Smoke on the water: the interplay of fire and water flow on Everglades restoration

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Recent research makes clear that much of the Everglade's flora and fauna have evolved to tolerate or require frequent fires. Nevertheless, restoration of the Everglades has thus far been conceptualized as primarily a water reallocation project. These two forces are directly linked by the influence of water flows on fire fuel moisture content, and are indirectly linked through a series of complex feedback loops. This interaction is made more complex by the alteration and compartmentalization of current water flows and fire regimes, the lack of communication between water and fire management agencies, and the already imperiled state of many local species. It is unlikely, therefore, that restoring water flows will automatically restore the appropriate fire regimes, leaving the prospect of successful restoration in some doubt. The decline of the Cape Sable seaside sparrow, and its potential for recovery, illustrates the complexity of the situation.

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Many people have written about the Everglades, but none have done so as elegantly as Marjorie Stoneman Douglass (1947): "There are no other Everglades in the world. They have always been one of the unique regions of the earth, remote, never wholly known. Nothing anywhere else is like them: their vast glittering openness, wider than the enormous visible round of the horizon, the racing free saltness and sweetness of their massive winds, under dazzling blue heights of space." It is largely through Douglass' efforts, and those of other local scientists and activists, that the federal and Florida state governments have committed to a 30-year, $8 billion restoration plan for the endangered ecosystem. This is an enormously complex endeavor and has no precedents.

Efforts to complete the Everglades restoration are hampered by a lack of knowledge concerning the processes that govern the ecosystem and the need to accommodate a population of over 5 million people. Through systematic drainage and development over the past century, the Everglades has been nearly halved in size, with no chance of recovering the lost portion. Restoration scientists have understandably focused on how to reformulate water flows to better mimic natural conditions, thus preserving (and sometimes enhancing) the remaining wetlands. However, water is not the only force affecting ecosystem function in the Everglades. The massive thunderstorms that drive water flows also regularly serve to ignite fires, but the effects of these have been dramatically altered through changes in water flow and human population growth. Nevertheless, there has been little attempt to determine whether "getting the water right" – the mantra of the Comprehensive Everglades Restoration Plan (CERP) – will also serve to "get the fire right". Here we review the interaction between fire and water in the Everglades and consider how this interaction may influence the success of restoration, using the recovery of the endangered Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*) as an example.

In a nutshell:

- A planned 30-year restoration of the Everglades aims to restore an ecosystem fundamentally altered by the systematic draining and conversion of its wetlands
- The region's water and fire regimes are linked through the effects of the local hydrology on biomass accumulation, plant species composition, and moisture content
- Fire frequencies have been changed by water management decisions and the creation of important urban–wildland interfaces
- Because much of the region's flora and fauna have evolved to tolerate, or require, fire, we must consider the interactions of fire in proposed water flow restoration scenarios

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Physical nature of the Everglades

About 5000–6000 years ago, rising ocean levels and a changing regional climate created hydrologic conditions that initiated the development of the current complex of Everglades wetlands (Winkler *et al.* 2001). These formed in and alongside a depression in the limestone bedrock underlying South Florida (Gleason *et al.* 1984; Figure 1). As sea levels rose, local rainfall supplemented by overflow from an expanding Lake Okeechobee caused water levels to rise in the nascent Everglades, stimulating wetland soil development. The soils formed in the center of the trough were peats, with calcitic marls along the trough's sides (Figure 1). The broad mapping units illustrated in Figure 1 are far from homogeneous. Even in the extensive peatlands near the center of the Everglades, small-scale biological and physical processes may result in ecologically important topographic variation.

Distinct wet and dry seasons characterize southern Florida's subtropical climate (Duever *et al.* 1994). Wet season precipitation – about 80% of the annual rainfall of 150–160 cm typically occurs between May and October – is associated with convective storms, generated within the Everglades itself, and with cyclonic weather systems that develop in warm waters in the Atlantic Ocean, Caribbean Sea, and the Gulf of Mexico. This seasonal cycle in Everglades climate is superimposed on longer term fluctuations. As elsewhere, climatic extremes in south Florida are cyclic phenomena subject to El Niño Southern Oscillation (ENSO) activity and other global factors (Duever *et al.* 1994; Beckage and Platt 2003). These climatic events are usually punctuated by hydrologic extremes such as excessive high water or prolonged drying.

