Chapter 6: Everglades Research and Evaluation

Edited by Fred Sklar and Thomas Dreschel

SUMMARY

The studies and findings discussed in this chapter are presented within four main fields: (1) wildlife ecology, (2) plant ecology, (3) ecosystem ecology, and (4) landscape patterns and ecology. Programs of study are based on the short-term operational needs and long-term restoration goals of the South Florida Water Management District (District or SFWMD), including large-scale and regional hydrologic needs in relation to regulation schedules, permitting, Everglades Forever Act (Section 373.4592, Florida Statutes) mandates, and the Comprehensive Everglades Restoration Plan (CERP). This chapter summarizes Water Year 2015 (WY2015) (May 1, 2014–April 30, 2015) hydrology in the Everglades Protection Area (EPA), followed by an overview of key Everglades studies on wildlife, plants, the ecosystem, and landscapes (Table 6-1).

HYDROLOGY

Rainfall in the Everglades was below its historical average in Water Conservation Area (WCA)-1, WCA-2, WCA-3 and in Everglades National Park (ENP). The year’s rainfall in the EPA was 3.5 to 10.5 inches below the long-term average. The difference of rainfall from its historical average increased from north to south, with ENP over 10.5 inches (19 percent) below average, while WCA-3 received 5.8 (11 percent) and WCA-1 and WCA-2 received 3.5 inches (6 percent) less than average. This year of lower rainfall follow two prior years of above average rain in WY2013 and WY2014.

WILDLIFE ECOLOGY

An estimated 33,140 wading bird nests were initiated in the Everglades (WCAs and ENP) during the 2015 nesting season (December to July). This is 30 percent more nests than last year and is almost identical to the average count of the past ten years (33,091.7 nests). This year’s improved nesting effort was the result of increased nesting effort by a single species, the white ibis (Eudocimus albus), which produced 34 percent more nests than the decadal average. All other focal indicator species [wood stork (Mycteria americana), great egret (Ardea alba), snowy egret (Egretta thula), and tricolored heron (Egretta tricolor)] exhibited reduced nesting effort in 2015 (between 25 and 99 percent below the decadal average).

The Loxahatchee Impoundment Landscape Assessment (LILA) facility continues to be an effective, living laboratory for evaluating fish, crayfish, wading bird, and hydrology interactions. This year, a LILA study continues to examine fish movement across habitat types with changing hydrology.

We also report results of the Cape Sable seaside sparrow (CSSS; Ammodramus maritimus mirabilis) nesting monitoring and habitat improvement project, and the alligator monitoring program for ENP.
Table 6-1. WY2015 Everglades research findings in relation to operational mandates.¹

<table>
<thead>
<tr>
<th>Project</th>
<th>Findings</th>
<th>Mandates¹</th>
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<tbody>
<tr>
<td><strong>Hydrology</strong></td>
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<tr>
<td>Hydrologic Patterns for WY2015</td>
<td>Rainfall was below its historical average for WCA-1, WCA-2, and WCA-3 and ENP. The year’s rainfall in the EPA was 3.5 to 10.5 inches below the long-term average during WY2015. This year of lower rainfall follows two prior years of above average rain in WY2013 and WY2014.</td>
<td>ROS MFL</td>
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<td><strong>Wildlife Ecology</strong></td>
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<tr>
<td>Wading Bird Nesting Patterns</td>
<td>An estimated 33,140 wading bird nests were initiated in the Everglades. This is 30 percent more nests than last year. This year’s improved nesting effort was the result of increased nesting effort by a single species, the white ibis. All other focal indicator species (wood stork, great egret, snowy egret, and tricolored heron) exhibited reduced nesting effort in 2015 (between 25 and 99 percent below the decadal average).</td>
<td>ROS CERP MFL FEIM</td>
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<tr>
<td>Fish Distribution in Relation to Seasonal and Short-term Changes in Hydrological Conditions</td>
<td>Results show that fish are highly responsive to changes in water levels, and responsiveness is higher than anticipated. Findings suggest that any reflooding event may be expected to alter fish distributions from deep to newly-flooded habitats, perhaps due to higher habitat profitability at first flooding. Findings also highlight that the rate of water recession appears to matter regardless of depth.</td>
<td>CERP MFL ROS</td>
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<tr>
<td>Cape Sable Seaside Sparrow Update</td>
<td>The CSSS Subpopulation D birds are surviving, do not seem to be affected by the C-111 Spreader Canal Western Project so far, and indicators of population health include observations of multiple clutches, success of multiple clutches, and migration between subpopulations.</td>
<td>CERP MFL ROS</td>
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<tr>
<td>Alligator Health Monitoring</td>
<td>The current size-class distribution—heavily skewed towards adults—is the same pattern observed following the extreme dry downs in the Everglades marsh in 2001. These dry downs possibly caused decreases in small and medium sized alligators. The number of hatchlings observed during WY2014 is encouraging and is similar to WY2013 hatchling observations in Shark Slough and Northeast Shark Slough. Additionally, the number of hatchlings observed in Northeast Shark Slough since WY2009 is well below those observed in Shark Slough.</td>
<td>CERP MFL ROS</td>
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</tbody>
</table>

¹Mandates

- **CERP**: Comprehensive Everglades Restoration Plan
- **EFA**: Everglades Forever Act, Section 373.4592, Florida Statute (F.S.)
- **FEIM**: Florida Everglades Improvement and Management
- **LTP**: Long-Term Plan for Achieving Water Quality Goals in the Everglades Protection Area
- **MFL**: Minimum Flows and Levels, Section 373.042, F.S., Chapter 40E-8, Florida Administrative Code
- **ROS**: Regulation and Operational Schedules
**Table 6-1. Continued.**

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<th>Projects</th>
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<tr>
<td>Plant Ecology</td>
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<tr>
<td>Tree Island Update: Surface-groundwater Interactions</td>
<td>Ion composition and water quality illustrated key findings that are useful in the development of metrics to assess tree island condition. Overall, stable isotope, ion composition, and water quality patterns are distinctive among tree islands, indicating a robust general characterization of the geochemistry of the different islands and plant communities within islands. A characteristic geochemical pattern of moderate total phosphorus concentrations, low extent of organic soil, and accumulation of total ions would indicate that the plant community distributed on the head has the potential to reestablish its capacity to develop mineral substrate that contributes to stabilization of the tree island system.</td>
<td>CERP EFA ROS</td>
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<tr>
<td>Ecosystem Ecology</td>
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<tr>
<td>Active Marsh Improvement Project</td>
<td>As expected, the combination of fire and herbicides to restore ridge and slough patterning produced habitat that was highly attractive to foraging wading birds. Birds began foraging in the plots immediately after open water habitat was created. On average, over 200 birds were observed per plot per week (during the period when water depths were suitable for foraging: 3 to 35 centimeters); and maximum counts for each dry season often exceeded 600 birds per plot. This intensive foraging activity was longer-lived than that often found at foraging locations in oligotrophic regions of the Everglades.</td>
<td>LTP ROS</td>
</tr>
<tr>
<td>Florida Bay Update</td>
<td>(1) Hydrologic patterns and water quality in Florida Bay showed little long-term change from the previous two years. (2) As part of Florida Bay coastal lakes research, groundwater conductivity decreased, indicating that during the wet season, a significant source of lower salinity water may be coming from the groundwater. (3) Increases in the cover of salt-tolerant <em>Thalassia testudinum</em>, decreases in <em>Halodule wrightii</em>, and the near complete absence of <em>Ruppia maritima</em> throughout the transition zone and coastal lakes is a signal that the overall benthic vegetation community is under stress. (4) The bay-wide submerged aquatic vegetation score for Florida Bay is yellow (fair) for 2014.</td>
<td>CERP MFL ROS</td>
</tr>
<tr>
<td>Peat Collapse Experiments</td>
<td>A critical concern for the management of freshwater and coastal habitats in coastal ENP is the potential for inland marshes exposed to increasing sea level rise to collapse. Collapsing peat may release nutrients into the water column that are eventually transported downstream. This may result in algal blooms and increased turbidity that would have cascading effects throughout Florida Bay and other adjacent coastal embayments.</td>
<td></td>
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</table>

¹Mandates
CERP Comprehensive Everglades Restoration Plan  
EFA Everglades Forever Act, Section 373.4592, F.S.  
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6-3
Table 6-1. Continued.

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<tr>
<td><strong>Landscape</strong></td>
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<tr>
<td>Ridge and Slough Multistate Model</td>
<td>Multistate models can directly estimate environmental parameters, past and present, connected with state/community changes. The output can provide decadal transition probabilities for each state (slough, wet prairie, and ridge) to be used to model the effects of changes in hydrology. This, in turn, can be affected by future water management and provides water management targets for maintaining a ridge and slough landscape. The best model included 15-year hydrologic amplitude, 15-year hydrological maximum, elevation, peat depth, and northing. The hydrology that creates the most stable ridge and slough landscape is an 80-centimeter 15-year average amplitude and between 80 and 90 centimeters for a 15-year average maximum.</td>
<td>CERP EFA ROS MFL</td>
</tr>
<tr>
<td>Interim Findings of the Decomp Physical Model (DPM)</td>
<td>The two flow events to date similarly achieved high slough velocities, increased sediment transport, and differential transport between ridge and slough. Closer examination of chemical and physical sediment properties indicated (1) transport of sediments (per day) was larger during the initial pulse than typical steady-state flow conditions, although steady-state transport increased with duration of culvert operations; (2) water quality changes occurred, likely linked to slough vegetation change; (3) analysis of floc biomarkers and synthetic floc experiments showed evidence of slough-sediments settling in ridges under high flow; (4) biomarker data showed widespread canal sediment sources changes with flow and (5) active management of vegetation was effective in maximizing flow velocities and sediment redistribution, warranting larger-scale field tests.</td>
<td>CERP MFL ROS</td>
</tr>
</tbody>
</table>

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CERP Comprehensive Everglades Restoration Plan
EFA Everglades Forever Act, Section 373.4592, F.S.
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ROS Regulation and Operational Schedules

**PLANT ECOLOGY**

The plant ecology study described in this chapter characterizes and compares tree islands of varying conditions within the Everglades. Characteristics of groundwater movement and nutrient and mineral accretion are compared between regions of a conserved and degraded tree island in the Everglades. Results from this study indicate that current hydrological conditions of high water level, low water flow, and impounded conditions are not conducive for restoring the structure and function of degraded tree islands.

**ECOSYSTEM ECOLOGY**

Three ecosystem-scale projects are reported in this chapter. First is an update on Active Marsh Improvement—a project designed to provide a better understanding of vegetation changes and the use of the created open plots by foraging wading birds. This study provided further evidence that burning, combined with herbicide application provides immediate open water habitat available for submerged aquatic vegetation. In these high nutrient areas, regrowth of undesirable vegetation from the seedbank and adjacent community, mean repeat application is necessary, at least initially, to ensure long-term success. However, wading birds seem to feed in denser emergent vegetation than we expected suggesting that treatments can benefit birds for extended periods without intensive management.
The second project describes monitoring and research being conducted in Florida Bay. This project has three components: (1) water quality, (2) coastal lakes research and (3) surveys of benthic vegetation. Water quality in Florida Bay (eastern, central, and western regions) has been monitored since 1991 (WY1992). Notable water quality findings for WY2015 include (1) chlorophyll $a$, total dissolved phosphorus, and turbidity were at or below the 25 percent quartile in all regions of the bay; (2) discrete salinity collected at the time of water quality sample collection was at or above the 75 percent quartile in all regions of the bay; (3) total organic carbon was less than the median in the eastern and western regions; and (4) dissolved inorganic nitrogen was at the 75 percent quartile for most of the water year in the western region and at the 25 percent quartile in the eastern region.

As part of Florida Bay coastal lakes research, groundwater conductivity decreased, indicating that during the wet season, a significant source of lower salinity water may be coming from the groundwater. This is consistent with hypothesis that groundwater may provide a significant flow into the lakes and downstream into Florida Bay.

