External Threats and Internal Management: the Hydrologic Regulation of the Everglades, Florida, USA

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ABSTRACT / The ecological character of seasonal marshes is determined in large part by the pattern of water level fluctuation. As a result, the ecological health of a wetland reserve can be controlled by hydrologic regulation external to its boundaries. As an example, the Everglades marsh of Everglades National Park in Florida, USA, has been severely effected by management of the inflow of surface water. The Everglades occupies most of the interior of southern Florida, but only the lower 6% of the original marsh is contained in Everglades National Park. Shallow surface water reservoirs north of the park enclose 3600 km^2 of Everglades. Their levee system confines surface water flow into the park to several structures. Historically this water flowed across the entire core of the natural drainage. Flows into the park have been on a congressionally mandated schedule of minimum deliveries that is supplemented by additional water released into the park in amounts determined solely by upstream water management needs. My research, aimed at evaluating the effects of water conditions, has shown that this regulatory system has adversely affected reproductive success, community structure, and population sizes of sensitive species whose population stability is tied to natural water level fluctuations. These adverse effects were caused by water levels that for over a decade have been maintained at unseasonably high levels. Mathematically deterministic models of water level effects can provide management options based on biologial criteria. Park managers must incorporate understanding gained from such models into internal management decisions. Modifications of water control structures and alternative policies for managing the distribution and amount of surface water flow into the park appear attainable, can improve biological conditions in the park, and need not be adverse to neighboring external interests. Thus far biological changes are severe, and to a large extent irreversible. Ecologically sensitive management of an external threat under constraints imposed by history and setting can better maintain some semblance of ecological processes in the Everglades. If management decisions do not reflect such understanding of ecological processes, further ecological deterioration will result.

It is well known that the ecology and management of river systems are influenced, often dictated, by maintenance of the quantity, quality, and seasonality of water flow from up-gradient reaches. The well-known ecological changes in the Colorado River resulting from upstream management provide an excellent example of the dilemma faced by managers of reserves composed of downstream aquatic ecosystems (Johnson and Carothers 1987, in this issue). It is perhaps less obvious that management of large marshes in parks and reserves may be similarly constrained. As an example, the Everglades in Florida in the USA is an extraordinarily large marsh that occupies much of the southern third of the Florida peninsula. Seasonal rainfall and slow drainage result in flooding by surface water, which flows slowly down-gradient, coastward. Because of this flow, the Everglades has been called the River of Grass (Douglas 1947), a name more allegorically than technically correct, in that the Everglades lacks the characteristics of lotic (river) systems: rapid water movement, strong current, land–water interchange of energy and materials, limited stratification, high material loads, shoreline features, and relatively deep water. Rather, the Everglades is best described as a palustrine emergent wetland or hyperseasonal savanna. However, down-gradient water levels in the Everglades cannot be maintained without seasonal surface water flow from more elevated portions of the marshes. It is for this fundamental reason that, like the Grand Canyon National Park, Everglades National Park can be adversely affected by hydrologic regulation external to its boundaries.

KEY WORDS: Alligators; Everglades; Freshwater fishes; Hydrology; Park management; Resources management; Wading birds; Water management

Protection and management of this wetland system are inherently complex but within the resources of technically enlightened managers. A resource manager must consider the potentially conflicting policies and mandates of local, state, and federal agencies, and the needs of local residents. Ecologically sound management should meet all needs, in that management policies affect all managers and users of the wetland system, as well as the ecological system itself. Thus upstream external activities cannot help but be of vital concern to managers of the downstream portion of the system. In this article I discuss the Everglades as an example of the challenging problems and possible solutions in such reserves, and I suggest approaches to biological management based on understanding the direct effects of management action on biological processes.

Background

External influences on Everglades National Park result from its geographic setting, as depicted in Figure 1. The Everglades is the largest hyperseasonal savanna in North America. Historically, it occupied an elongated basin of 9300 km^2, which extended from Lake Okeechobee to the mangrove swamps of the southwest coast following a gentle land surface gradient of 3.6 cm/km from an elevation of 5.2 m above sea level. Everglades National Park occupies the very bottom of this drainage, and the park's core of Everglades marsh, the Shark River Slough, encompasses only 6% of the original Everglades.

The limestone basin is overlain by deposits of freshwater peat, ranging from 2 m deep in the north to less than a meter in the south. Soil on the lateral edges includes marl derived from epiphytic algae. Both bedrock and soils are permeable, and the water table rises through them in the summer–fall wet season.

The predominant vegetation (Figure 2) is a marsh community dominated by sawgrass (*Mariscus jamaicensis*) covering 70% of the remaining Everglades. Lower sites support a marsh containing *Eleocharis, Panicum,* and *Rhynchospora.* The deepest basins are occupied by ponds, maintained by alligators; scattered limestone outcrops permit development of small evergreen hardwood forests.