During the pre-drainage era, less-than-perfect correlation between rainfall and flooding duration resulted from the vastness of the Everglades drainage, in combination with the slow movement of water through the system. Local topography and natural drainage patterns primarily determined the duration of flooding. In today's highly regulated and compartmentalized Everglades, most of the discrepancies between rainfall amount and flooding are due to water management actions.

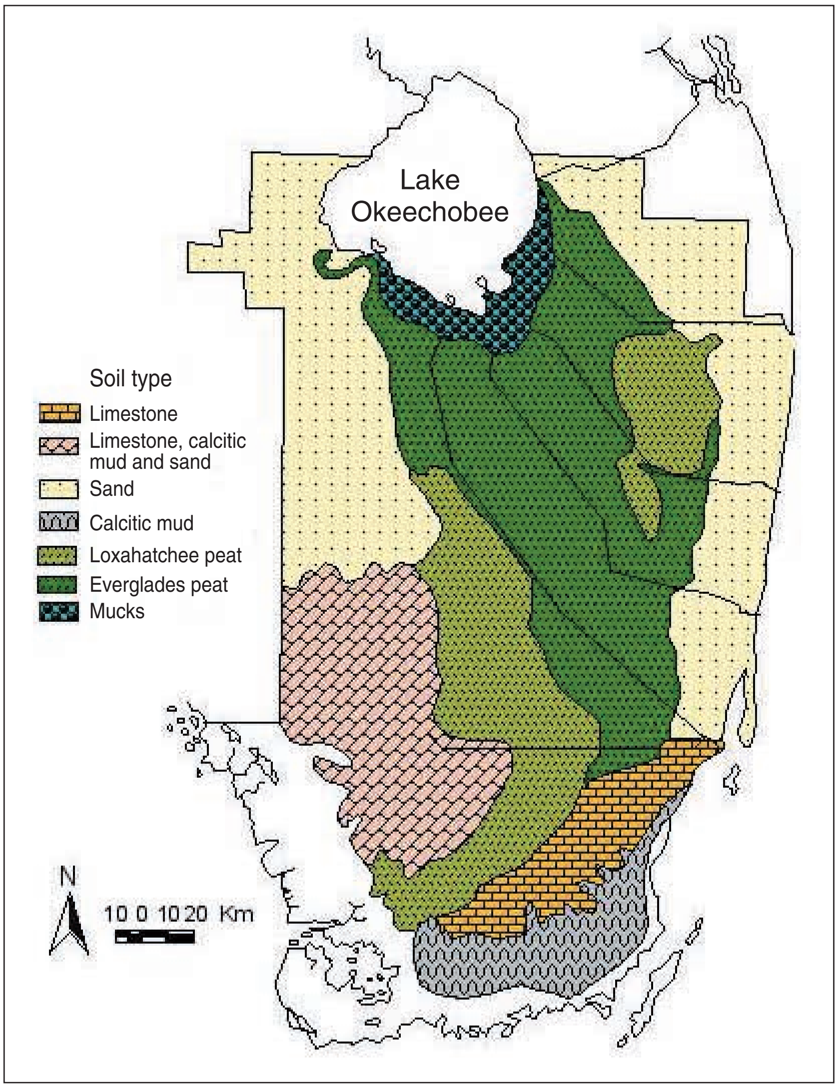

Figure 1. *Generalized map of surface sediments in South Florida from Gleason* et al. *(1984). Mucks are mineral-rich overflow deposits from Lake Okeechobee prior to dyking. Calcitic muds typically form in calcium-rich waters that are submerged for a substantial part of each year. Peats form in more persistently flooded sites. Everglades peat is believed to have formed under sawgrass (*Cladium jamaicense*) cover, Loxahatchee peat under water lily (*Nymphaea *sp) cover.*

In conjunction with substrate, climate, and hydrology, the local disturbance regime is a fundamental component of the south Florida environment. From an ecological point of view, the most important disturbances are fires, hurricanes, and freeze events. The latter two occur frequently enough and exert sufficient force to influence vegetation patterns within the region (Egler 1952; Craighead and Gilbert 1962; Olmsted *et al.* 1993). However, we focus here on fire, whose interactions with hydrology are direct and predictable.