Benthic vegetation surveys in Florida Bay, used in assessing the effectiveness of the current Florida Bay Minimum Flows and Levels (MFL) rule, found two notable trends. First, cover of *Ruppia maritima* has still not rebounded from the dramatic decreases observed following record high cover in WY2011 and WY2012. Second, *Thalassia testudinum* continues to be alive and healthy at the downstream end of the many monitoring transects. A new development in WY2015 was a significant decrease in *Halodule wrightii* cover within the central and western Florida Bay basins compared to the previous two years. Increases in the cover of salt-tolerant *T. testudinum*, decreases in *H. wrightii*, and the near complete absence of *R. maritima* throughout the transition zone in WY2015 is a signal that the overall benthic vegetation community is under stress.

The third study examines the potential for peat collapse in ENP with rising sea levels. Results so far suggest that saltwater intrusion will cause changes in soil water chemistry, increased loss of peat, and increases in microbial enzymes that break down peat. Efflux measurements showed that peat soils subjected to exposure and elevated salinity have a more positive carbon net-ecosystem-exchange rate. They become a net source of carbon to the atmosphere rather than a net sink.

**LANDSCAPE**

Two projects are described that involve the evaluation of landscape-level changes. The first project explores the ridge and slough patterning and the transition from one to the other, using a multistate probability model to predict the hydropatterns required. Parameterization suggested that deeper peat makes sloughs more resilient to a transition to a drier community, and that both ridge and slough are more stable in deep peat. Higher amplitudes (maximum – minimum annual water depth) lead to increased transitions to drier communities, but lower amplitudes did not necessarily lead to more ridge-to-slough transitions.

In the second landscape project, a summary update to the Decomp Physical Model (DPM) effort is provided. The DPM, the second largest adaptive management restoration program in United States history, examined the impacts of restoring flow between WCA-3A and WCA-3B. In WY2015, water total phosphorus and suspended sediment concentrations were briefly elevated during initial pulse releases, mainly in sloughs. The tenfold increases in suspended sediment concentrations suggest such short-term pulses could be an effective operational tool for water management in redistributing sediments and rebuilding topography. Appendix 6-1 of this volume provides a detailed description of the hydrological, biogeochemical, and biological studies conducted.
HYDROLOGIC PATTERNS FOR WATER YEAR 2015

Martha K. Nungesser and Fred Sklar

Rainfall in the Everglades for WY2015 was below its historical average (Table 6-2) in WCA-1, WCA-2, WCA-3, and ENP. The year’s rainfall in the EPA was 3.5 to 10.5 inches below the long-term average during WY2015. The difference of rainfall from its historical average increased from north to south, with ENP over 10.5 inches (19 percent) below average, while WCA-3 received 5.8 inches (11 percent), and WCA-1 and WCA-2 received 3.5 inches (6 percent) less than average. This year of lower rainfall follows two prior years of above average rain in WY2013 and WY2014.

Table 6-2. Rainfall and stage for WY2015. Total annual rainfall (inches) and annual stage [average, minimum (min), and maximum (max) stage in feet National Geodetic Vertical Datum of 1929 (NGVD29)] are compared to their historical averages.¹ Average depth is the difference between stage and elevation.

<table>
<thead>
<tr>
<th>Area</th>
<th>WY2015 Rainfall</th>
<th>Historic Rainfall</th>
<th>WY2015 Stage Mean (min; max)</th>
<th>Historic Stage Mean (min; max)</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCA-1</td>
<td>48.43</td>
<td>51.96</td>
<td>16.49 (15.18; 17.41)</td>
<td>15.66 (10.0; 18.16)</td>
<td>15.1</td>
</tr>
<tr>
<td>WCA-2</td>
<td>48.43</td>
<td>51.96</td>
<td>12.30 (11.20; 14.23)</td>
<td>12.51 (9.33; 15.64)</td>
<td>11.2</td>
</tr>
<tr>
<td>WCA-3</td>
<td>45.56</td>
<td>51.24</td>
<td>9.74 (8.58; 10.63)</td>
<td>9.59 (4.78; 12.79)</td>
<td>8.2</td>
</tr>
<tr>
<td>ENP</td>
<td>44.68</td>
<td>55.22</td>
<td>6.28 (5.59; 6.92)</td>
<td>6.01 (2.01; 8.08)</td>
<td>5.1</td>
</tr>
</tbody>
</table>

¹ Historical averages are based upon varying lengths of records at gauges. See Chapter 2 of this volume for a more detailed description of rain, stage, inflows, outflows, and historic databases.

The below average rainfall was not reflected clearly in this year’s annual average stages (Table 6-2), which were all above the historical mean average stages. This disconnect was probably because the previous wetter years provided adequate rainfall to sustain elevated stages and water managers continued to retain this water in the Everglades for environmental reasons. Another factor affecting stages in the WCAs was that water managers made ongoing releases into the WCAs from Lake Okeechobee following treatment in the Everglades Stormwater Treatment Areas (STAs); this practice was initiated jointly between the District water managers and the interagency Multispecies Management Team, who have been collaborating now for six years. Additionally, water managers held stages in WCA-1 higher upon request of the United States Fish and Wildlife Service over the dry season for ecological benefits.

In the following sections, the figures of hydropatterns at select gauges highlight the average stage changes in each of the WCAs for the last 2.5 years relative to historic averages, flooding tolerances for tree islands, drought tolerances for wetland peat, and recession rates and depths that support foraging and nesting needs of wading birds. The District uses these indices to make ecological recommendations to water managers at weekly operational meetings. Tree island inundation tolerances are considered exceeded when depths on the islands are above 2.0 or 2.5 feet for longer than 120 days (Wu et al. 2002), depending on the height of the tree islands. The drought tolerance of peat is considered exceeded when water levels are more than one foot below ground for more than 30 days, according to the criterion for MFLs in the Everglades (SFWMD 2014a).
The ground elevations in Figures 6-1 through 6-7 are used to indicate the threshold for peat conservation.

Wading bird foraging habitat suitability is divided into three categories (red, yellow, and green) based upon research on foraging by wading birds in the Everglades (Gawlik 2002, Beerens et al. 2011, 2015, Cook et al. 2014). A green label indicates good recession rates and depths for wading birds. A yellow label indicates water levels that are too shallow or too deep and/or recession rates that are slightly too rapid or too slow. A red label indicates poor conditions resulting from poor depths and/or unsuitable recession rates that are rising or falling too rapidly.

WATER CONSERVATION AREA 1

The water levels in WCA-1, also known as the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR) at the start of WY2015 were average and rose to high levels that remained elevated throughout most of the rest of the water year, as requested by staff of the United States Fish and Wildlife Service to improve ecological conditions in the LNWR. Recession rates during the wading bird breeding season (from January through May) were good to fair, providing good foraging and nesting conditions for thousands of wading birds and their nesting colonies. The small reversal in April resulted in poor foraging conditions and nest abandonment at a number of WCA-1 colonies but the extended drydown into July due to the late start of the wet season allowed for additional late and successful nesting for some species. While tree islands generally should not be inundated for more than 120 days per year, occasional events of this duration are usually not a problem for the tree island plant communities so long as they do not occur sequentially for more than two or three years in a row (Wu et al. 2002), and they probably need some dry periods for survival (Heisler et al. 2002). Sensitivity to extended inundation duration depends largely on the species comprising the forest communities on tree islands.

Figure 6-1. Hydrology in WCA-1 in relation to the 20-year median stage, as well as indices for tree island flooding, peat conservation, and wading bird foraging. [Notes: NGVD29 – National Geodetic Vertical Datum of 1929 and USGS – United States Geological Survey.]
WATER CONSERVATION AREA 2A AND 2B

Similar to the hydropattern in WCA-1, stages during the WY2015 wet season briefly exceeded the upper flood tolerance for tree islands in WCA-2A (Figure 6-2), but for much less time. In WY2014, WCA-2A water levels spiked three times during the wet season and a fourth time in the middle of the wading bird breeding season (Figure 6-2). This year’s pattern was more typical, with one peak towards the end of the wet season (early October) followed by an initially rapid then gradual recession through the end of the dry season. Recession rates were slow from January through mid-February, followed by a resumption of good recession rates. As recession rates and depths improved, wading birds moved into WCA-2A for foraging late in the breeding season. Typically, WCA-2A provides later season foraging for wading birds as the nearby areas dry out with falling water stages.

Figure 6-2. Hydrology in WCA-2A in relation to the recent 20-year average, with indices for tree islands, peat conservation, and wading bird foraging.

Unlike WCA-2A, WCA-2B tends to be utilized by wading birds only during relatively dry conditions because it tends to stay deeper for longer periods than the rest of the EPA (Figure 6-3). This year, the rapid recession rates and unusually low water levels provided excellent late season foraging conditions for wading birds.
Figure 6-3. Hydrology in WCA-2B (gauge 99) in relation to the recent 20-year average with indices for tree islands, peat conservation, and wading bird foraging.

WATER CONSERVATION AREA 3A

Water levels in northeastern WCA-3A at gauge 63 during WY2015 were very different from those of the previous two water years (Figure 6-4). Water levels started at ground level at the beginning of June and rose relatively quickly through early October, then receded gradually to ground level again by the end of May 2015. This gauge is near the Alley North colony, in most years, the largest wading bird colony in the Everglades. Much of WCA-3AN lacks defined ridges and sloughs and has dense cattail (Typha spp.) and sawgrass (Cladium jamaicense) cover with limited open water areas, which is generally poor foraging habitat for wading birds. Despite the relatively dry antecedent conditions, which reduces fish production, and the limited available foraging habitat, foraging conditions in this area were excellent in 2015. Counts exceeding 10,000 birds [white ibis, glossy ibis (Plegadis falcinellus), and roseate spoonbills (Platalea ajaja)] fed in the burned areas for many weeks, an unusual behavior not noted previously. During the previous winter, northeastern WCA-3A experienced several large surface fires that thinned the cattails and thereby allowed birds to access prey that was previously unavailable. A second unusual event was that white ibises nested in large numbers in the cattail adjacent to Alley North colony, not in the shrubs and trees of the colony itself. About 9,000 white ibis nests produced many thousands of successful fledglings. While nesting in cattail has been noted previously at this colony and elsewhere, nesting close to the ground like this is rarely so successful because of mammalian predation.

This gauge is near the Alley North colony, one of the most productive for wading birds in the Everglades. Unusual and noteworthy breeding behavior occurred this year. During the previous winter, northeastern WCA-3A experienced several large surface fires that thinned the cattails and this year appeared to provide excellent foraging conditions. Large numbers of white ibis, glossy ibis, great egrets, and roseate spoonbills were feeding in mid-February in the burned areas, an
unusual behavior not noted previously. This area lacks marked ridges and sloughs and had dense cattail cover, which generally produces relatively poor foraging conditions for wading birds. A second unusual event was that the white ibises nested in the wetlands adjacent to the tree island in cattails, not in the shrubs and trees of Alley North colony. White ibis nests appeared to be successful in this unusual nesting location, which normally does not occur. Similar nesting in cattails by white ibises was also observed in Lake Okeechobee this year.

Repairs to the S-150 structure at the northeastern corner of WCA-3A beginning in the late dry season of WY2014 prevented flows of additional rehydrating water into this area during Fiscal Year 2014-2015 (October 1, 2014–September 30, 2015), causing very dry conditions by the end of the water year with water levels at ground level. The closing of S-150 occurred about the time that water levels dropped almost one foot at the end of May 2014. While conditions were poor at the end of the Fiscal Year 2014-2015 breeding season, previous conditions had been good for ibises, as described above.

The hydrologic pattern in central WCA-3A (gauge 64) (Figure 6-5) was similar to that in northeastern WCA-3A as described above, except water depths stayed above ground, which conserves peat. The reduced depths and associated shorter hydroperiods at the end of WY2014 likely reduced fish production and the relatively slow recession rates from October to March 2015 likely limited their availability to birds. During WY2015, water levels did not exceed the upper tolerance depths for tree islands, providing conditions that allow better root aeration for most of the wet season (Heiser et al. 2002). During the prior year (WY2014), the tree island inundation duration was extended, but less than 120 days, so the lower water levels this year were probably beneficial to the tree island plant communities.