The Everglades historically was bordered by periodically flooded flatlands (Figure 1) of wet prairies, ponds, and rivers, which blended into pine forests and drier prairies. Along its western border, the Everglades merged with the Big Cypress Swamp. At its southeastern edge, the Everglades drained through higher elevations of the Atlantic coastal ridge via elongated glades, short rivers, and underground. To the southwest the Everglades drained into the extensive coastal estuaries through mangrove-lined rivers and intervening coastal swamps, and during the wet season into the Gulf of Mexico. Thus the Everglades was confluent with and drained into other wetlands along its entire periphery.

The ontogeny of human alternation of the Everglades and nearby areas began with settlement of the

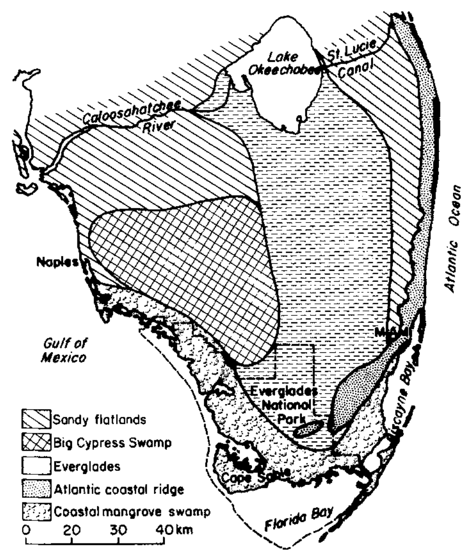

Figure 1. Physiographic features of southern Florida prior to development and the current position of Everglades National Park.

Figure 2. Ground view of the Everglades Marsh.

high ground along the east coast and subsequent migration of settlement inland as artificial drainage made land available. Settlement was relatively recent; Miami was a small village before 1896. Human immigration over the past 80 years led to the emplacement of over 2 million people along the southeast Florida coast. Nowhere in the USA does such a large population reside on the doorstep of such a vast wetland. Nearly all settlement, however, has been on the higher ridge along the Atlantic Coast and on drained land nearby rather than in the most floodable core of the interior marshes (Figure 3). Intrinsically, this is an environmentally sound land-use pattern, which occurred despite drainage attempts. The first canals were dug in the late 1800s and are still being dug in the 1980s. Wetland reclamation was particularly successful south of

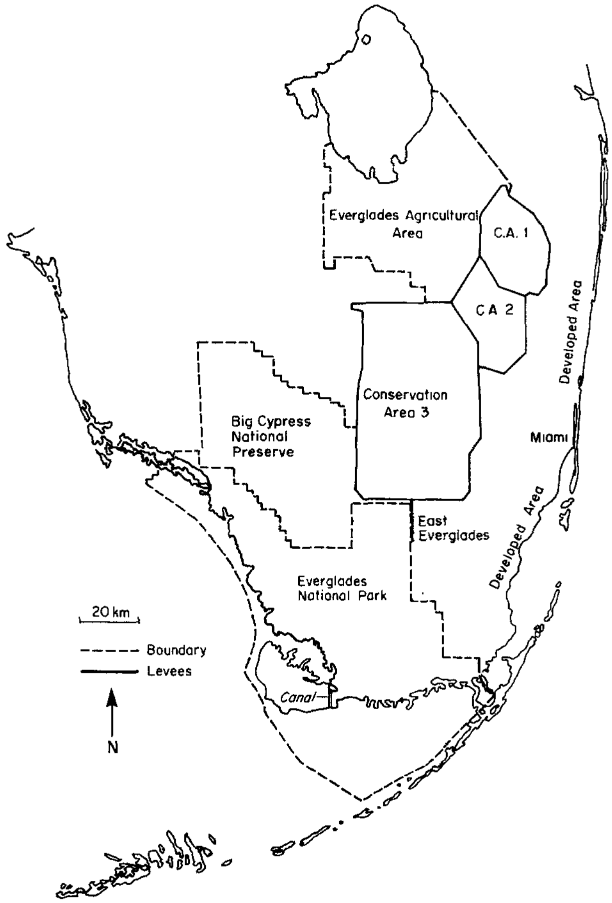

Figure 3. Political boundaries within the remaining wetland of south Florida.

Lake Okeechobee, after its southern border was diked in the 1930s (Leach and others 1972), establishing the Everglades Agricultural Area, which now encompasses 2150 km² (Figure 3).

As flooding from hurricanes or other episodes of high rainfall occurred periodically, management for land reclamation gave way to flood control, which required canals, dams, and culverts. In recent years increased emphasis has been placed on water supply, which requires a water storage and delivery system. The end result of these control measures is the plumbing of the Everglades with an elaborate system of canals and levees, some of which now enclose large, shallow reservoirs called water conservation areas (Figure 3), upstream from Everglades National Park. The primary purposes of these areas are to prevent flooding during the summer–fall wet season and to retain water into the winter–spring dry season in order to supply well fields along the east coast. Unfortunately, trying to save water in the Everglades for use in the dry season is like trying to maintain a waterlogged sponge in a warm oven. During most dry seasons, the conservation areas' marshes are naturally dry and supply little water. The actual reservoir of last resort is Lake Okeechobee, from which water may be transported via leaky canals to the populated coast.