The Everglades' "natural" fire frequency, though often the subject of speculation, is not well understood. Dendrochronological techniques that have proved useful in temperate regions have rarely been attempted in south Florida because of problems encountered in aging many subtropical tree species via growth rings. Descriptions of charcoal layers in sediment cores provide qualitative evidence of the importance of fire in the region (Winkler *et al.* 2001), but these data do not translate easily into precise fire frequencies. For south Florida pine forests, the best evidence regarding historical fire frequency may lie in characteristics of the current ecosystem (Robertson 1953; Snyder *et al.* 1990). By this logic, historical fire frequency is bracketed on the low end by the minimum time needed after a fire for enough fuel to accumulate to sustain another one (typically 2–3 years), and on the high end by the time required before the developing hardwood canopy shades out a richly endemic understory flora of fire-tolerant herbs (10–15 years). Although no comparable evidence has been offered for Everglades marshes, researchers have emphasized the importance of seasonal and longer term climatic variation, including ENSO cycles that produce drought conditions every 10–14 years (Gunderson and Snyder 1994; Beckage *et al.* 2004). Beckage and Platt (2003) report that during years in which the most extensive non-prescribed fires occurred in Everglades National Park (ENP), the marsh was characterized by lower-than-normal water levels in April and May, when fuel, weather,

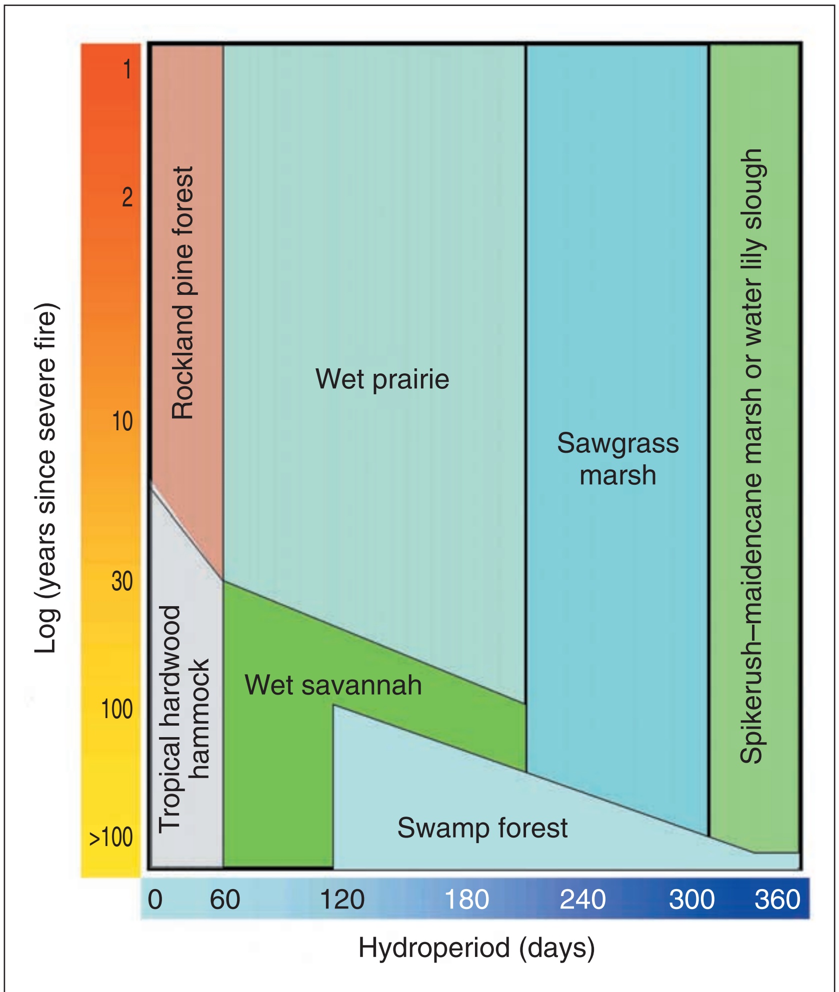

Figure 2. *Distribution of major freshwater plant communities in the Everglades along axes of hydroperiod (days with surface water present per year) and time since severe fire. Note that encroachment of broadleaved woody plants is more rapid on well-drained sites, but can be interrupted by fire anywhere.*

and hydrologic conditions are most conducive to large fires (Beckage *et al.* 2004).