**Figure 6-4.** Hydrology in northeastern WCA-3A (gauge 63) in relation to the recent 21-year average with indices for tree islands, peat conservation, and wading bird foraging.
As in the previous three years, water levels declined steadily during the dry season (Figure 6-6). Water levels in WY2015 were below average until mid-December and then followed the 21-year average. Water levels have not been high enough to provide extended inundation duration over the prior three years but they did reach that stage in WY2014. The dryer conditions this year prevented even those stages from being met.

As with WCA-3AS, reduced depths and short hydroperiods at the end of WY2014 likely limited fish production. However, optimal recession rates from October to March 2015 made that limited prey base available to birds. While District staff did not survey wading birds in WCA-3B, anecdotal information from other District staff indicated that towards the end of the breeding season, wading birds began to use eastern WCA-3B for foraging because depths and recession rates were optimal.

**WATER CONSERVATION AREA 3B**

Figure 6-5. Hydrology in central WCA-3A (gauge 64) in relation to the recent 21-year average with indices for tree islands, peat conservation, and wading bird foraging.
This year, water levels began WY2015 with dry conditions and water approximately 0.7 feet below ground (Figure 6-7). By later in July, water levels exceeded the 31-year average slightly, peaking three times before January, after which water levels receded steadily at good rates back to ground level again by early April. Water remained below ground through the rest of the dry season. These dry conditions have not provided good foraging conditions for wading birds this year, and produced poor conditions for Everglades snail kites (*Rostrhamus sociabilis plumbeus*) as well. Heavy rainfall that affected other areas in ENP did raise the NESRS2 gauge stage to ground level again, but dry conditions returned by the end of the dry season with the water table two feet below ground (Figure 6-7). This area of ENP has repeatedly had dry conditions near the end of the dry season, preventing conditions that favor a good prey base for foraging. Florida apple snails (*Pomacea paludosa*) that provide food for snail kites that nest nearby in many years would also be absent with repeated droughts in northeastern ENP other than in the local canals.
Figure 6-7. Hydrology in Northeast Shark River Slough in relation to the recent 31-year average with indices for tree islands, peat conservation, and wading bird foraging.

**EVERGLADES NATIONAL PARK: MARL PRAIRIES**

The marl prairies of ENP differ greatly from the wetlands of the WCAs. These are shorter hydroperiod wetlands supporting mixed graminoid, short hydroperiod, wet prairie vegetation, and are particularly important for their support of the endangered CSSS. Conditions at Gauge NP-CR3 (Figure 6-8) are typical for this habitat.

WY2015 began with very dry conditions. Although it was rising, water in the marl prairie site (NP-CR3) was approximately 2.5 feet below ground on June 1. It rose above ground soon thereafter and reached a maximum depth of approximately 0.7 feet in early October. With the onset of the dry season, water levels fell below ground again in early January, dropping over 3.5 feet to less than 0.5-feet North American Vertical Datum of 1988 (NAVD88) stage. Water remained below ground through the rest of the dry season. As can be seen in Figure 6-8, stages at the end of the dry season have been lower each year consecutively from 2013 through 2015. The pattern of dry to wet conditions is typical of the hydrology of the ENP wet prairies.

Preferred habitat for the endangered CSSS is this short hydroperiod wet prairie vegetation. They breed from around the middle of March or earlier through at least the middle of July if conditions remain good. Water levels need to remain below ground with enough damp areas to provide aquatic insects for their feeding. Sparrows nest close to the ground in clumps of bunch grasses. Dry conditions extending 60 to 90 days or more are needed to provide adequate time to nest and fledge chicks. The extended dry periods in both WY2014 and WY2015 were favorable for the CSSS nesting in the subpopulations monitored by SFWMD and ENP staff.
FLORIDA BAY HYDROLOGY

Amanda McDonald

The District is part of a multi-agency partnership that maintains a long-term monitoring network throughout the southern Everglades and Florida Bay to provide a continuous record of salinity and its associated hydrologic inputs for the Florida Bay watershed. These data are used in support of District operations, in developing and monitoring CERP performance measures, assessing effectiveness of MFLs, and supporting calibration and verification of hydrologic models.

Methods

Salinity, rainfall, water elevation, and flow are monitored at instrumented platforms with salinity and rainfall reported every hour and flows measured every 15 minutes. Rainfall and most salinity platforms are maintained by ENP and are located to allow determination of upstream to downstream effects (Figure 6-9). Flow has been measured by USGS at five creeks discharging into Florida Bay since WY1997. Rainfall is also estimated by radar for Taylor Slough and the area southwest of the C-111 canal. For the purposes of this assessment, data from WY2001 to WY2015 are examined to coincide with the installation and operations of S-332D, which was a significant change to the management of the South Dade Conveyance System and water movement towards Florida Bay.
Figure 6-9. Salinity sampling points within Florida Bay and southern Everglades, showing areas influenced by water management operations from Whitewater Bay in the west to Barnes Sound in the east. Environmental parameters are monitored by SFWMD, USGS, and ENP.

Results

The wet season of WY2015 was the second driest during the period of May 2000 through April 2015 at 25 inches of rainfall and is only 0.4 inches greater than the driest wet season, which was in WY2005 (Figure 6-10). The dry season of WY2015 was also dry until April. April rainfall accounted for 54 percent of the dry season rainfall. The results of this low rainfall were low creek flows into Florida Bay (Figure 6-11) and high salinities (Figure 6-12) within Florida Bay. Water levels in Taylor Slough were near average, which is due to elevated water levels the previous year and as a result of water managers moving water into the area through the South Dade Conveyance System. Flows through S-332-D were near average for most of WY2015 despite the local dryness.

Flow into Florida Bay through the five monitored creeks during WY2015 was 46 percent of the average for WY2001–WY2013 with only 142,693 acre-feet. This allowed salinities in the bay to remain elevated throughout the wet season and rise even higher in the dry season. Salinities did not decrease below 30 in Florida Bay during WY2015 and continued to increase through the dry season (Figure 6-12). The 30-day moving average salinity at the TR station in the mangrove ecotone, which is monitored as part of the Florida Bay MFL criteria, peaked at 31.5 in July 2014 and was rising again at the end of April 2015.
Figure 6-10. Wet and dry season cumulative rainfall estimated by radar for Taylor Slough and the area south and west of the C-111 canal. The box plot on the left of each graphic shows the minimum to the maximum rainfall in inches across the period of WY2001–WY2013 with the 25th, 50th, and 75th percentiles denoted by the box and the shades of green. The columns to the right show the rainfall amounts for WY2013, WY2014, and WY2015. The red in the dry season panel denotes the amount of the dry season rainfall that occurred in April of that year.
Figure 6-11. The two criteria tracked for the Florida Bay MFL Rule: (1) the 365-day moving sum for flow from the five creeks (365-d moving sum 5 creek flow in legend of top panel) and the 30-day moving average (dma) salinity at the ENP-Taylor River platform (bottom panel); and (2) the 365-day moving sum flow is compared to the mean plus or minus one standard deviation [WY2001-WY2013 (WY01–13) average (ave.) ± standard deviation (st. dev.)] for WY2001–WY2013 showing the persistent lower than average flow in WY2015. Summed flow below the MFL threshold of 105,000 acre-feet and averaged salinity above the MFL threshold of 30 are highlighted in each panel. Flow data are provisional for October 2014 forward and supplied courtesy of USGS.
Figure 6-12. Mean monthly salinity values in the mangrove ecotone at the ENP-Taylor River platform (top), eastern Florida Bay (middle), and central Florida Bay (bottom) in WY2013–WY2015 (WY 13-15 in the legend), compared to monthly means (WY01-13) and standard deviation [WY 01-13 s.d.] for WY2001–WY2013. The eastern and central bay salinity values are averaged between two continuous monitoring platforms within each region.
Relevance to Water Management

Below average rainfall caused low creek flow to Florida Bay and elevated salinities throughout WY2015. Water releases through the South Dade Conveyance System and the C-111 Spreader Canal Western Project helped to attenuate the effects of the severe local drought but could not reverse the rising salinities in Florida Bay. As a result, the 30-day moving average at the Florida Bay MFL compliance site rose to 31.5 in July 2014 constituting an exceedance and was rising again at the end of WY2015.

A second criterion for the Florida Bay MFL is that the 365-day moving sum of cumulative flow from the five monitored creeks cannot go below 105,000 acre-feet. In January 2015, the 365-day moving sum of flow decreased below 120,000 acre-feet for only the second time since the adoption of the MFL. The first time was in WY2009, when the 365-day moving sum of flow from the five creeks decreased to about 113,500 acre-feet in August 2008. April 2015 saw the lowest value since the adoption of the MFL, with a 365-day moving sum of flow from the five creeks of approximately 110,800 acre-feet, which is still above the 105,000 acre-feet criteria.

WILDLIFE ECOLOGY

The District currently focuses its wildlife research toward gaining a better understanding of the links among hydrology, aquatic prey availability, and wading bird foraging and reproduction. These relationships have been formalized in the Trophic Hypothesis, a conceptual ecological model that provides the underlying scientific framework for District wildlife research (RECOVER 2012; http://141.232.10.32/pm/ssr_2012/ssr_2012_pdfs/2012_ssr_full_web.pdf). This research has improved both the District’s capacity to effectively manage the system and ability to predict future restoration scenarios. This utility of the research stems not only from an improved knowledge of how key ecological drivers affect wading bird reproduction, but also from the recasting of these data into practical spatially explicit tools to predict foraging and nesting responses to physical and biological processes in real time and space. This section (1) summarizes wading bird nesting effort and success in the Everglades and Florida Bay during the WY2015 breeding season, (2) describes a study that examines inter-habitat movements of remotely tagged fish in response to water-level changes in the LILA area, (3) reports on nesting success monitoring of the CSSS and habitat improvement efforts and, (4) the results of alligator monitoring in ENP.

WADING BIRD MONITORING

Large populations of colonially nesting wading birds (order Pelecaniformes: egrets, ibises, herons, spoonbills; and order Ciconiiformes: storks) were a common and defining feature of the predrainage Everglades. Long-term records of their nesting stretch back to the early part of the last century, and some clear reproductive responses to anthropogenic alterations have been established. These include the following:

- A marked decline in the nesting populations of several species, particularly the tactile foraging species
- A movement of colonies from the overdrained estuarine region to the more ponded interior marshes
- A marked decrease in the frequency of exceptionally large aggregations of nesting white ibises
- Delayed nest initiations of wood storks by a few months (from November/December to February/March), resulting in reduced nestling survival
These responses appear to be consistent with mechanisms that involve foraging and specifically the role that hydrology plays on the production and vulnerability to predation of aquatic prey animals (see Frederick et al. 2009 and references within).

Wading birds are excellent indicators of wetland ecosystem health and have a central role in CERP. Nesting figures for CERP performance measures are restricted to colonies in the Greater Everglades region, i.e., WCAs and ENP, for the following five species:

- Great egret
- Snowy egret
- Tricolored heron
- White ibis
- Wood stork

The timing of breeding, number of nests, and location of nesting colonies within the Everglades are used as CERP targets to evaluate the progress of the Everglades restoration effort. In addition to CERP, wading birds are of special interest to the public and play a prominent role in adaptive protocols, MFLs, and day-to-day operations of the District.

