer drier marshes. One of these is the Cape Sable seaside sparrow. Reduced water levels in the Taylor Slough headwaters and the consequent encroachment of muhly marsh into the area has led to an increase in the species (Kushlan and Bass, 1983). Thus the sparrow has benefited from the reduction of water tables along the Everglades periphery outside of the core Everglades.

Much publicity has attended the periodic mortality of deer caused by high waters in the Everglades. Particularly noted has been the causal role of water management in the water conservation areas. The herds have built up in the drier northern ends of the conservation areas but succumbed when those areas reflood. The die-off appears to be due ultimately to declining condition because of the lack of required dry ground rather than a lack of food, which remains present in the marshes in abundance.

There is no evidence of a decrease of alligator numbers from historic levels in the southern Everglades. However, in local areas of extended hydroperiods, such as the southern end of Conservation Area 3, populations have decreased due to reduced nesting effort and success. The relationship between alligator nesting success and water levels in the wet season requires predictable fluctuations of water levels during the early wet season (Jacobsen and Kushlan, in preparation). We have found that the hydrological predictability disappeared in the southern Everglades during the current period of water management. As a result the flooding of alligator eggs in the southern Everglades has increased fivefold during this time period.

In summary, reclamation of higher elevation Everglades marshes and construction of levees around most of the remaining marsh have led to substantial disruption of the Everglades ecosystem. Water quality has decreased because of nutrient loading and short-circuiting of marsh renovation, which has altered plant and periphyton communities. In the water conservation areas, hydroperiods have decreased in the upstream ends, leading to vegetation shifts and fires, and have lengthened in the southern ends, leading to replacement of sawgrass marsh by deeper water communities. In the southern Everglades, drainage of peripheral marshes has decreased hydroperiods, which has benefited high ground species. Within the central core of the marsh in Everglades National Park, seasonally excess discharge has resulted in failure of the normal drying conditions and subsequent failure of bird nesting. These long-term failures have resulted in population decreases and shifts. In the wet season, unpredictable discharges have caused higher mortality of alligator nests. Thus the drainage of peripheral wetlands and the inappropriate maintenance of seasonally high water levels in the remnant marsh have been the cause of system disruptions under the current regime of water management.

FUTURE PERSPECTIVES

The hydrological and biological effects of drainage and water management are indicative of fundamental disruptions to the natural functioning of the Everglades ecosystem. To some extent the species and communities discussed above can serve as indicators of natural ecosystem function. One can be assured that additional, unstudied system components are also being adversely affected. The insidious alteration of population sizes and ecological relationships has resulted in substantial, although undocumented, changes in the pathways and control of energy flow throughout the ecosystem.

It is likely that most of the changes are irreversible. Reclaimed wetland area cannot be restored, and most of the remnant marsh is required for flood control and water management in support of the human population of southern Florida. With regard to natural functioning, all that is possible is to attempt to provide active management in the single natural zone, Everglades National Park. At best this would result only in an approach to, but certainly not a return to, preexisting system function because of the smaller size, changes in surrounding areas, required structural controls, and conflicting demands for water supplies (Kushlan, 1979b).

On the positive side, there is no evidence that any species has been eliminated from the Everglades wetland, despite the dramatic population decreases observed in some. This may not continue to be the case, however, and it is worthwhile to ponder whether an Everglades without wood storks would be acceptable. As a large, highly specialized top predator, the loss of the wood stork would be an expected early consequence of ecosystem degradation (Kushlan, 1979b). The southern Everglades population presently seems to be in the process of shifting northward out of Everglades National Park (Kushlan and Frohring, 1986). To preserve the presence of some endangered species, especially those with contrasting hydrological requirements such as wood storks, snail kites, and Cape Sable sparrows, as well as some distinctive plant communities, it may be necessary to establish additional zones to be managed as wildlife refuges (Kushlan, 1983).

Water management in southern Florida has had two major results: habitat loss and hydrologic management. These are interrelated in that initial drainage and habitat loss in turn require continued flood control to protect resulting residential and agricultural developments as well as additional management in the remaining wetlands. Flood control and water supply considerations have resulted in the compartmentalizing of the once confluent marsh, reducing its capacity to buffer the local effects of hydrologic events. Compartmentalization, however, has also permitted a surprising degree of hydrological management, which is most effective in small controllable areas.