Fire, water, and Everglades biotic communities

In the Everglades, many plant and animal communities have evolved to tolerate, or even require occasional burning (Egler 1952; Robertson 1953; Beckage *et al.* 2004). However, the interplay of hydroperiod (annual flooding duration) and plant species composition leads to differences in fire regime among these communities (Wade *et al.* 1980). Fuel characteristics that favor frequent fires include low fuel moisture content and the rapid accumulation of biomass. Hydrologic conditions affect fuel moisture content directly and biomass indirectly through their influence on plant species composition and productivity.

In Figure 2, we adapt a diagram initially presented by Duever *et al.* (1986) to arrange the major freshwater plant communities of the Everglades along gradients of hydroperiod and time since a severe fire. The schematic divides Everglades vegetation into four hydrologic groups: rockland pine forest (0–2 months hydroperiod), wet prairie (2–7 months), sawgrass marsh (7–11 months), and spikerush–maidencane marsh or water lily slough (> 11 months). Mineral substrates (ie marl) predominate in the less frequently flooded half of the figure, while soils in the wetter sites are generally organic (ie peat). The expected timelines for the successional changes in Figure 2 are speculative, but there is considerable support for the idea that succession to broadleaved wooded communities in the Everglades proceeds more slowly as hydroperiod increases, becoming impossibly long in the wettest sites.

The successional model in Figure 2 is limited on several counts. First, a perfect reversibility is implied; for example, a severely burned hardwood hammock immediately returns to pine forest. In reality, reversing the encroachment of woody plants usually requires a series of fires (Wade *et al.* 1980), because a single fire, even if quite severe, rarely removes all vestiges of the pre-burn community, including the seed or meristem bank. A second limitation is that interactions between fire, hydrology, and vegetation are not dynamically integrated. This integration is especially relevant in the long hydroperiod marshes of the central and southern Everglades, where topographic relief in the organic soils more often changes due to a positive feedback between organic soil accretion and initial elevation (Ross *et al.* 2003). Enhanced accretion on slightly elevated sites may result from autogenic processes such as higher in situ production, or from the preferential deposition of organic sediments suspended in Everglades sheetflow. In either case, fire may regulate this positive feedback loop, and may create variability in the marsh surface by periodically removing most standing plant biomass and lowering elevation through the oxidation of the peat soils (Figure 3).

Human alterations to fire and flood regimes

In the pre-drainage era, the annual water flow cycle was seen as a nuisance to agriculture, as it prevented the establishment of standard crops such as vegetables and sugarcane (Snyder and Davidson 1994). Moreover, the longer term flood/drought cycle distressed residents by regularly flooding cities, towns, and cattle ranches built in low-lying areas (Light and Dineen 1994). The result of this conflict between water flows and human enterprise was a massive replumbing project, largely accomplished by the US Army Corps of Engineers by 1970. This water project, called the Central and South Florida Project (CSFP), created the template upon which ecosystem restoration must be structured today.

Changes in fire regimes are much more subtle than those for water, and substantial deviations from natural fire regimes have occurred more recently, with changes in attitudes towards fire by local people and land management agencies. After the designation of ENP and other public lands in the early 1940s, fires were suppressed in the Everglades, as they were across much of North America. However, resource managers in ENP were among the first to change this practice, and today they allow naturally ignited fires to burn freely unless they threaten critical biological or cultural resources. Managers also use prescribed fires to reduce fuel loads, to enhance wildlife resources, or to reinitiate fire frequencies that mimic more natural regimes.