Recovery of pre-drainage (1930–1940) wading bird nesting patterns is evaluated using the two independent sets of measures. CERP’s Restoration Coordination and Verification Team (RECOVER) established three performance measures, which include the three-year running average number of nesting pairs of the five key wading bird species, timing of wood stork nesting, and proportion of the wading bird population that nests in the marsh-coastal ecotone (Ogden 1994, http://141.232.10.32/pm/recover/perf_ge.aspx). In addition, the South Florida Ecosystem Task Force developed two additional measures for annual spotlight reports: the ratio of visual to tactile wading bird species breeding in the Everglades, and the frequency of exceptionally large white ibis nesting events (Frederick et al. 2009). The measures are as follows:

- Increase and maintain the total number of pairs of nesting birds in mainland colonies to a minimum of 4,000 pairs of great egrets, 10,000–20,000 combined pairs of snowy egrets and tricolored herons, 10,000–25,000 pairs of white ibises, and 1,500–2,500 pairs of wood storks.
- Shift in timing of nesting in mainland colonies to more closely match pre-drainage conditions. Specific recovery objectives would be for wood storks to initiate nesting no later than January in most years and for ibis, egrets, and herons to initiate nesting in February–March in most years.
- Return of major wood stork, great egret, white ibis and Egretta nesting colonies from the Everglades to the coastal areas and the freshwater ecotone of the mangrove estuary of Florida Bay and the Gulf of Mexico.
- Reestablish historical distribution of wood stork nesting colonies in the Big Cypress Basin and in the region of mainland mangrove forests downstream from the Shark Slough and Taylor Slough basins. Increase the proportion of birds that nest in the southern ridge and slough marsh-mangrove ecotone to greater than 50 percent of the total for the entire Greater Everglades.
- For wood storks, restore productivity for all colonies combined to greater than 1.5 chicks per nest.
- Return to an interval between exceptional white ibis nesting events, defined as greater than 70th percentile of annual nest numbers for the period of record.
Summary of Nesting Year 2015

The information reported in this section represents a compilation of data collected by the District, University of Florida, ENP and Audubon of Florida. The population counts include all wading bird species (except cattle egret, *Bubulcus ibis*) nesting throughout the Greater Everglades region (WCAs, ENP, and Florida Bay), and the period covered is the nesting season from January to July 2015. Note that counts do not include estimates of precision due to the challenges of estimating detection bias at the landscape scale, although progress is being made in this respect (e.g., Fredrick et al. 2003, Williams et al. 2011). For details on independent sampling methods see Cook (2014).

Nesting Effort

During the 2015 nesting season, an estimated 33,140 wading bird nests were initiated in the WCAs and ENP. This nesting effort is within a single percentage point of the decadal average (33091.7 nests), 27 percent greater than the five-year average (26,097.6 nests), and 55 percent lower than the banner year 2009 when a record high of 73,096 nests was recorded in the Everglades.

This year’s improved nesting effort was due entirely to increased nesting effort by a single species, the white ibis, which produced 34 percent more nests than the decadal average, and 69 percent more than the five-year average (Figure 6-13). Most other species exhibited reduced nesting effort in 2015. Numbers of great egret and wood stork nests were down 25 and 53 percent, respectively, from the ten-year average, and down 21 and 58 percent, respectively, from the five-year average. The smaller *Egretta* herons, which have exhibited a consistent decline in nest numbers in recent years, had another relatively poor nesting season: nesting effort was reduced 66 percent for the snowy egret relative to the ten-year average, while tricolored heron and little blue heron (*Egretta caerulea*) nesting was down 99 and 94 percent, respectively. These declines in *Egretta* herons do not appear to be due to changes in the distribution of nesting and instead appear to reflect a general reduction in overall nesting effort in the Everglades.

Roseate spoonbill nesting generally improved during 2015 relative to recent years. In Florida Bay, spoonbills produced 365 nests, which is almost 3 times more than last year (126 nests) and 1.5 times more than the five-year mean (269.8 nests). However, this effort was poor from a historical perspective being 23 percent lower than the 30-year mean (475 nests) and a considerable drop relative to the mid-twentieth century when over 1,000 nests per year were common. Moreover, the location of nesting colonies within the Florida Bay area has shifted in recent years. Whereas most nesting has always occurred on small keys within the bay itself, recent years has seen a movement of nesting to mainland colonies adjacent to the coast (i.e. Madeira Hammock and Paurotis Pond colonies). The reason for this move is unclear but might reflect the recent reduction in mammalian predators (raccoons) on the mainland or a reduction in the suitability of habitat for nesting on the keys. Some individuals have deserted Florida Bay entirely. For three of the past four years, about 200 pairs have nested at colonies in the central freshwater Everglades such as northern WCA-3A. This trend continued during 2015, with 190 nests found at inland colonies.

Spatial Distribution

ENP historically supported the majority of nests in the Greater Everglades, but in recent decades there has been a shift towards nesting at inland colonies in the WCAs. An important goal of restoration is to restore the hydrologic conditions that will reestablish prey availability across the southern Everglades landscape that, in turn, will support the return of large successful wading bird colonies to the traditional estuarine rookeries downstream of Shark Slough. In 2015, ENP supported 18 percent of nests, while WCA-3A and WCA-1 supported 60 and 22 percent, respectively. This represents a slight decrease in the proportion of birds nesting in ENP relative to the decadal average (22 percent) and falls far short of the 50 percent restoration target.
Figure 6-13. Historical wading bird nesting numbers in the Everglades for individual species since 1997.
**Timing of Nesting**

Wood storks have a relatively long reproductive period (about four months), and it is critical they start nesting early in the dry season to ensure nestlings have time to fledge and gain independence prior to the onset of the rainy season in May–June. This is because their prey (fish) are easy to find and feed upon when concentrated at high densities in shallow water during the dry season, but are not available to birds when they disperse back into the deeper marsh after water levels rise in the summer. Without the dry season supply of highly concentrated prey, parent birds are unable to support their offspring and nest successfully. Historically, stork nesting started in November–December, but in recent decades it has shifted to January–March. The reason for this delay is due to a reduction in the availability and quality of short hydroperiod wetlands, which provide suitable foraging habitat early in the breeding season. In 2015, wood storks initiated nesting in late February at the coastal colonies and late February and early March at the inland colonies. These start times are later than last year (late January), and fall short of the CERP target date (December).

Other early nesting species, such as the great egret, nested about a four weeks later than average. White ibises and the *Egretta* herons, which tend to nest later in the season (March–April), started nesting on time but there was an unusual late surge of ibis nesting in May and June that was largely successful due to the late start to the wet season.

Roseate spoonbills in Florida Bay typically nest very early in the nesting season (November–December) but the mean lay date in 2015 was February 10, which is 43 days later than last year’s mean lay date. Moreover, the timing of laying was considerably more asynchronous than usual, with mean lay dates for colonies spanning January through April.

**Nesting Success**

The University of Florida measured nest success (p, the probability of fledging at least one young, the Mayfield method) at seven colonies in the WCAs and ENP. Nest success varied among species with *Egretta* herons \( p = 0.818 \) (standard deviation (SD) = 0.0682) and great egrets \( p = 0.645 \) (SD = 0.0346) being the most successful, while white ibis fared less well \( p = 0.367 \) (SD = 0.0639). Success of each species also varied considerably among colonies; for example, great egret nest success was 94 percent at Tamiami West Colony but only 27 percent at Joule.

**Role of Hydrology on Nesting Patterns**

Wading bird reproductive patterns in South Florida are driven principally by hydrology through its influence on aquatic prey production and vulnerability to predation (Frederick et al. 2009). The 2015 breeding season was generally preceded by dryer than average conditions during the 2014 dry season, which kept water levels below ground for extended periods across large areas of the central and southern Everglades. Such conditions generally limit the production of small fish (Trexler et al. 2005), and any reduced fish biomass might account for the observed late nesting and decreased nesting effort by the piscivorous wood stork and great egret in 2015. In contrast to fish, production of the slough crayfish (*Procambarus fallax*) typically increases after dry conditions via predator release or nutrient pulse mechanisms (Frederick and Ogden 2001, Dorn et al. 2011, Dorn and Cook, in press). The dryer conditions during 2014 were conducive for crayfish production and this might explain the increased nesting by the invertivorous white ibis in 2015, which relies heavily on crayfish during reproduction (Boyle et al. 2014). With regard to prey vulnerability, recession rates and water depths were generally good for wading bird foraging from October 2014 through April 2015 but rain events in April caused water level reversals and the dispersal of concentrated prey. This probably accounts for the observed nest abandonments by white ibis that started shortly after the reversal events.
**Restoration Targets**

Wood storks, white ibises, and great egrets met the numeric CERP targets (three-year running averages) but snowy egrets/tricolored herons did not (Table 6-3). The two other CERP targets (an increase in the proportion of nesting wading birds in the coastal Everglades and a shift in the timing of wood stork nesting to earlier in the breeding season) are discussed above and did not meet the necessary requirements. With respect to the annual spotlight targets, the 2015 white ibis nesting effort did attain the number of nests (> 16,977 nests) required for an exceptional nesting event, and the interval between such events averaged over the past five years is 2.0 years, which is only slightly greater than the restoration target of 1.6 years recorded from the 1930s. The ratio of tactile to visual foragers was only 4.4, almost an order of magnitude lower than the restoration target of 32.

**Table 6-3.** Numbers of wading bird nests in the WCAs and ENP compared to CERP targets and historical ranges. Target numbers are based on known numbers of nests for each species during the predrainage period 1930–1940, and which were summarized by Ogden (1994).

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<td>Great Egret</td>
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<td>5,869</td>
<td>6,956</td>
<td>6,774</td>
<td>8,303</td>
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<td>6,961</td>
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<td>Snowy Egret/Tricolored Heron</td>
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<td>4,400</td>
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<td>1,723</td>
<td>2,442</td>
<td>2,622</td>
<td>1,004</td>
<td>716</td>
<td>583</td>
<td>372</td>
<td>10,000–20,000</td>
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<td>White Ibis</td>
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<td>21,133</td>
<td>17,541</td>
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<td>20,081</td>
<td>22,020</td>
<td>11,889</td>
<td>16,282</td>
<td>17,261</td>
<td>21,406</td>
<td>10,000–25,000</td>
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<td>552</td>
<td>1,468</td>
<td>1,736</td>
<td>2,263</td>
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**FISH DISTRIBUTION IN RELATION TO SEASONAL AND SHORT-TERM CHANGES IN HYDROLOGICAL CONDITIONS**

Jennifer S. Rehage¹, Gregory E. Hill¹, Mark I. Cook and Eric Cline

An important knowledge gap in Everglades ecology and ongoing restoration efforts is, what factors contribute to the formation of high quality foraging patches for wading birds. A major goal of CERP is to reestablish hydrological conditions that promote wet season prey production and dry season prey concentration to support improved wading bird foraging and nesting success (RECOVER 2006). However, understanding of how fish concentrations form remains limited. Understanding this requires a more detailed examination of how fish distribution is affected by hydrological variation at finer spatiotemporal scales.

In response to the receding waters of the dry season, Everglades fishes are known to move and concentrate in lower elevation habitats. These deeper areas include local depth maxima in marshes

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(Gawlik and Botson 2008, Botson et al. 2011, Cook et al. 2014), and deeper and perhaps more distant ‘refuge’ habitats such as solution holes, alligator holes, canals, and coastal creeks (Rehage and Trexler 2006, Parkos et al. 2011, Boucek and Rehage 2013, Rehage et al. 2014a, Parkos and Trexler 2014). Therefore, fish are expected to make movement decisions in response to varying water levels (Nathan et al. 2008). These decisions will have important implications for the quality of prey concentrations (e.g., quantity, availability, and location), yet little is known about how fish behaviorally respond to hydrological variation. For instance, do fish perceive small changes in water levels, and if so at what depths? And, how do consistent versus erratic changes in water levels affect fish distribution?

The aim of this study is to understand the fine-scale distribution of Everglades fishes in response to varying water levels. In particular, two questions are asked: (1) How is fish distribution across multiple habitats affected by seasonal hydrology? and (2) Are these seasonal distributional patterns affected by unseasonal changes in water levels such as reversals? Reversals refer to hydrological discontinuities caused by unseasonal rain or water management events that cause a reversal in the drying pattern and therefore an increase in water levels during a recession period (Bereens et al. 2011). Hydrological reversals are of interest since they are thought to disrupt prey concentrations, and have a negative effect on prey availability for wading birds (Cook and Herring 2007, Gawlik and Botson 2008, Bereens et al. 2011). To answer these questions, a combination of large field enclosures and passive antenna detection systems were used (Rehage et al. 2014b, Rehage et al. 2015) to continuously track the distribution of tagged fish over periods of varying hydrology.