A de facto result of building the water conservation areas was to further confine development to the east coast. The 3600 km² of Everglades marsh land within the levee system represents far more conserved Everglades than is in the park. Primary management of the conservation areas rests with a state agency. Conservation Area 1 is also the US Fish and Wildlife Service's Loxahatchee Wildlife Refuge. Wildlife management in the other areas is the responsibility of the state game commission. West of Conservation Area 3, 1600 km² of the Big Cypress Swamp is included in the Big Cypress National Preserve (Figure 3), managed by the National Park Service. The principal stated purpose of the preserve is to protect the watershed for the western portion of Everglades National Park, although it has significant biological resources in its own right. East of the park the East Everglades is a mixture of wetland, private lands, and areas now owned by the water management district. This physical and political partitioning of the Everglades system is accompanied by the differeing management policies governing each responsible agency.

Everglades National Park, authorized in 1936 and established in 1947, encompasses the southwestern tip of the Florida peninsula. Its purpose is clearly legislated: the conservation of unique biological resources. The Everglades was set aside for its animals, plants, and the ecological processes connecting them. The direct impact of visitation is slight in that the fewer than 400,000 visitors each year confine themselves mostly to a single roadway, interpretive foot trails, and designated camping areas. Regulations can prohibit access to areas in which animals and plant communities are sensitive to human disturbance. Sport or commercial fishing occurs in the park. Although stocks of some marine game fishes appear to have become depressed over recent years, there is no evidence that decreases were due to harvest (Davis 1980). By far, then, the most serious threats to the park come from hydrologic management outside park boundaries.

Hydrologic Regime

One of the prominent hydrologic characteristics of the Everglades is the seasonal fluctuation of its rainfall. On the average, 85% of the 1250 mm average annual rainfall is confined to half the year. As rainfall decreases from winter to spring so do water depths

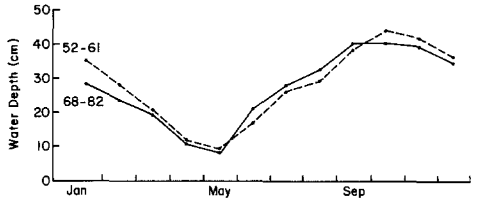

Figure 4. Average monthly water depths in the Everglades of Everglades National Park before construction of boundary levies (1952–1961) and during the recent period of water management (1968–1982).

(Figure 4). During the spring, higher temperatures result in increasing rates of evaporation and transpiration, which further acclerate the decrease in water level. Year to year rainfall varies substantially from the annual average. It is clear that seasonal water level fluctuation is the most critical ecological process to be conserved and managed in the Everglades.

Historically the surface water that flowed southward varied seasonally in amount, peaking in fall. Water flowed into the southern Everglades (Shark River Slough) across its entire transverse cross section as far east as the eastern coastal ridge. Compartmentalization of the Everglades by levees and canals has altered surface flows (Figure 5). Water moves through the conservation areas, mostly as directed by canals, and impounds behind the southernmost levees, which raises water levels there. Flows permitted into the park have been restricted to four gated structures, only two of which are in the central flow-way of Shark River Slough (Figure 5). The eastern segment of the slough (now called Northeast Shark River Slough) is outside the park and hydrologically isolated from it by a levee (L-67E). Water from the two western gates (S-12A, S-12B) flows southwestward into the Big Cypress Swamp. Water from the two eastern gates (S-12C, S-12D) can be inserted rapidly into the center of the slough along the eastern park boundary via a canal (L-67E) that dissects the natural drainageway.

Before 1962, surface water was relatively unimpeded and flowed in response to rainfall down the breadth of the Everglades. In December 1962, the gates in the newly completed transverse levee (L-29) at the northern park boundary were closed and remained closed or minimally opened for two years. The severe dry conditions that followed in the park raised public awareness of the need for surface water flow into the park. The droughts and surface flow blockage eventually led to federal legislated action (Public Law 91-282) in 1970 that guaranteed deliveries of 320 ha-m annually to the park on a monthly schedule (Figure 6), which was set at approximately the median of historic monthly flows. At this time the Park Service confirmed that it would also take any extra water available above the minimum schedule, thereby permitting dumping of excess water in flows above historic median levels whenever it was thought desirable by managers of the upstream water supply. This law and agreement constituted the water management plan for Everglades National Park that was a decade-long experiment in management of what has become an external threat to the park wetland ecosystem. The implied premise of this plan was that restoring the hydrology (that is, requiring scheduled discharge) would maintain the downstream ecology. As will become clear, this experiment failed.

A naturally caused drought in 1971 bolstered the public impression that lack of water was the most critical peril to Everglades National Park (see, for example, Ward 1972). However, the mandated delivery schedule had insured that the park would no longer suffer unnaturally from an inflicted drought. Rather, from the early 1970s, the park's critical problem has been excess water. Until very recently, the only route for draining excess water from the conservation areas was directly into the park. Except for drought years, water in excess of the standard engineering limits established for Conservation Area 3 was released directly into the park, in exactly the way the system was designed, public law required, and Park Service agreements encouraged.