Management of the Everglades has come to be divided among public agencies and private landowners (Fig. 3), each having understandably differing perspectives. This present compartmentalization of the Everglades is not only a fact; it is inevitable and probably desirable from the perspective of public planning for multiple resource use, in that it essentially represents zoning of the former Everglades into use-areas for water management, recreation, wildlife, agriculture, urban development, and a natural area preserve. It is crucial to realize that the management goals of these several zones must differ and that the differing needs of the various users must be factored into management plans in each zone. In southern Florida the conflicting interests might seem to represent irreconcilable positions. In fact, apparent conflicts are to a large degree resolvable, and sufficient knowledge exists to manage the former and present Everglades for the benefit of its diverse constituents, as discussed below.

Within the natural area zone of the Everglades included in Everglades National Park, the legislated requirement is to preserve distinctive animal and plant populations naturally occurring there. Management should, therefore, aim at preserving ecological processes by concentrating on the effects of water management on sensitive natural populations. The natural, rainfall-driven pattern of water level fluctuation provided inherently predictable sequences of events to which natural populations could accommodate. The timing and speed of water level decrease in the dry season, maximum submergence depth, and inundation periods all affect the survival and reproduction of the distinctive aquatic plant and animal populations. It is such relationships that must be actively managed to preserve ecosystem functions in the natural area zone. Such potential impacts can be used to form the basis for establishing hydrobiological criteria for evaluating the effects of water management in the natural area zone in Everglades National Park (Kushlan, 1987).

Within the zone of the Everglades used for water management and flood control, management approaches must differ significantly. The eastern levee system keeps surface water from flowing eastward over former Everglades land, which has now been developed and is no longer available as wetland. The remnant Everglades within the water conservation areas thus provide flood protection during seasonal and storm-derived periods of high rainfall. On the water supply side, the Everglades is the recharge area for the Biscayne Aquifer, which supplies water required by the populated Florida east coast. Water conservation requires the retardation of runoff of water in the interior Everglades that otherwise would have to be drained off populated areas to the east. It also requires dry season movement of remaining conserved water to the coast via canals to maintain a hydraulic head against the intrusion of salt water into the aquifer and to recharge domestic well fields. To do this, unnaturally high water levels must be maintained in the water conservation areas in order to preserve the wetland character, enhance habitat for certain wildlife, and provide recreation opportunities. It should be realized that with respect to preserving water supplies and providing flood control in southern Florida, the compartmentalization and management of this zone of the Everglades has been a resounding success.

Management of the natural zone of the Everglades requires strict maintenance of patterns of water level fluctuation. Appropriate management cannot proceed, as is often proposed, through the elimination of existing structural and policy constraints on water movements or by the "restoration" of large volume water flows. A fraction of its former size, the remnant Everglades cannot survive under the volumes of water that flowed through it naturally. The capture by the water conservation areas of surface water that would have overflowed in all directions allows more water to flow over remaining land than was present over that same area in the past. Permitting free flow of this captured water would only further flood the natural zone of the Everglades (i.e., Everglades National Park) while further drying the northern parts of the water conservation area, adversely affecting biotic communities, water supplies, and flood control. Thus, structural management will have to be continued and may even need to be increased to provide finer control for ecological and water management purposes. Procedures that restore marsh flow, retard downgradient movement, and eliminate canal flows, except under conditions of flood or drought, would decrease unseasonal downgradient flooding and restore surface water quality. Management of timing of water flows should involve restoration of meteorologically based patterns of water level fluctuations, but the amounts of flow should be constrained by their biological effects. Because the downstream effect of the water delivery, and not the amount of water release per se, is crucial, the amounts released into the natural zone should not cause water level fluctuations that would adversely impact sensitive plant and animal populations.

None of these measures in natural area and water management zones need conflict with appropriate use of other nearby land. Recreation and farming are two such appropriate uses. Farming on land immediately adjacent to Everglades National Park has not resulted in the movement of contaminants into the park (Requejo et al., 1977). Therefore, there is no reason why certain agricultural practices (i.e., dry season row crops accepting risk of periodic flooding) could not continue or even expand into former marshland next to the other zones. Similarly, existing residential developments can probably be protected by levees and local positive drainage without further impacting the Everglades marsh of the natural area zone.

In summary, two potentially useful observations from the Everglades perspective are: first, that not only drainage but also relatively slight alterations of the critical seasonal pattern of water level fluctuation can lead to system disruption; and second, that zoning for different management objectives may permit appropriate multiple use of wetlands resources. Environmental changes and biological impacts in natural area zones can be subtle and recognizable only in time periods of decades. In the Everglades, for example, slight delays in the timing of discharges can readily affect such crucial population characteristics as reproductive success and population sizes that may take generations to reveal themselves. Nevertheless conservation of wetlands like the Everglades is possible but requires active manipulation for specified goals that differ among management zones. In this way, such wetlands can be managed effectively for humans as well as for wildlife.

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