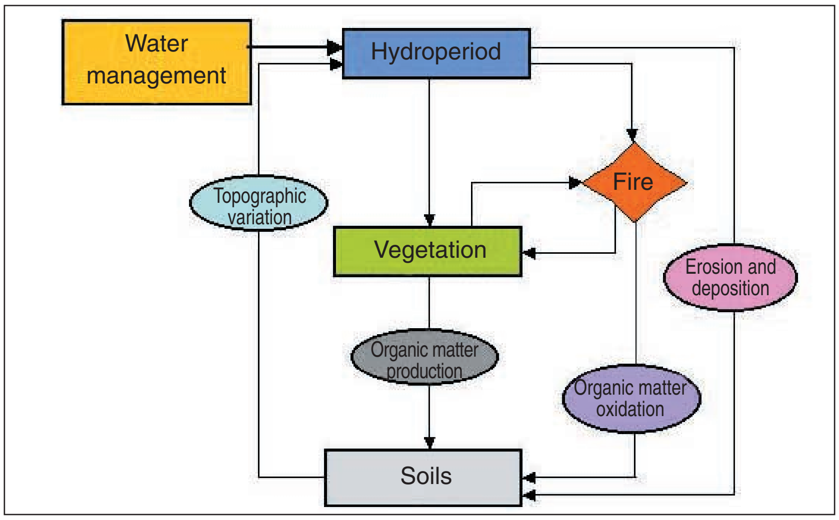

Figure 3. *The biotic communities of the Everglades are influenced by the dynamic integration of fire regimes, water flows, and topography. This ensures that changes to water flows will influence fire regimes, either directly through changing moisture levels or indirectly through the effect of water on plant species composition.*

Nevertheless, current fire extent and periodicity are often different from what are believed to be natural regimes. Fires should naturally begin most often and burn the most acres when an increase in lightning strikes occurs during the time of year when water levels are at their annual lows; in the Everglades, this is in April and May (Gunderson and Snyder 1994). However, in order to avoid large uncontrollable burns that may spread into adjacent agricultural and suburban areas, prescribed burns are sometimes undertaken in winter or late summer (Gunderson and Snyder 1994). In addition, the number of anthropogenic accidental or arson fires that cross park boundaries and burn within natural areas is increasing. These fires are most common from March to May, which matches the natural peak in fire activity. However, the increase in ignitions near the urban–wildland interface, in conjunction with the tendency for managers to divert water away from these urban areas, means that natural areas adjacent to urban boundaries burn much more frequently than they probably would have otherwise (Curnutt *et al.* 1998).

Management agencies and environmental groups responded to the effects these alterations (along with habitat loss) have wrought by pushing for the preservation and restoration of what is left of the ecosystem. Thus far, efforts have concentrated on devising water management schemes that more accurately reflect historical flow patterns. These hydrological manipulations are encapsulated in the Comprehensive Everglades Restoration Plan (CERP), a multi-stakeholder plan implemented through a Federal–state partnership, with the Army Corps of Engineers and the South Florida Water Management District as respective lead agencies. Despite considerable input from the scientific community on hydrology-related issues, nowhere in CERP is fire considered substantively, though it is just as critical a force in the evolution of Everglades plants and animals as flooding. To successfully preserve and enhance the remaining natural pieces of the Everglades, we must begin to ask how CERP will interact with natural and human-ignited fires to determine the biological fate of the ecosystem.

The easy answer is that getting the water right will get the fire right, simply through the physical correlation of hydroperiod with fire frequency and extent (Figure 3). However, as shown in Figure 3, the direct connection between fire regimes and hydroperiod is only one of several links that join them. The existence of such complex feedback loops makes it difficult to pinpoint the primary forces controlling the Everglades' biotic communities. Thus, even under the best of management circumstances, it would be difficult to restore the Everglades. Restoration is made even more difficult, however, by the fact that managers tightly controlled the Everglades' water flows and fire regimes during the period in which most research into the processes outlined in Figure 3 was conducted. The rules by which managers have been, and are, controlling fire and water are very often different from what were thought to be the rules under which the Everglades were formed.

Given this level of ignorance, can we simply allow fire and fire managers to respond ad hoc to water flow changes prescribed by CERP and expect restoration to be successful? We use the case study of wet marl prairies and the recovery of the endangered Cape Sable seaside sparrow as an example of the complexity of restoring the Everglades when fire and water flows are considered in tandem.