Some of the hydrological effects of the water management program are illustrated by deviations of recent discharge from historic discharge (Figures 4, 6, and 7). Discharge over the entire flow segment along the northernmost boundary of the park was partitioned in 1962, by the levee (L-67E) on the eastern park boundary (Figure 5). Flow into Northeast Shark River Slough east of the levee was reduced to seepage. Flow into the park west of the levee, after being nearly eliminated in 1962–1965, usually exceeded what had occurred historically on a monthly basis (Figure 7). Some of this water represented flow that naturally would have moved into Northeast Shark River Slough to the east, or to the west into the southern Big Cypress Swamp. However, the north–south levees of the conservation area block all lateral surface flow. Without this blockage water would have flowed southwestward, would have covered former wetlands between the conservation area levees and the Atlantic Coastal Ridge, or would have flowed through or under the ridge. This water now remained in storage behind levees north of the park and eventually contributed to flow directly into the park (Leach and others 1972). Now additional water also enters the

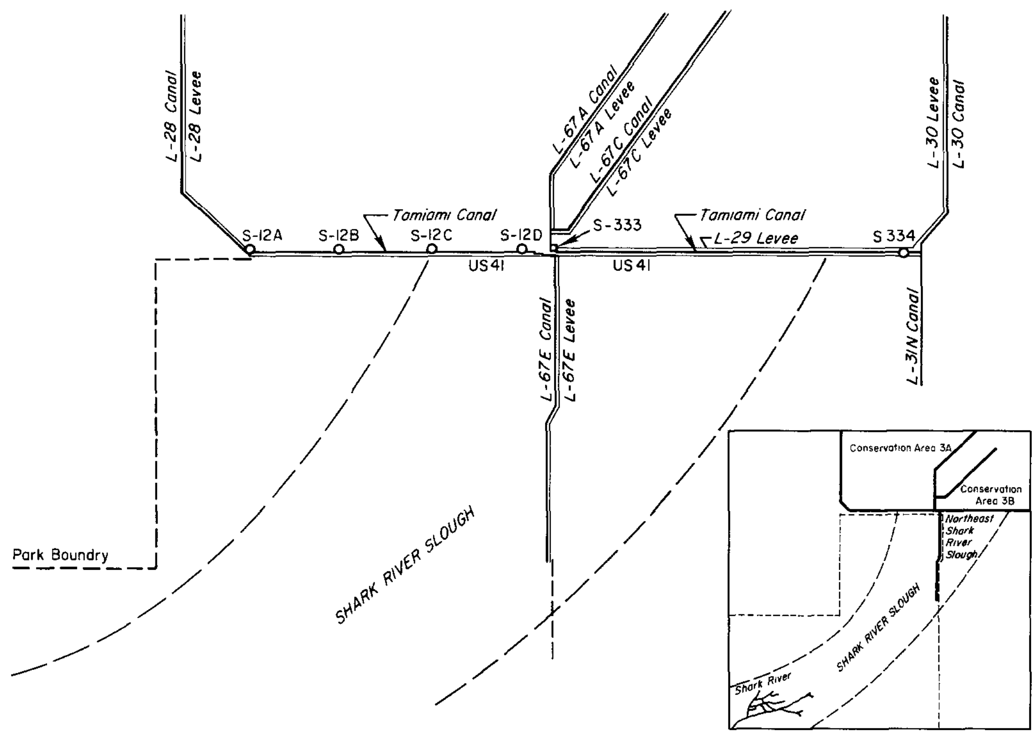

Figure 5. Water control structures along the northern boundary of Everglades National Park.

conservation areas from drained agricultural lands, drainage of the western flatlands, and positive pumping of water from the east (Figure 3). Thus the quantity of water in the remnant Everglades available to flow into the park exceeded that which would have flowed there without the current water management system. When water exceeded specified regulation levels in Conservation Area 3A north of the park, it was released into the park west of the core of the Shark River Slough drainage. The result of water management practices external to the park, therefore, has been to exaggerate the downstream effects of high discharge.

Such flow diversions have affected water quality in the park. Klein and others (1975) demonstrated that the chloride concentration of water in the northern reaches of Shark River Slough increased substantially after 1962. This dramatic deviation from natural water quality was caused by the delivery of water into the park via canals. Canal water, being in contact with the limestone baserock and receiving contributions from agricultural and developed lands, has a higher chloride concentration than does marsh water. Flora and Rosendahl (1982) found that the effect extended over much of the length of the Everglades in the park. This detectable deviation in water quality from natural marsh conditions can be attributed unhesitatingly to water management. It raises unanswered questions about changes in other water quality parameters that are not being detected, possible future changes in water quality because of canal delivery of water, and how these changes might affect biological processes. Future increases in back-pumping of water from low-lying residential and agricultural land into the conservation area may cause additional changes, if the water moves south quickly via canals rather than being renovated by flowing through marshes before entering the park.