Methods

In six large (12 meter (m) x 4 m) replicate enclosures constructed at LILA, fine-scale movement and distribution of passive integrated transponder (PIT)-tagged spotted sunfish (*Lepomis punctatus*) (Figure 6-14) were tracked. Each enclosure contains three representative marsh habitats along a depth gradient: (1) 25 percent shallow ridge [0–30 centimeters (cm) depth], (2) 50 percent mid-water slough (0–70 cm depth), and (3) 25 percent deep alligator hole (60–120 cm depth). Three flat-bed passive antennas placed at the edges and center of each habitat allow fish movement to be recorded in and out of each habitat (Figure 6-14; Rehage et al. 2014b). When PIT-tagged fish cross the electromagnetic field of an antenna at any depth, the unique code of the tag is read and stored in the data logger along with a time stamp, allowing for continuous tracking of each individual sunfish across the three enclosed habitats (Figure 6-15). Five to seven spotted sunfish were stocked per enclosure and their distribution was recorded across wet to drying conditions between January and July 2015 (Figures 6-16 and 6-17). In April–May, an experimental reversal was induced where water levels were raised for a period of 16 days mid-recession.

The focal species was spotted sunfish, a widespread centrarchid throughout Everglades habitats (Rehage and Trexler 2006, Rehage et al. 2014a Fig. 1). This is the second centrarchid species tested in the enclosure system (after warmouth (*Lepomis gulosus*) see Rehage et al. 2015). Centrarchids (sunfishes) are the dominant mesoconsumers in the freshwater Everglades (Rehage and Trexler 2006, Parkos et al. 2011, Boucek and Rehage 2013), and preferred prey for wading birds (Ogden et al. 1976), particularly spotted sunfish (Gawlik et al., Florida Atlantic University, unpublished data). Centrarchids are also known to move and alter habitat use in response to seasonal hydrology (Parkos et al. 2011, Boucek and Rehage 2013). Spotted sunfish were captured by hook and line in Macrocosm 1 at LILA. All fish were weighed, measured, photographed, PIT tagged, and stocked in enclosures in January 2015.
Figure 6-14. Aerial of Macrososm 1 at LILA showing location of the six study enclosures. Schematic shows enclosure dimensions and setup of three antennas used for continuous fish detection across ridge, slough, and alligator hole habitats. Images show focal fish species in 2015, native spotted sunfish, and a PIT tag used to uniquely identify study fish.
Figure 6-15. Example of continuous individual detections for one of the study spotted sunfish (Tag # 9456) across the three habitats (ridge, slough, and alligator hole) in April–May 2015. Blue shading shows the timing of the experimental reversal (see Figures 6-16 and 6-17 for exact water levels during the reversal). Detections show a change in habitat use with the flooding of the ridge during the reversal. Fish #9456 increases use of the ridge and lowers use of the deepest habitat, the alligator hole.
Figure 6-16. Daily probability of detecting a spotted sunfish in each of the three enclosed habitats between January and July 2015. Blue lines show water levels in each habitat, including during the experimental reversal in late April–early May (grey shading).
Figure 6-17. Proportion of antenna detections across enclosure habitats for spotted sunfish between January and July 2015. Blue lines show water levels in each habitat, including during the experimental reversal in late April–early May (grey shading).
From continuous detection data (179 days and up to 90,000 detections per fish), daily measures of distribution were obtained by calculating the probability of detecting a fish in a particular habitat, and the proportion of detections per habitat for each fish. These daily proportions of antenna detections (averaged for all fish detected each day of data collection) were compared across the three habitats and three hydrological periods of interest (recession prereversal, reversal, and recession postreversal) using a two-way analysis of variance (ANOVA) in SYSTAT® 13.

**Results**

The distribution of spotted sunfish across the three enclosed habitats varied significantly as a function of hydrological conditions (hydrological period x habitat interaction, $F_{4, 465} = 137.5$, $p = 0.0001$). Overall, spotted sunfish had a consistently higher probability of being detected in the alligator hole than in the other two habitats ($>0.9$, Figure 6-16). But, movement of spotted sunfish in the ridge and slough habitats was highly responsive to water levels. Between January and April 2015 as water levels receded, the likelihood of detecting a spotted sunfish in the ridge and the slough decreased from greater than 0.9 to close to zero. Over this recession period, fish distribution also switched rapidly in response to small but fast drops in stage. For instance, a 5-cm drop in stage over three days in mid-February caused a greater than 30 percent shift in distribution or detections from the slough to the alligator hole (Figure 6-17).

The reversal reflooded the ridge, raising water levels there above 15 cm for 11 days, and increasing depth in the slough from 17 cm to above 50 cm. As water levels increased, the probability of detecting sunfish in both the slough and ridge approximated 1 (Figure 6-16), indicating that all tagged fish were responsive to the reversal event, and moved to shallower habitats as these became available (ridge) or deeper (slough). Use of the ridge and the slough peaked during the reversal with over 40 percent of tag detections in the ridge and 30 percent in the slough, higher than at any other period over data collection—even than at deeper conditions early in the wet season (January–February, Figure 6-17). Post-reversal as water receded, a decline was seen in the use of these two shallower habitats. But, slight increases in stage due to rain events in both early June and July resulted in rapid shifts in sunfish distribution that again moved fish out of the alligator hole and into shallower habitats, further highlighting that any increase in water levels, whether minor or large (reversal), elicited a change in fish distribution.

**Discussion and Relevance to Water Management**

Linkages among hydrological variation, prey dynamics and wading bird foraging and nesting success remain poorly understood, yet are critical to Everglades restoration and water management. A key unknown is how does hydrological variation affect fish distribution and habitat selection across the landscape, and therefore influence their concentration and availability to wading birds as prey.

Three key findings are highlighted from this study. First, any increase in water depth during the study resulted in an almost instantaneous shift in spotted sunfish distribution. Rapid shifts were noted in distribution from deep water (alligator hole) to shallower habitats (ridge and slough) as a result of the reversal and of two minor rain-caused increases in depth postreversal. These responses are similar to those noted during a recent study on the warmouth sunfish (Rehage et al. 2015). Second, this species appears to use rapid recession rates as a proximate cue for movement to deeper habitats. A rapid recession event in February 2015 where water levels receded at a rate of 2.4 cm per day elicited a major drop (30 percent) in use of the slough and a corresponding increase in the use of the alligator hole. This was despite the slough being considerably deeper (~50–60 cm) than depths typically needed to prompt prey movements [e.g., warmouth 18–20 cm, Rehage et al. 2015; slough crayfish < 5 cm, Cook et al. 2014]. This behavioral response to recession rate has not previously been noted in Everglades fish species, yet mirrors closely increased wading bird
foraging and nesting responses to increased recession rates (Herring et al. 2010, Beerens et al. 2011). Next year, we hope to experimentally examine the relative roles of recession rate and water depth on fish movement. Third, fish used shallow habitats more when these were first reflooded. Use of the ridge by sunfish was greatest during the reversal, which doubled the use observed earlier in the wet season at higher depths. In January–February, although depths in the ridge were above 20 cm, use of the ridge was minimal. Similar behavioral patterns were also noted for warmouth in a 2014 study (Rehage et al. 2015).

Overall, results show that fish are highly responsive to changes in water levels, and responsiveness is higher than anticipated. Findings suggest that any reflooding event may be expected to alter fish distributions from deep to newly-flooded habitats, perhaps due to higher habitat profitability at first flooding. Findings also highlight that the rate of water recession appears to matter regardless of depth. The study points to the fact that any alterations to natural hydrological patterns may be expected to affect fish distribution rapidly, resulting in losses in prey concentration in deeper habitats and a redistribution of fish to shallower habitats, affecting prey availability for wading bird foraging.

CAPE SABLE SEASIDE SPARROWS, SUBPOPULATION D

Martha Nungesser, Tom Virzi2, and Michelle J. Davis2

The Cape Sable seaside sparrow (CSSS, *Ammodramus maritimus mirabilis*) is a federally designated endangered subspecies of the more broadly distributed seaside sparrows. This subspecies is found only in ENP (Figure 6-18). Because some of its critical habitat (Subpopulations C and D) are located in the area affected by one of the District’s Everglades restoration projects, the C-111 Spreader Canal Western Project, the District is required by a biological opinion (USFWS 2009) to monitor Subpopulation D annually to determine what, if any, impact the project is having on the sparrows (SFWMD 2015a). The project, a component of CERP, is intended to improve the quantity, timing, and distribution of water delivered to Florida Bay through Taylor Slough, improve hydroperiod and hydropattern in the Southern Glades and Model Lands, and reduce ecologically damaging flows to Florida Bay and other receiving waters (USACE and SFWMD 2009).

For the last three years, the District has contracted with CSSS expert scientists to survey the sparrow in Subpopulation D from March 1 through July 14, the time period over which the sparrows nest. The birds use bunchgrasses (mixed graminoid, short hydroperiod, wet prairie vegetation) (Lockwood et al. 1997, 2006, 2008, Pimm et al. 2002) for cover and to construct nests about 4 cm above the ground in the base of the grasses (Figure 6-19). During their nesting, they require dry ground below the nests, but also areas nearby with enough moisture to provide the aquatic insects they consume while breeding. Hydropatterns of at least 60 consecutive days of dry ground under the nests are understood to provide adequate time for nest building, egg production, and fledging chicks (Walters et al. 2000, Virzi et al. 2011). If dry periods continue, then second and possibly third nests can succeed (USFWS 2009). The quality and duration of the breeding season are generally determined by local weather rather than by water management. Heavy rainfall may affect breeding; if rainfall causes water levels to rise to or above the level of the nest, chicks and eggs may not survive. Overly dry conditions may also reduce prey availability, affecting nest success.

Ground elevations in the northern and central portion of Subpopulation D are suitable for preferred sparrow vegetation and its associated hydrological conditions (Virzi et al. 2011). The

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2011 CSSS habitat baseline surveys showed that, as in previous years, CSSS activity was concentrated in the central and northern portions of Subpopulation D (Virzi et al. 2011), locations less likely than more southerly areas to be affected by increasing water depths resulting from sea level rise (Titus and Narayanan 1995, Wanless 2008).

**Figure 6-18.** Designated critical habitat and undesignated habitat for the six CSSS subpopulations, five in ENP and one in adjacent state-owned land (Subpopulation D). Adult male CSSS (photo courtesy of M. Davis, Ecostudies Institute).

**Figure 6-19.** Nest and nesting location of a CSSS pair (photos courtesy of M. Davis, Ecostudies Institute).
Both the SFWMD and the National Park Service monitor the sparrows and both support field surveys. In addition, the National Park Service staff from ENP conducts surveys via helicopter at predetermined sites in all six subpopulations, indicated in Subpopulation D by the regularly spaced circles in Figure 6-20. The helicopter surveys are conducted once during the breeding season to locate calling males. This survey, repeated annually, provides a standard protocol to address questions of population estimates and changes over time. In contrast to the annual helicopter surveys, field crews contracted by both SFWMD and ENP conduct up to daily ground surveys within the subpopulations (in 2015, surveying Subpopulations A, B, and D), visiting several times a week and more frequently when active nests are located. In Subpopulation D, field crews monitor the previously identified breeding grounds shown in Figure 6-20 where three stage gauges, CSSD1, CSSSD2, and SWEVER4, mark the perimeter of the area where recent breeding has occurred. Field crews determine the number of males and their territories, females in the area, and the nests with eggs, nestlings, and fledglings. Nests are monitored frequently to assure that nesting was completed and chicks were banded or until the nest failed. The scientists follow the progress of courting, nesting, and other behaviors. Because individual birds are banded as adults or as chicks, demographic data can be associated with each bird. Through identification of banded birds, they can determine whether a sparrow is local or has immigrated from another subpopulation, its gender, age, and other information.