Swimming sparrows and burning prairie

The Cape Sable seaside sparrow is restricted in range to the wet prairies of the southern Everglades, and has been listed as endangered since the 1973 Endangered Species

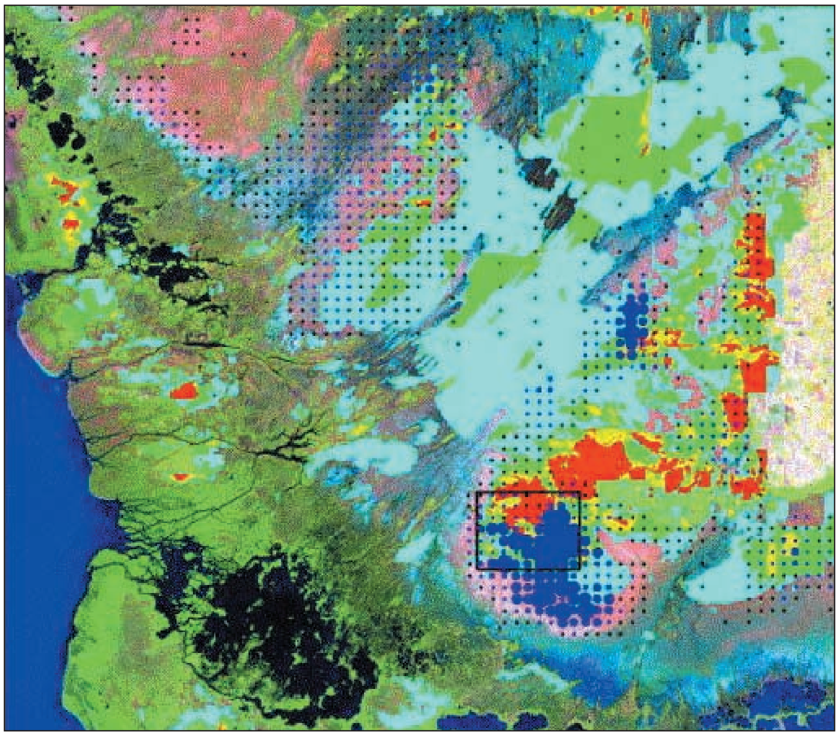

Figure 4. *Distribution of the Cape Sable seaside sparrow (*Ammodramus maritimus mirabilis*) as recorded in range-wide surveys conducted between 1993–2001 in the southern Everglades. Black points are locations of survey points from which sparrows were censused. Blue points represent locations where sparrows were detected at least once, with larger blue points representing relatively more sparrows detected. Overlaid is the frequency with which fires have occurred between 1981–2001. Light blue areas have burned once during this period, green twice, yellow three times, and red four or more times. The white–pink areas on the right represent the urban sprawl of greater Miami and the urban–wildland interface of ENP.*

Act came into force. The sparrow's current distribution is mostly within the boundaries of Everglades National Park and Big Cypress National Preserve (Figure 4). Sparrow breeding activity peaks during the months of extreme dry-down in the Everglades (April–June). The birds are very vulnerable to both fires and floods, since they build their nests only about 16 cm above the ground (Lockwood *et al.* 1997), and have a short life span of 4–5 years. If water accumulates more than 20 cm deep during the breeding season, adult sparrows either will not breed, or will probably see any nests they succeed in building flooded and lost. If fire moves through sparrow habitat during the breeding season, nests will also be lost. If fire and/or flooding prevent successful reproduction for periods that approach the average life span of an adult sparrow, their numbers will inevitably decline, since most adults will die before they can replace themselves (Lockwood *et al.* 2001).

These two forces, fire and flood, pose spatially distinct threats to sparrow populations. Until very recently, water has been preferentially directed to the western section of ENP, where permanent human residences were largely absent and regulation of flood levels was not seen as a priority. The extended hydroperiods have, in turn, excluded prairie fires from this area for at least 14 years (Figure 4). Conversely, water flows are much reduced in the eastern wet prairies of ENP, in large part because adjacent urban areas require flood protection. Human ignition sources and low moisture levels have lead to frequent fires in this area (Figure 4).