In addition to effects on quantity and quality, the timing of water discharged has been affected. For example, in 1980 actual monthly discharges nearly mirrored the usual pattern of seasonal variation, which is approximated by the legislated minimal delivery (Figure 6). Over the long term, average water depths changed from the situation prior to management, caused in part by such discharge. The Everglades now experiences a slower water level fall in the drying season, higher levels in the early wet season, and lower levels in the late wet season (Figure 4).

Alteration of upstream drainage could be expected to adversely affect water level fluctuations and the dependent ecological processes downstream. Such effects may be dramatic and immediate, or subtle and delayed. When overland flow was stopped in the early 1960s, disruptions were obvious; the Everglades dried, the marsh burned, and animal populations decreased

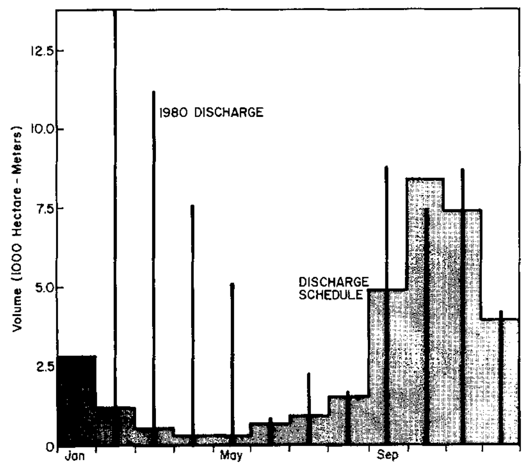

Figure 6. The schedule of minimum monthly water discharges into Everglades National Park reflecting the historic median flow (*bars*), and for comparison of recent deviations, the actual discharge in 1980 (*vertical lines*).

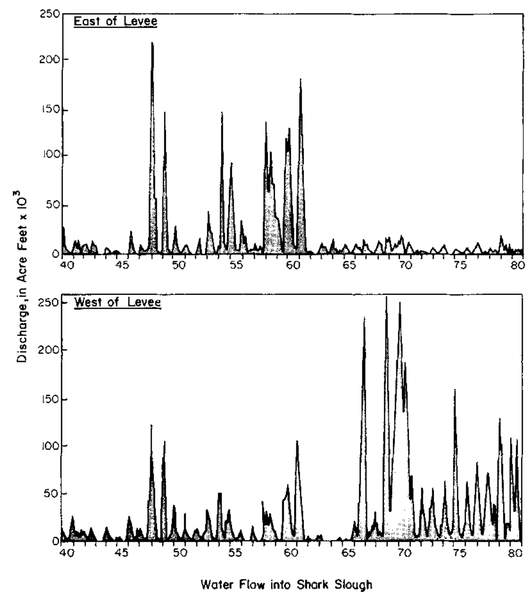

Figure 7. History of discharge into the southern Everglades. Discharge west of the eastern levee (L-67 extended) flows directly into Everglades National Park. Discharge east of the levee flows into the core of the natural drainage of the southern Everglades (see Figure 5).

and suffered reproductive failure. Under current water management practices, higher water levels have caused disruptions that are just as critical but not as obvious as a burning marsh caused by low water levels.

Maintenance of Ecological Processes

A particularly powerful tool for improving water management procedures is to base decisions on specific documented research results which explain the direct effects of water management on the ecological processes to be preserved. Initially a basic understanding of how the system functions is required, and this understanding is best gained through use of dynamic models (Lugo and others 1971, Odum and Brown 1976). Models allow selection of elements for study and formulation of hypotheses by which one can discern the biological effects of water conditions and ultimately of water management. This approach suggests how management affects the way the system works.

The more usual approach taken in the past has been the repeated determination of the status of various interesting plant or animal species under current conditions, followed by qualitative opinions about management strategies. This "best professional judgment" approach is both indefensible and irrefutable. However, the Everglades has been so altered that present population sizes reflect neither past nor future carrying capacities. Such populations are often in flux as they accommodate to man-caused conditions that are also continually changing during the period of study. Knowing only current levels and distribution of interesting populations can in itself reveal little about ecological processes or their management.

The more incisive, system-oriented approach aims at understanding ecological and populational processes that indicate ecosystem function. Such processes can be thought of as a series of cause-and-effect operations, responding to forcing functions, that produce deterministic ecological results. The forcing function of concern should ideally be one at least partially under management control. Ecological effects may include pathways of energy flow, fluxes of energy or nutrients, and populational parameters such as standing stock, productivity, or food habits. Basic ecosystem processes tend to persist despite some ecological disruption, and therefore study of these processes helps us to understand how the ecosystem functions irrespective of changes in current sizes of constituent populations. By studying the ecological effects of such processes, one can infer how key aspects of the ecosystem function naturally. Management aimed at maintaining indicator processes should lead to a more comprehensive conservation of the Everglades ecosystem than one concerned with species or population sizes for their own sakes.