**Figure 6-20.** Sampling sites for CSSS subpopulation D. The numbered circles are helicopter sampling sites for the National Park Service. The light gray circles represent known nesting locations in Subpopulation D. The green lettered sites are stage gauges that monitor stages near the CSSS preferred habitat.
Summary of Annual Surveys

Over the last three years, the CSSS Subpopulation D has been stable or increasing slightly. It has been dominated by males with very few females, but each year nesting has succeeded in fledging at least one set of chicks. In 2013, the population was very low, with only four males and two females (Table 6-4). The number of males increased greatly the next year with eleven males and three females. In 2015, eight males were located, but only one female was seen. In all these years, even with few females, nests fledged between six and eight chicks over the breeding season.

Table 6-4. Annual counts for the CSSS in Subpopulation D

<table>
<thead>
<tr>
<th>Year</th>
<th>Males</th>
<th>Females</th>
<th>Nests</th>
<th>Chicks Fledged</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>11</td>
<td>3</td>
<td>5</td>
<td>7 or 8</td>
<td>One pair produced 3 nests, 7 or 8 chicks</td>
</tr>
<tr>
<td>2015</td>
<td>11</td>
<td>1</td>
<td>2</td>
<td>2 + 4 eggs hatched</td>
<td>One pair produced 2 nests, &gt; 2 chicks</td>
</tr>
</tbody>
</table>

Highlights from these years are that, in 2014, one pair successfully fledged three nests, totaling 7 or 8 chicks. This is the first record of three successful nests in one season by one pair in this subpopulation. While both parent birds were experienced, this was their first year to be paired. Their habitat remained dry into early August, facilitating their successful multiple brooding. In 2015, a different pair nested three times, successfully fledging two chicks from the first nest, but their second and third nests were predated prior to fledging the chicks. In 2014, one male was identified that had migrated to Subpopulation D from Subpopulation B, verifying that such exchanges are occurring. Another positive discovery was that one female sighted in Subpopulation D had been hatched and banded there and remained there to breed as an adult.

During these years, additional surveys occurred in Subpopulations A and B. Details on these subpopulations can be found in the annual CSSS reports (Virzi and Davis 2013, 2014).

In summary, the CSSS Subpopulation D birds are surviving, do not seem to be affected by the C-111 Spreader Canal Western Project so far, and that the sparrows can fledge up to three clutches a year and that migration between subpopulations is occurring (Virzi and Davis 2015).

CSSS Habitat Improvement Plan (2015–2019), Subpopulation D

An additional responsibility of the District is to improve the habitat in Subpopulation D for the sparrows. Major improvements are being made in the northern portion of Subpopulation D because ground elevations are suitable for the specific wet prairie vegetation preferred by the sparrows, and this is the area in which they currently nest (Figure 6-21). The habitat restoration conducted from 2010 to 2014 included removal of woody vegetation that had encroached following overdrainage. Some of the woody vegetation included native species that normally would have been constrained to tree islands under higher water depths and other species were invasive or exotic species.

Vegetation removal was by a combination of prescribed fire in 2010 followed by hand treatment (pulling and very limited chemical treatment) in 2012–2014. These treatments are conducted on District territory outside of the breeding season of the sparrows. Hydrologic improvement in 2014 included cutting three 40-foot sections three feet deep across a dirt road that had impeded southward flow of water, causing local ponding (SFWMD 2014b). Flow across the roads is occurring and ponding has been reduced. Over the next five years, additional controlled
burns, hand pulling, and limited treatment with herbicides are planned and will be determined by interagency land managers (SFWMD 2014b).

**Figure 6-21.** Proposed habitat improvement plan for CSSS Subpopulation D from 2015 through 2019 (SFWMD 2014b).

**MONITORING RELATIVE DENSITY AND BODY CONDITION OF THE AMERICAN ALLIGATOR IN EVERGLADES NATIONAL PARK**

Frank J. Mazzotti³, Jeff Beauchamp³ and Laura Brandt⁴

The American alligator (Alligator mississippiensis), a species that integrates biological impacts of hydrologic conditions at all life stages (Mazzotti 1999, Mazzotti and Brandt 1994, Mazzotti and Cherkiss 2003, Rice et al. 2005), is an important indicator of the health of the Everglades ecosystem (Mazzotti et al. 2009) because research has linked three key aspects of Everglades’ ecology to them. First, top predators such as alligators are directly dependent on prey density, especially aquatic and semi-aquatic organisms and, therefore, they provide a surrogate for status of many other species.

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Second, drier (nests) and wetter (trails and holes) conditions created by ecosystem engineers like alligators provide habitat for plants and animals that otherwise would not be able to survive. This increases diversity and productivity of Everglades marshes (Campbell and Mazzotti 2004, Kushlan and Kushlan 1980, Palmer and Mazzotti 2004) and, therefore, alligator monitoring, can indicate overall health of the marsh. Also, the distribution, abundance, and condition of alligators in estuaries are directly dependent on timing, amount, and location of freshwater flow (Dunson and Mazzotti 1989, Mazzotti and Dunson 1989).

Historically, alligators were present in all wetland habitats of the Everglades with highest abundance in habitats peripheral to the deeper sloughs and in freshwater mangrove areas (Craighead 1968). Alterations to habitats and hydrology have changed the spatial distribution and abundance patterns of alligators with relative densities and body condition lower than restoration targets in ENP (Mazzotti et al. 2010)

Projects to improve water flow north of Tamiami Trail and south into ENP are key components of overall efforts to restore the South Florida ecosystem. Restoration of landscape integrity and protection/conservation of critical species such as alligators are a part of overall ecosystem restoration. Efforts underway to accomplish this include both CERP projects such as those in the Central Everglades Planning Project and non-CERP projects such as the Tamiami Trail Modification Project. Water management and these projects collectively should protect and restore landscape integrity including the quantity, timing, and distribution of water delivered to ENP via Shark Slough and Northeast Shark Slough (NESS). As projects are implemented, positive responses in both alligator relative density and body condition are expected.

Objectives

The objective of this project is to monitor changes in relative density and body condition of alligators in Fiscal Year 2013-2014 in three locations south of Tamiami Trail in ENP in response to restoration projects and changes in hydrology. This work enhances and builds upon research and monitoring programs for alligators that have been funded as part of the Critical Ecosystem Study Initiative, Modified Water Deliveries, Priority Ecosystems Studies program, and Restoration Coordination and Verification Program (RECOVER).

Methods

Relative density was determined by conducting spot-light surveys along established routes in NESS, Shark Slough (SS) and Shark River (SR) using protocols established for RECOVER. Each survey route consisted of two 10-kilometer transects and was surveyed twice in fall (September/October 2013) and twice in spring (March/April 2014) at least 14 days apart in order to achieve independent counts (Woodward and Moore 1990). Alligator locations were recorded using a global positioning system (GPS; UTM WGS 84). Sizes of alligators were estimated in quarter meter increments or if size could not be estimated, animals were placed in small, medium, large, or unknown size classes.

Body condition was determined in fall and spring by capturing 15 alligators ≥ 1.25 m adjacent to each survey route. Total length, snout-vent length, head length, tail girth, and mass were measured; sex was determined; and any abnormalities/deformities were noted. Each alligator was tagged using a Florida Fish and Wildlife Conservation Commission web tag. Locations were recorded using GPS (UTM WGS 84). Body condition (Fulton’s K, Zweig et al. 2014) was calculated for each animal using snout-vent length and mass [(mass/snout-vent length) x 105].
Hydrology

Daily water stage from three gauges adjacent to survey routes—NESS, USGS NESRS1; SS, National Park Service NP-203; and SR, USGS Shark River—were obtained from the Everglades Depth Estimation Network from May 1, 2003 to April 30, 2014. Water depths were calculated by subtracted the minimum ground elevation from the stage level. Missing data were excluded from the analysis. Ten-year mean, maximum, and minimum values were calculated for each gauge for WY2004–WY2014.

Trend Analysis

Five-year trends in relative density were calculated using multiple regression. Log-transformed counts of alligators per kilometer for spring surveys were regressed on water year and water depth measured at the beginning and end of each survey route. Additionally, three-year trends in body condition were calculated using multiple regression with body condition indices regressed on water year, water depth at time of capture, and season.

Results

A total of 243 alligators were observed during fall and spring surveys in NESS, SS, and SR. Of those, 60 were classified as large (≥ 1.75 m), 4 were medium (1.25–1.74 m), 19 were small (0.5—1.24 m), 142 were hatchlings (< 0.5 m), and 18 were unknown. Mean spring non-hatchling relative density [alligators per kilometer (alligators/km)] at NESS was 0.225 ± 0.17 (SD); spring relative density at SS was 0.475 ± 0.05 (SD); and spring relative density at SR was 0.1 ± 0.08 (SD). Figure 6-22 shows the mean spring relative densities from WY2003 to WY2014. No five-year trends were detected for spring surveys at any of the three survey routes from WY2010 to WY2014. Spring surveys at SS and NESS were plotted against water depths at gauges adjacent to the survey routes shows spring relative densities have not been able to rebound to observed densities during WY2004–WY2005.

A total of 91 alligators (34 female, 57 male, and 1 unknown) were captured at SR, SS, and NESS, ranging in size from 140.8-cm total length to 315.7 cm total length. Mean body condition of alligators for WY2014 was 2.12, 2.10, and 2.00 for SR, NESS, and SS, respectively. All three WY2014 values for body condition fall below the restoration goal of 2.27 (Hart et al. 2012). No three-year trends in body condition were detected for WY2014 at SR, SS, or NESS.

Body condition has remained relatively consistent at each sampling location with the only three-year positive trends detected in SR from Calendar Year 2008 (CY2008)–CY2010, CY2009–CY2011, and CY2010–CY2012. Additionally, no significant difference (p > 0.05) has been found between the fall and spring captures or between males and females. Overall, the SR alligators have significantly higher body condition than marsh alligators (SR = 2.26 ± 0.37 SD, SS and NESS = 2.02 ± 0.23 SD, p < 0.000).

Relevance for Water Management

For WY2014, all three spring values of relative density fall well below the restoration target of 1.7 alligators/km (Hart et al. 2012). Both NESS and SR had the lowest spring relative densities since sampling began in WY2004. SS has remained consistently around 0.5 non-hatchling alligators/km for the last 3 years, but is well below the observations in 2004 and 2005. Significant negative trends were observed in relative density at both NESS and SS from WY2004–WY2009. The observed negative trends were most likely due to the extreme dry down event that occurred in 2001, which limited recruitment. This, coupled with the already low relative densities during WY2004–WY2005 (NESS and SS were still below the restoration target), severely limited the NESS and SS alligator populations ability to recover. These negative trends coupled with the
extreme dry down events during CY2009–CY2010 and again in CY2011–CY2012 likely contributed to the patterns currently observed where recruitment of alligators into the population was hindered by the number and intensity of the dry downs.

**Figure 6-22.** Eleven-year spring relative densities of non-hatchling alligators in ENP. Error bars represent the standard deviation. Green line represent the restoration target (1.7 alligators/km); red line (0.8 alligators/km) indicates relative density is well below restoration target. Restoration targets are described in Mazzotti et al. 2009 and Hart et al. 2012 and are based on quartile ranks for relative density values from WY2004 through WY2009.
Table 6-5. Summary of body condition indices (Fulton’s K) for alligators captured in WY2014. Thirty alligators (34 percent) were well below the restoration target (< 1.95 meters), 41 alligators (46 percent) were below the restoration target (1.95–2.27 meters), and 18 alligators (20 percent) met the restoration target (> 2.27 meters).