In addition to the direct negative effects of nest flooding, variations in hydrology can also negatively affect the composition of sparrow habitat. Preliminary analyses of wet prairie plant composition indicate that the longer the hydroperiod, the more sawgrass *(Cladium jamaicense)* tends to dominate (Figure 5). With shorter hydroperiods, graminoids such as muhly *(Muhlenbergia filipes)*, cordgrass *(Spartina bakeri)*, and Florida bluestem *(Schizachyrium rhizomatum)* are more abundant. Superimposing the frequency of sparrows detected from point-count surveys conducted in these same areas in 2001 and 2002, it becomes clear that sparrows are found at higher densities in prairies, where the hydroperiod is relatively short and sawgrass is not dominant (Figure 5).

Changes in water flows due to management decisions have substantially shifted hydroperiods along this axis. For example, a water monitoring station (NP205) located in the western part of ENP indicates that the number of dry days (ie showing no standing water) between 1972 and 1996 varied from 0–90 days (Nott *et al.* 1998). If we place this range within Figure 5, we see that at its driest, the area around NP205 falls on the tail end of suitable sparrow habitat. When hydroperiods are lengthened so that there are fewer than 60 dry days per year, conditions will probably shift into zones that favor the establishment of plant assemblages unsuitable for sparrow use.

Such long hydroperiod conditions (> 300 days of inundation annually) prevailed from 1993–1996, and the sparrow population near NP205 declined by 90% (Nott *et al.* 1998). Although water managers have ensured that the hydroperiod in this area has stayed at or below 300 days per year since 1998, sparrow numbers have not substantially rebounded (Pimm and Bass 2002).

It is not clear how the lack of fire in the wet prairies of western ENP has influenced this decline, or if the lack of fire has increased the likelihood that a conflagration will impact the area in the future. However, the detrimental effects on sparrow populations of increased fire frequency due to the opposite problem of artificially shorter hydroperiods are apparent in the wet prairies of eastern ENP.

Sparrow habitat that lies on the eastern boundary of ENP has among the shortest hydroperiods recorded within wet prairies (120–200 days of inundation annually). This is partly due to the low water levels maintained in this region to prevent the flooding of neighboring urban and agricultural areas. These shorter hydroperiod prairies currently support higher numbers of sparrows than areas where flooding is more extended (Figure 5). However, considerable acreage of the former type lies immediately inside the ENP boundary, along the Park's urban interface. As such, this area is prone to burning as a result of accidental and arson fires; these reach their peak in April and May (Gunderson and Snyder 1994), and they tend to burn significantly more acres than fires that are ignited in the wet season or in areas with longer hydroperiods (Beckage *et al.* 2004). These expansive boundary fires are perfectly timed to halt the sparrow's breeding season prematurely.

Burned prairies are unsuitable for sparrow use for at least 2 years (Pimm *et al.* 2002). However, a level of plant biomass (fuel load) high enough to support a fire can apparently still be too short to support sparrow breeding. If an ignition source is regularly available, therefore, fires can burn shorter hydroperiod wet prairies so often that sparrows cannot use them (Curnutt *et al.* 1998). As a result, several sparrow populations have been driven to extinction along the eastern boundary of ENP since 1981 (Curnutt *et al.* 1998).