Evaluating the effects of ecosystem processes on sensitive population parameters may be the most decisive research approach. It is not possible to study all forcing functions, processes, or results. Maximum applicability occurs when subjects chosen for study are those susceptible to measurement and management.

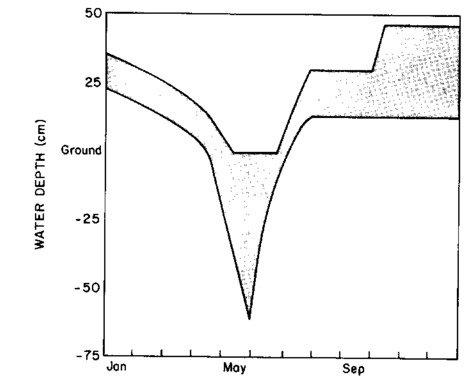

Figure 8. Biological criteria for water management in the southern Everglades. Discharge amount and distribution create a pattern of water level fluctuation within the hydrographic bounds shown. Bounds in the drying season are determined by requirements for successful nesting of wading birds. The upper bound in the early wet season is determined by historical levels of alligator nest flooding. Wet season water level rises must restore historical predictability. Within a broad range there is no restriction on water levels in the late wet season, when high discharges into the estuary are required.

In the Everglades the principal environmental factor, water level fluctuation, is in part amenable to management by control of upland discharge. Although water level fluctuations affect all aspects of the ecosystem from geochemical cycles to ecosystem energy flows, animal populations are particularly suitable subjects for study and tools for management in that they are discrete and quantifiable, their responses can be direct and unambiguous, and they possess specific adaptations and accommodative abilities, thereby enhancing chances of finding predictable relationships with the forcing functions of interest. With respect to management applicability, ecosystem-level modeling may suffer from the generalizations required for tractability and from within-system accommodations to changing conditions. At the other extreme of ecological organization, geochemical factors (such as water quality) may not be sensitive to forcing functions in ways that produce clear biological results. Population-level studies permit specific tests of the effects of water levels. By examining several populations and population parameters having different responses to water fluctuation, it becomes possible to infer a composite approximation of system function and management effects.

In the Everglades, I have examined the effects of water fluctuations on key populations. The hydrologic parameters included the pattern, extent, and timing of fluctuations. I chose populations of fishes, alligators, and wading birds that were important to ecosystem function at higher trophic levels and were responsive to hydrologic conditions. The specific population parameters studied emphasized those affected by differential water level fluctuations, namely population trends, food habits, and reproductive success. Therefore the hypotheses tested involved the deterministic effects of water conditions on sensitive parameters of critical populations.

The studies took advantage of nonrepeatable experiments inadvertantly being conducted throughout the compartmentalized Everglades, through the effects of levees, canals, and controlled discharge. These experiments included (a) temporal differences from one year to the next at the same site that were due to annual variation in water levels and (b) geographic differences from one place to the next that were due to geographic variation in water levels. These experiments were used to detect the results of water fluctuation, in order to understand system function. Under current conditions one cannot, however, use the rainfall and discharge situation in any year to predict future biological results under the same hydrological situation because management decisions are continually changing water delivery operations so that no specific series of past actions has totally repeatable future results.

The effects of water level fluctuation on the productivity of the American alligator (*Alligator mississippiensis*) and wading birds are good examples of the power of the approach. The reproductive success of the alligator depends on water levels during the summer nesting season (Kushlan and Jacobsen 1986). In late June, alligators build nest mounds into which they place their eggs for a two-month incubation period. Nesting occurs during the summer period of rising water levels (Figure 4). If water levels rise to the height of the egg cavity, nests flood and the eggs die. The percentages of nests that flood differ in different years and is determined by the maximum water levels reached during the incubation period. In three years from 1976 to 1981, substantial nest flooding occurred twice directly caused by water management manipulations. These actions involved delaying the downstream movement of rainfall-derived surface flow by withholding water in the upstream conservation areas and releasing it into the park later, at biologically inappropriate times. The loss of nests to flooding is determined by water levels at the time of egg laying and by the maximum water levels reached during the period of incubation. Modeling these relationships, we estimated the extent of flooding before and after the institution of water management in 1962. This comparison indicated that nest flooding is five times greater during the current period of water management than during the period prior to levee construction. In addition, this analysis suggested that the predictability of summer hydrology in the marsh has been destroyed under current water management practices. Before the levees were installed, the maximum water levels during the incubation period (which flooded nests) were statistically predictable from the water levels at the time of egg laying (which determines the elevation at which the eggs are laid). This relationship no longer exists, and the ability of alligators to accommodate to summer high water has been fatally compromised by the unpredictability of current water management practices. Because the alligator is the dominant species in the Everglades (Kushlan 1974), impacts on alligators may affect the function of the Everglades ecosystem.