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample Size</th>
<th>Snout-Vent Length (cm)</th>
<th>Fulton’s K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>SR</td>
<td>29</td>
<td>116.6</td>
<td>15.3</td>
</tr>
<tr>
<td>Fall</td>
<td>14</td>
<td>116.3</td>
<td>14.5</td>
</tr>
<tr>
<td>Spring</td>
<td>15</td>
<td>116.8</td>
<td>16.4</td>
</tr>
<tr>
<td>NESS</td>
<td>30</td>
<td>105.5</td>
<td>21.2</td>
</tr>
<tr>
<td>Fall</td>
<td>15</td>
<td>106.4</td>
<td>21.2</td>
</tr>
<tr>
<td>Spring</td>
<td>15</td>
<td>104.5</td>
<td>22.0</td>
</tr>
<tr>
<td>SS</td>
<td>30</td>
<td>110.2</td>
<td>18.9</td>
</tr>
<tr>
<td>Fall</td>
<td>15</td>
<td>112.5</td>
<td>22.4</td>
</tr>
<tr>
<td>Spring</td>
<td>15</td>
<td>107.9</td>
<td>15.1</td>
</tr>
</tbody>
</table>

Restoration targets are described in Mazzotti et al. 2009 and Hart et al. 2012 and are based on quartile ranks for relative density values from CY2004 to CY2009. The current size-class distribution—heavily skewed towards adults—is the same pattern Fujisaki et al. (2011) observed following the extreme dry downs in the Everglades marsh in CY2001. These dry downs possibly caused decreases in small- and medium-sized alligators. The number of hatchlings observed during WY2014 is encouraging and is similar to WY2013 hatchling observations in SS and NESS. These values are well above the number of hatchlings observed from WY2009 to WY2012. Additionally, the number of hatchlings observed in NESS since WY2009 is well below those observed in SS. Before WY2009, the observed hatchlings at NESS and SS were very similar. This observed shift that occurred before and after WY2009 could be related to the number of times the water levels dropped below 6 inches (the depth where marsh levels are dry “through the eyes of an alligator”). In the last 10 years, NESS has had 8 years where water levels dropped below 6 inches, while SS has had 3 years. It is hypothesize that, on average, dry downs once every three to five years and no longer than 40 days may support alligator populations at levels targeted by restoration performance measures.
PLANT ECOLOGY

Plant studies form an important basis for evaluating restoration success. This section evaluates the hydrologic interactions between soil, groundwater, marsh, and trees on conserved and a degraded tree islands in WCA-3.

SURFACE-GROUNDWATER INTERACTIONS IN EVERGLADES TREE ISLANDS: UNDERSTANDING MECHANISMS TO RESTORE DEGRADED TREE ISLANDS

Tiffany Troxler¹ and Carlos Coronado-Molina

In the Everglades, tree islands are considered characteristic of the ecological “health” of the landscape (Sklar and van der Valk 2002). Phosphorus (P) levels in upland tree island soils are > 100 times higher than the P in adjacent marsh soils (Wetzel et al. 2005, Jayachandran et al. 2004, Wetzel et al. 2011). Tree islands are hypothesized to be an active sink of P in the landscape, contributing to the P balance of Everglades slough wetlands (Wetzel et al 2005, Troxler et al. 2013). However, due to increasing tree island degradation in the Everglades, a better understanding on how to best maintain and restore tree islands is needed. Thus, the purpose of this tree island research is (1) to achieve a better understanding of the mechanisms leading to the degradation and disappearance of tree islands, and (2) to identify critical ecological information for determining what tree island restoration actions have the best opportunity to succeed.

Methods

This project was developed to compare hydraulic and hydrogeochemical patterns at multiple temporal and spatial scales of four diverse hydrological and ecological Everglades tree islands in the WCA-3A and WCA-3B (Figure 6-23): wet, intact (3AS3); wet, degraded (3AS17-6 Ghost Island); dry, degraded 3BS2, and 3BS10 (Twin Heads). Hydraulic and geochemical properties, including nutrients and ions, were used monitor the ecological condition of tree islands and determine how the structure and function of tree islands can be maintained and restored. Specific objectives were to (1) characterize spatial and temporal variability in diurnal evapotranspiration (ET) patterns, 2) determine temporal hydraulic patterns, and 3) compare spatial and temporal hydrogeochemical patterns in ions and nutrients among four tree island plant communities with an adjacent deep water slough. Results from ET and hydrological patterns have been reported in the 2014 RECOVER System Status Report (RECOVER 2014). In this report, ions, nutrients, isotopes, and hydrological results are integrated as metrics to evaluate ecological condition on tree islands.
Results

This report presents on-going monitoring of hydraulic and geochemical properties that are key to unveil how the structure and function of tree islands can be maintained and restored. In this sense, results on ion composition, nutrient and carbon concentrations continue to follow trends observed and reported in the 2014 RECOVER System Status Report (RECOVER 2014). In general, stable isotopes indicate that tree island plant communities can reflect P availability and hydrologic status in nitrogen isotopes ($^{15}\text{N}$) and carbon isotopes ($^{13}\text{C}$) signatures. Our results on patterns of isotopic signatures suggest that higher $^{15}\text{N}$ concentrations correspond with greater nitrogen (N) demand and higher P availability while higher $^{13}\text{C}$ concentrations correspond with greater carbon (C) demand. For instance, high $^{15}\text{N}$ on the head (HH) of 3AS3 suggest higher P availability in the HH relative to the wet head (WH), near tail (NT) and marsh (MR) of 3AS3. Similarly, there is greater P availability in HH and WH as compared with NT and MR of Ghost Island (Figure 6-24a). There was little variation among plant communities in the two dry islands, except higher values of $^{15}\text{N}$ on 3BS10 in the MR plant community. For $^{13}\text{C}$, values were generally higher in the long hydroperiod Ghost Island, possibly signaling physiological stressful conditions. The dry islands
generally had the most depleted values of $^{13}$C, but there was a general trend of higher values with wetter plant communities, from HH to MR (Figure 6-24b).

**Figure 6-24.** Plant community average ± standard error (SE) of green leaf (a) $^{15}$N and (b) $^{13}$C for all four tree islands. Colors represent different tree islands: 3AS3 (blue), 3BS2 (red), Ghost Island (GI) (green), and Twin Head (TH) (purple).

Overall, stable isotope, ion composition, and water quality patterns are distinctive among tree islands, indicating a robust general characterization of the geochemistry of the different islands and plant communities within islands. In particular, isotopic signature results indicate that tree island plant community reflect P availability and hydrologic status in $^{15}$N and $^{13}$C. This evidence corresponds with observations of high total phosphorus (TP) soil and total dissolved phosphorus (TDP) soil water concentrations. Thus, ion composition and water quality samplings illustrated key findings that were useful in the development of metrics to assess tree island condition (Table 6-6).
Based on these results, the geochemical pattern on tree islands was evaluated utilizing five metrics: (1) ion concentration, (2) phosphorus concentration, (3) extent of organic soil type, (4) residence time/redox condition, and (5) accumulation of chloride (Cl) relative to calcium (Ca) (Table 6-6).

Table 6-6. Five metrics for interpreting general tree island geochemical patterns and stoplight indicators of tree island condition for the five metrics. Green color indicates that the metric is fully met, yellow color indicate the metric is partially met, and red color indicate that the metric is not met. [Note: D – deep; DOC – dissolved organic carbon, S – shallow; TDPO4 – total dissolved phosphorus, and TDS – total dissolved solids.]

<table>
<thead>
<tr>
<th>TREE ISLAND</th>
<th>Ion concentration in HH and differentiation among communities (TDS)</th>
<th>Phosphorus concentration in High Head (TDPO4)</th>
<th>Extent of organic soil type (DOC)</th>
<th>Water depth below soil surface</th>
<th>Cl concentration (Ca/Cl) in HH S &amp; D</th>
</tr>
</thead>
<tbody>
<tr>
<td>3AS3</td>
<td>Green</td>
<td>Red</td>
<td>Yellow</td>
<td>Green</td>
<td>Red</td>
</tr>
<tr>
<td>Twin Heads</td>
<td>Red</td>
<td>Green</td>
<td>Green</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>Ghost Island</td>
<td>Yellow</td>
<td>Red</td>
<td>N/A</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>3BS2</td>
<td>Yellow</td>
<td>Red</td>
<td>Red</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

An assessment of these metrics suggested that 3BS10 and 3BS2 tree islands are in the poorest condition. Soil data from these islands shows that TP is lower in 3BS10, in the upper part of the soil profile, suggesting that the island has lost TP. So, although soil water TP is similar between 3AS3 and 3BS10, active ion accumulation and potential for mineral and P accumulation appears to be inactive (limited extent of low organic type soil and high Ca/Cl) when all metrics are considered together. The island 3BS2, while high in TP and low differentiation of ion concentrations among plant communities, still had moderate Ca/Cl and total ion concentrations in the HH plant community. A characteristic geochemical pattern of moderate TP concentrations, low extent of organic soil, and accumulation of total ions and Cl in the HH (relative to other communities) would indicate that the foundation community, distributed on the head, has reestablished its capacity to develop mineral substrate that contributes to stabilization of the tree island system.

Relevance to Water Management

The hydrologic interactions between soil, groundwater, marsh and trees are unique on tree islands. Compiling these data along with water level and daily drawdown data, and a resolved understanding of surface elevations and topography, will place these results in the context of current and recent past wetland hydrologic condition and refine our current understanding of tree island plant-soil-water interactions. Tree islands may be one of the critical elements to preserving the low nutrient content of the Everglades marsh and now there are indications that the biogeochemical dynamics on the heads of degraded islands can potentially be restored.
ECOSYSTEM ECOLOGY

This section focuses on both the freshwater and coastal areas of the Everglades. The first project presents the results of the active marsh improvement project slough study, examining the changes in vegetation and the utilization of the open areas by wading birds. The second ecosystem project is a detailed description of ecological monitoring and research conducted in Florida Bay including water quality (temporal and spatial analyses) and benthic vegetation (monitoring and modeling relative to restoration projects).

ACTIVE MARSH IMPROVEMENT PROJECTS

Susan Newman, Michael Manna, Mark Cook and LeRoy Rodgers

The Cattail Habitat Improvement Project (CHIP), a large-scale in situ study, was the first study to demonstrate that a combination of herbicides and fire can successfully rehabilitate slough habitat in cattail areas producing a spikerush (*Eleocharis* spp.)-submerged aquatic vegetation (SAV) regime, thus breaking the resilience of the cattail regime. As a result of the CHIP study, three important questions regarding how to actively improve habitat conditions were identified including (1) what are the hydrologic interactions on the vegetation community that facilitate cattail reinvasion; (2) how important is spatial heterogeneity of the habitat and vegetated edges for wading bird foraging; and (3) what is the limitation of using broad spectrum herbicides on vegetation succession.

The questions associated with the interaction of herbicide effectiveness and hydrologic conditions on plant growth, and habitat edge contributions to foraging wading birds, were incorporated into the experimental design of a large-scale landscape treatment—the Active Marsh Improvement Ridge and Slough Restoration Study, abbreviated to AMI-1.

Active Marsh Improvement Ridge and Slough Landscape Restoration Study

The large-scale AMI-1 was designed to build upon observations from the CHIP slough restoration study by conducting active marsh manipulation at a scale that encapsulates the larger ridge and slough landscape. The overarching question is, Can active marsh restoration techniques be employed to restore ridge and slough patterning and structure within nutrient enriched cattail areas? Larger plots should allow a greater diversity of vegetation and habitats compared to CHIP plots such that the vegetation communities and the historical structural patterning of sawgrass ridges and open water sloughs are retained. Within this general framework two things can be assessed: (1) wading bird usage and the importance of edges for foraging, and (2) the significance of the west-east gradient in hydrology, which appears to control the rate and extent of cattail reinvasion. It was hypothesized that the rate and extent of cattail invasion would be significantly less in the western versus the eastern plots due to hydrologic stress caused by the higher frequency of dry outs in the western plots.

Methods

Landscape-scale openings were created, two 500-m x 750-m plots, for the AMI-1 project using the CHIP approach—a combination of herbicide and burning treatment—with the expectation that because imazamox was used, where CHIP initially used the broad spectrum combination of glyphosate and imazapyr, cattail will be disproportionately impacted allowing desirable vegetation recovery and succession following the burn to occur sooner than observed in CHIP.
Plots were aerially sprayed in April 2011 with imazamox at a rate of 0.28 grams active ingredients per hectare and burned January 2012. Aerial reconnaissance of the plots (June 2012, Rodgers and Newman, SFWMD, personal observation) indicated that while there was extensive sawgrass and other species present, both plots had experienced rapid regrowth of cattail. In other studies where herbicides were applied later in the year, successful cattail control was observed 12 months after treatment (Newman et al. 2013, Rodgers and Black 2012). Therefore, the preliminary conclusion was that rapid cattail regrowth in AMI-1 was due to time of year of treatment and plots were resprayed in January 2013.