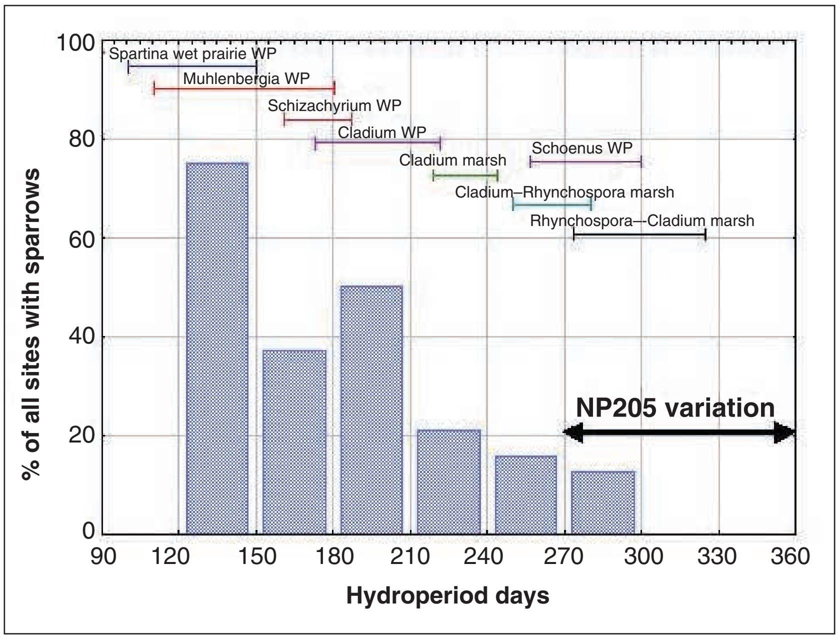

Figure 5. *Distribution of Cape Sable seaside sparrows and wet prairie plant assemblages along a hydroperiod gradient. Plant community classification is based on cluster analysis of species cover values at 179 remote sites. Hydroperiods are inferred from species composition, based on weighted averaging regression and calibration procedure, and a training dataset from sites of known hydroperiod and composition (Birks* et al. *1990). Frequencies of sparrow occurrence are based on combined census data from 2001 and 2002. Locations with longer hydroperiods support communities dominated by sawgrass (*Cladium jamaicense*) and do not support many sparrows. Hydroperiods within sparrow habitat can easily be moved along the x-axis by water managers, as can be seen by the variation in hydroperiod recorded between 1972 and 1996 at the ENP water monitoring station NP205.*

Not surprisingly, sparrow populations that use prairies in the heart of ENP, far from most water control structures and the park's urban interface, are the most stable in number (Figure 4). This does not mean that their habitat is immune to the effects of fire, and it is of central concern to managers not to allow a large natural fire to consume the remaining habitat, especially given the longer term trend in acreage burned that follows the ENSO. The last large fire that occurred during a La Niña year (1989) consumed 40 000 ha, an area that easily encompasses the remaining habitat where sparrows occur. Restoring water flows will not remove this threat, as such fires seem to be a natural (if intermittent) event. Instead, water flows and fire regimes must be better integrated across the entire sparrow range, so that all sparrow eggs are not in one basket, geographically speaking.

It is not clear how fine-tuned the interaction between water flows, fire regimes, and vegetation needs to be in order to make the recovery of the Cape Sable seaside sparrow a success. We do not fully understand how flexible sparrows are in their habitat needs, especially as they relate to fire and prolonged flooding. We are beginning to understand how hydroperiod affects plant composition and structure (see Figure 5), but we do not have a sufficient understanding of how the effects of fire "map" onto Figure 5. We must be able to integrate this information with what we are learning about the influences of habitat and disturbance events on sparrow demography. Even when we gain this detailed information, we have to be aware of how management for this one species affects other biotic elements in the ecosystem.

The long haul

South Florida is fortunate to have considerable institutional capacity in terms of fire management. Nearly all land management agencies in south Florida control or prescribe fire. However, like the ecosystem, these efforts are fragmented and critical relationships have not been forged. There is currently no formal mechanism in place for the various land management agencies to coordinate their approaches to fire management, nor is there a forum to better integrate water and fire decisions. For example, changes in fire management activities related to the recovery of the Cape Sable seaside sparrow must include consultation with representatives from ENP, Big Cypress National Preserve, Florida Division of Fish and Wildlife, and the US Fish and Wildlife Service (USFWS), as well as principal academic researchers. Only during the past 2 years have representatives from these agencies been able to meet annually to devise a long-term fire management plan that promotes sparrow recovery. Meanwhile, water management decisions concerning the sparrow are made without regard to the activities of fire managers, and include a largely separate set of agencies. This situation is currently the best-case scenario for most federally listed species, and does not include consideration of how species-specific plans may impact other biotic components of the Everglades.

Over the long haul, the success of Everglades restoration depends on developing a much more seamless integration of research, resource monitoring, and fire management across the entire ecosystem. This integration must have the same funding status as water management issues, thereby forcing the integration of water and fire management decisions. Finally, it seems well worth the price to set aside funds to develop a cross-agency, ecosystem-wide approach to managing fire during the 30 years of CERP that remain.

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