The wood stork's (*Myteria americana*) nesting success also depends on drying conditions. The stork feeds in a peculiarly tactile manner by putting its bill in the water and waiting for a fish to bump into it (Kushlan and others 1975, Ogden and others 1976). This predator requires high densities of large fishes of only a few species to be continuously available within 80 km of its nesting colony for four months during the drying season. Under usual conditions as the Everglades dries, fishes become densely packed into deep areas where storks feed on them. As a result of this process, wood storks nest during the drying period. Elimination of, or interruption of, the drying period causes fishes to disperse and lowers their densities. Under these conditions wood storks abandon their nests and nestlings, or do not nest at all. I have found that a direct predictive relationship exists between the rate of water level recession in the drying season and the time of wood stork nesting (Kushlan and others 1975). Slow drying delays colony formation. If delayed beyond February, the reproductive effort fails because the onset of the summer wet season disperses prey before the nesting season is completed. Wood storks have failed to nest successfully in Everglades National Park in 17 of the last 20 yr since the institution of water management. As a direct result, the nesting population of storks in Everglades National Park has decreased from over 2000 in 1967 to 670 in 1982 (Kushland and Frohring 1986).

The numbers and size-class distribution of Everglades fish populations are determined by the annual pattern of water level fluctuation (Kushlan 1976). When dry seasons fail to occur, population density and size-classes of certain species increase while populations of other species decrease. This happens because under normal dry conditions populations of larger fishes suffer greater mortality than do populations of smaller ones. Conversely, when drying fails to occur, survival of large-bodied species is greater. Reduction in the frequency and severity of dry seasons leads to the differential survival of those populations more typical of lakes than of marshes.

Other studies have demonstrated how variation in water levels affects the downstream estuaries of the Everglades. Davis (1980) found a shift in species and sizes of fishes caught in the Everglades estuary from 1958 to 1978, probably caused by increased salinity. Information is also available on catch of pink shrimp on the Dry Tortugas grounds. These shrimp have been shown to be derived at least in part from the Everglades estuary (Costello and Allen 1966). Browder (1985) found a positive relationship between water levels at the southern end of Shark River Slough in fall and summer and shrimp catch on the Dry Tortugas. Low water levels during the usual spring dry season had no effect on shrimp.

These findings, suggesting the need for high discharges into the estuary in the fall, are congruent with my findings in the higher freshwater marshes. My studies have not demonstrated any biological constraint in the Everglades marsh on the amounts of discharge or water levels (within very broad limits) during the fall, when high discharges are required in the estuary. Thus it appears that the low water levels required in the freshwater marsh in spring and early summer do not conflict with requirements for high water levels, and discharge, in the estuary during the fall.

In general, discharges into the estuary have been relatively high over the past decade. Moreover, the effects of such upland discharges on the Everglades estuary have been confounded by the impact of coastal canals dug on Cape Sable (Figure 1). The National Park Service itself dug a major canal in 1957 to provide easy access to the Shark River Slough estuary by park visitors despite a congressional mandate to construct no visitor facility that would adversely affect the unique animal and plant populations found in the park. This canal opened the estuary to the infusion of hypersaline water from Florida Bay, which increased salinity in the estuary and partly caused the change in fish stocks demonstrated by Davis (1980). The canal was dammed in 1982, and freshwater conditions are already being restored to the estuary (J. Tilmant personal communication). Four additional canals on Cape Sable remain unplugged or poorly plugged.

Taken together, these results show wide-ranging adverse effects of the recent water management policy on animal populations in both the inland marshes and the estuary. Comparison of the average water levels during the recent management era with those prior to it demonstrates the long-term changes (Figure 4). Under recent procedures, water levels fall more slowly in the dry season, adversely affecting wading birds, rise higher in the early wet season, adversely affecting alligators, and are lower in the late fall, adversely affecting estuarine species.

Management Options

Understanding cause-and-effect relationships between an environmental factor such as water fluctuation and animal population parameters makes available ecologically sound management options. As currently understood, biological problems with Everglades animal populations appear to be related to quantity, quality, distribution, and timing of water deliveries. Thus primary goals should be to restore the annual dry season and to prevent water levels from rising too high in the early summer. Such biological criteria can direct management action. In addition, the requirements for flood control and water supplies outside the park cannot be unreasonably compromised.

Structural changes are the first step in meeting these goals (see Figure 5). Water should be delivered into the park through Northeast Shark River Slough. This may require elevation of a 60-year-old federal highway and of Indian settlements, and the purchase of the property rights of marshland owners. Complete removal of the canal and levee on the eastern park boundary is required to restore natural downstream flow and avoid high-water flooding of property to the east of the core drainageway. This would eliminate rapid infusions of water into the center of the Everglades in the park. Culverting the southwestern levee in the Conservation Area 3 would restore flow from the Everglades to the west coast, also reducing the amount of water requiring discharge into the southern Everglades marsh. Damming and culverting the delivery canal (Miami Canal) in Conservation Area 3 would: force water into the marsh, reducing the effects of canal deliveries; increase residence time of water in the conservation area marsh; decrease the amount requiring venting south because of high evapotranspiration losses in the marsh; and aid in the renovation of the quality of water originating from agriculture and urban runoff. Thus water coming into the park would derive from marsh flow rather than canal flow and would have suitable chemical characteristics. Spreading water delivery through the Northeast Slough would bring this area back into the southern Everglades system, increase water storage, increase biological production, and reduce the adverse biological impacts of any given quantity of water requiring discharge toward the park. At the seaward end of the Everglades, damming all coastal canals in and next to the park would restore the estuaries and coastal marshes.

Such structural changes would permit managing the quantity and timing of water delivery to maintain ecological processes. It is important to realize that the actual quantity of water discharged into Shark River Slough is unimportant except as it produces downstream ecological effects. A specific effect might be produced by several combinations of amount, distribution, and timing. *Timing* of water discharge needs to respond to real-time events so that rainfall creates immediate flows rather than being impounded for several months. Such *timing* can be tied to rainfall by means of models predicting discharge from rainfall, and by other antecedent conditions. The appropriate water *quantity* actually delivered is one that does not exceed biologically based criteria downstream as indicated by hydrographs at index stations. A model of these criteria is shown in Figure 8. Managed discharges should provide hydrological conditions within the hydrographic zone depicted. This zone is defined in the drying season by biologically marginal years for wading bird nesting success, and in the flooding season by levels that would not exceed historic losses of alligator nests. Rates of water recession should approximate the mathematical relationships for successful nesting of wading birds. Rising water levels should restore the mathematical predictability of summer water conditions. There are presently no known constraints on water depths in the marsh in the fall, when maximum discharges naturally occur and would have beneficial effects in the estuaries. High-water and low-water years were historically part of the system, depending on annual rainfall. These must also be part of the future system, and the criteria could be exceeded on some intermittant basis, perhaps one year in five. The Everglades should not be allowed to dry sufficiently to experience peat fires and should not remain flooded long enough to change fish populations. The actual discharges necessary to achieve water depths and fluctuations within biological criteria are matters of engineering and operation of gates at the northern boundary of the park.

This approach uses biological criteria to direct and constrain water management actions. The previous approach based only on hydrological criteria has failed, in that its attempt to recreate some semblance of historical discharge did not reproduce historical water levels (Figure 4) and adversely affected biological conditions in the Everglades. An alternative approach that relies on the same philosophy is to remove all structural constraints on water movement in the Everglades. This flow-through system is totally inappropriate. With storage of increasing amounts of water in a remnant Everglades, water levels in down-gradient areas would inevitably exceed historical levels seasonally, and the critical storage of water in various upstream compartments would be compromised by overdrainage of the conservation areas. Unfortunately, because of previous history, active management of the Everglades can never be relinquished.

Conclusion

Management that deals with an external threat to a natural-area reserve needs to consider numerous constraints including multiple uses, legislated mandates, competing needs, and inevitable system changes. In many reserves, providing for multiple uses affects management. Although this is not the case within Everglades National Park, the adjacent conservation areas are managed for many purposes including flood control, water storage, recreation, wildlife, and water delivery. All these potentially competing needs can dictate the amounts of water available for discharge southward, into the park. Such a situation is analogous to managing dammed river systems (Johnson and Carothers 1987, in this issue).

The legislated mandate for Everglades National Park is clear: the conservation of its unique natural populations. Thus management actions that center on wildlife and fish criteria and aim to return the marsh to naturally fluctuating conditions are particularly appropriate. An important point is that such management is not "management for species" but management that uses the responses of selected species to set appropriate criteria that maintain ecological function. Although animal populations have decreased since water management, none has apparently yet been lost from the park due to it. Many biological changes observed are irreversible, but it may be possible to restore some semblance of natural system processes; thus some approximation to the natural Everglades may yet be conserved by ecologically sensitive management. However, the historic Everglades can never be restored.

Management within a preserve must involve consideration for the valid needs of external interests and may in reality be dictated by the requirements of local residents and policies of other government agencies. However, water management in the Everglades National Park need not conflict with the concerns of neighbors, in that all rely ultimately on sound ecologically based water management. The requirements of water storage, flood control, farming, and residents all can be met while providing for more ecologically sound management in the park. A natural reserve need not be a bad neighbor.

Perhaps the greatest constraint to management is history. The Everglades has been irretreivably altered by the cumulative impacts of area reduction and hydrologic modification (Kushlan 1986). Much of it is drained; most of it is confined by levees; carrying capacities for many plant and animal populations are reduced. In such a large wetland it may have been inevitable, and not inappropriate, that areas would have become zones for agriculture, development, water management, and a natural area reserve. It is *only* in the latter area that management for system processes need take precedence. The management of surrounding lands, however, dictates how close reserve management can come to its goals (Kushlan 1979). Internal and external strategies must be synchronized and coordinated, and, once set, maintained over the long term without ad hoc deviations for political purposes.

Like all such extensive marshes today, the Everglades is and always will be managed, and one goal must be to improve the biological effects of that management in the natural area zone. Information on the direct effects of managing a forcing function (water level) to preserve ecological processes should underpin ecologically sound decisions within the constraints imposed by history and the regional setting.

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