Twelve 100-m belt transects were used to capture species occurrence throughout the spatial extent of each plot. Along each belt transect, three 2-m x 0.5-m quadrats per belt transect were used to quantify percent total vegetative and nonvegetative cover, species relative percent cover, percent composition, density, and frequency of occurrence. Measurements were repeated annually. Vegetation differences were assessed using nonparametric methods (Wilcoxon, K-Wallis) and followed by Steel-Dwass for multiple comparisons (JMP 2013, version 11; SAS 2013).

Aerial wading bird surveys were conducted approximately weekly during the dry seasons (November to May; n = 16 to 23 survey weeks per year) of WY2012 to WY2015.

**Results and Discussion**

Our initial hypothesis that dry outs in the western area would reduce the recovery of emergent vegetation in AMI-West versus AMI-East was not testable during this initial study period. An examination of hydrologic conditions in the area indicate that while the western plot experienced an extensive dry out, May–June 2011, any water inputs during the WY2012 came from STA-2 at the west-northwest side of WCA-2A. In contrast, in WY2013, water levels generally remained above ground in both west and east regions, with significant inputs from both the S-10 structures and STA-2 discharge; therefore, the west-east hydrologic gradient was generally negated. However, there were observable differences in vegetation responses. Cattail presence was not reduced from project initiation to the first sampling event, maintaining a frequency of occurrence ranging 86–97 percent. However, it was drastically reduced following the implementation of the second herbicide treatment; frequency of occurrence decreased to 11–25 percent. In contrast, while cattails are obviously more sensitive to imazamox, sawgrass growth was stunted and flowering was eliminated for one year following the initial herbicide treatment. Sawgrass showed a consistent decline in occurrence from the initial to 12- and 24-month sampling events, averaging 94, 81, and 69 percent in the east plot and 56, 44, and 42 percent in the west plot. The second treatment had a greater effect on sawgrass in the east plot, likely due to higher coverage of sawgrass in the area; 10 versus 5 percent, at 12 months in east and west plots, respectively.

Overall, both east and west plots showed a significant increase in open water habitat in response to the herbicide and fire treatment (Figure 6-25). As planned, the burning of the plots caused a dramatic decline in plant litter. The percent cover of standing dead material was significantly reduced from greater than 60 percent to approximately 10 percent resulting in a significant increase in the open water and SAV habitats (Figure 6-26). The second herbicide application, prompted by the observed recovery of emergent macrophytes, particularly cattail, at 12 months, caused a significant decline in live emergent vegetation and an increase in dead vegetation at 24 months. By 24 months, the open water area was also developing an aquatic plant community as SAV cover increased from 0 to 8 percent in the west plot, but was only sparsely present at 1 percent cover in the east. This observation that SAV takes two or more years to establish in a newly created habitat is consistent with observations from CHIP data. Similarly to CHIP, the majority of the overall SAV was *Chara*, however, *Utricularia* spp., also first appeared in the plots during the 24-month sampling, contributing 17 percent of SAV cover in the west and 100 percent in the east. The greater SAV abundance in the west plots is likely due to the consolidated spatial patterning of the
vegetation. While the overall percent open area was greater in the eastern plots, there was a greater proportion of sparse emergent vegetation in those areas compared to the western plots (M. Manna, SFWMD, personal observation).

Figure 6-25. Changes in vegetation patterns in the eastern (top) and western (bottom) AMI-1 plots during May 2011 and September 2014. A CHIP open plot can be seen in the background for size comparison.
Figure 6-26. Change in percent cover of vegetation habitats within the western (top) and eastern (bottom) AMI plots. Different letters represent significant differences of a community type across sampling periods. $\alpha = 0.05$.

[Note: mon – month.]

**Wading Birds**

The role of habitat heterogeneity and edge effects on wading bird foraging responses due to the unexpected rapid regrowth of cattail in the treatment plots could not be examined. However, initial data do provide some useful insights into the efficacy of this management approach for wading bird habitat restoration.

Over the four dry seasons, for both east and west plots pooled, 23,936 individuals representing ten of the 15 species of the northern Everglades wading bird guild were recorded. White ibis was the dominant species comprising 73.2 percent of the total count. Glossy ibis (9.4 percent), great egret (4.8 percent), little blue heron (4.6 percent), snowy egret (2.6 percent), roseate spoonbill (2.1 percent), and tricolored heron (2.0 percent) were observed regularly but each made up a relatively small proportion of the total. Great blue heron, (*Ardea herodias*; 0.6 percent), black-crowned night-heron, (*Nycticorax nycticorax*; 0.6 percent), and wood stork (< 0.1 percent) were infrequent visitors. American bittern (*Botaurus lentiginosus*), least bittern (*Ixobrychus exilis*), and
green heron (*Butorides virescens*) were also observed in the treatment plots but their abundances were not quantified. Cattle egret and yellow-crowned night-heron (*Nyctanassa violacea*) were not observed.

As expected, this management approach to restore ridge and slough patterning produced habitat that was highly attractive to foraging wading birds (Figure 6-27, bottom right panel). Birds started foraging in the plots immediately after the burn treatment created open water foraging habitat. On average, over 200 birds per plot per week were observed (during the period when water depths were suitable for foraging; 3–35 cm), and maximum counts for each dry season often exceeded 600 birds per plot (Table 6-7). This intensive foraging activity was not short lived, as is often the case at foraging locations in oligotrophic regions of the Everglades (M. Cook, SFWMD, personal observation), but lasted between 10 and 14 weeks per year over a relatively large range of water depths. Note that a control comparison in AMI-1 was not included because it was previously demonstrated that nutrient enriched cattail areas provide very limited foraging opportunities for wading birds (Hagerthey et al. 2014, Madden et al. 2012).

**Figure 6-27.** Counts of wading birds (all species pooled) in AMI-West and AMI-East treatments during the dry seasons of WY2012–WY2015.
Table 6-7. A comparison of wading bird usage of AMI-East and AMI-West plots during WY2012–WY2015 dry seasons. Usage is measured in terms of mean ± SD count of birds per treatment per week (all species pooled) during weeks when depths were conducive to foraging (5–35 cm), and maximum recorded count per year (in parentheses). [n = 14 weeks for WY2012, WY2014, WY2015; n = 10 weeks for 2013.]

<table>
<thead>
<tr>
<th>Water Year</th>
<th>AMI-E</th>
<th>AMI-W</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>243.2±191.6 (649)</td>
<td>179.1±159.5 (493)</td>
</tr>
<tr>
<td>2013</td>
<td>300.7±175.5 (601)</td>
<td>225.4±154.3 (518)</td>
</tr>
<tr>
<td>2014</td>
<td>225.8±227.1 (805)</td>
<td>172.1±197.1 (625)</td>
</tr>
<tr>
<td>2015</td>
<td>256.7±196.1 (609)</td>
<td>135.3±125.4 (414)</td>
</tr>
</tbody>
</table>

The temporal pattern and magnitude of wading bird foraging appeared to vary little among the four study years (Figure 6-27). Bird abundance was similar for a comparable duration of the dry season during each of the four study years, despite considerable increases in vegetation density due to the regrowth of cattail. This suggests that emergent vegetation density may have little effect on foraging habitat selection until some maximum threshold density is reached that was not attained in this study. On the other hand, bird abundance did appear to be influenced by spatial factors (Figure 6-27 and Table 6-7). AMI-E had 45 percent more foraging birds than AMI-W in terms of the mean ± SD total number of birds counted per year (AMI-E 3291.7 ± 129.9; AMI-W 2266.3 ± 134.6, n = 4 years), although limited sample size precluded statistical analysis.

Relevance to Water Management

Nutrient loads to the Everglades have been significantly reduced; however the downstream ecosystem is resilient and resists change. Active marsh improvement projects suggest these areas may be able to be rehabilitated. This study provides further evidence that burning, combined with herbicide application provides immediate open water habitat available for SAV and other desirable vegetation such as sawgrass, and use by wading birds, by removing dead thatch accumulated. As observed in CHIP, in these high nutrient areas, regrowth of undesirable vegetation from the seedbank and adjacent community, as well as swaths of vegetation missed during herbicide application, mean repeat application is necessary, at least initially, to ensure long-term success. However, a significant finding of this study is that birds seem to feed in denser emergent vegetation than expected, suggesting that treatments can benefit birds for extended periods without intensive management to keep them open.

Active marsh improvement projects provide managers with important information on how to optimize vegetation management and ecosystem restoration by documenting the selectively of imazamox, timing and frequency of application for large-scale management, and the relationship between hydrology, wildlife use, and cattail reinvasion.

FLORIDA BAY WATER QUALITY CONDITIONS AND STATUS

Stephen Kelly

Water quality in Florida Bay (eastern, central and western regions) has been monitored since 1991 (WY1992) to ensure that District operations and projects protect and restore the ecosystem to the extent possible. CERP performance measures focus on chlorophyll \(a\) (Chla) concentration, an indicator of algal blooms, as well as the nutrient inputs that initiate and sustain blooms. Operational
changes to the South Dade Conveyance System including implementation of the C-111 South Dade Project, Modified Water Deliveries to ENP (especially Tamiami Trail modifications), and the C-111 Spreader Canal Western Project, which became operational during WY2013, will further change freshwater flow patterns and may alter downstream water quality. As in WY2014, conditions during WY2015 have not changed significantly and presented here is a brief update of ecologically important parameters and how they have changed in WY2015. For a complete description of water quality assessments in Florida Bay, refer to Chapter 6 of the 2015 South Florida Environmental Report (SFER) – Volume I (Sklar and Dreschel, 2015).

Water samples and physical parameters (temperature, salinity, conductivity, pH, and dissolved oxygen) are collected every other month at all sites. Samples are collected at 0.5 m below the surface and processed according to the SFWMD Field Sampling Quality Manual (SFWMD 2015c) following Florida Department of Environmental Protection (FDEP) protocols. Physical parameters are collected with a calibrated multi-parameter water quality sonde following SFWMD protocols. Samples are processed on site, stored on ice, and shipped overnight to the SFWMD Analytical Lab in West Palm Beach for analysis according to the SFWMD Chemistry Laboratory Quality Manual (SFWMD 2015b) and following FDEP protocols. All sample results are quality assured before being uploaded to the District’s corporate environmental database, DBHYDRO.

There are many factors that influence the nutrient and Chla concentrations and variation in the bay including inflows, storm and wind events, circulation patterns, nutrient recycling and even construction events. It is not possible to attribute any one of these factors as the most important driver of current conditions, but rather it is likely a synergistic effect of some or all of them [Chapter 12 (Abbot et al. 2007) and Appendix 12-3 (Rudnick et al. 2007) of the 2007 SFER]. Annual averages of all parameters analyzed [Chla, TDP, total dissolved nitrogen (TDN), total organic carbon (TOC), dissolved inorganic nitrogen (DIN), and turbidity], continue to be stable during the last six water years, indicated by little to no interannual concentration changes, and were statistically similar between WY2014 and WY2015 with a few exceptions (Table 6-8). In addition, in the following figures, the monthly spatial averages of each parameter in the three regions of the bay were compared to the temporal median of the monthly spatial means and the interquartile range for the entire period of record (WY1992–WY2012). Notable findings for WY2015 that include results far above or below the long-term monthly median include Chla, TDP, and turbidity were at or below the 25 percent quartile in all regions of the bay (Figures 6-28 and 6-29); discrete salinity collected at the time of sample collection during WY2015 was at or above the 75 percent quartile in all regions of the bay; TOC was less than the median in the eastern and western regions; TDN was at or above the median in the eastern and central regions, and at or below the median in the western region (Figure 6-30); DIN was at the 75 percent quartile for most of the water year in the western region and at the 25 percent quartile in the eastern region. A summary of these results can be found in Table 6-9.

### Table 6-8. Statistically significant differences (p < 0.05) between annual averages of WY2014 and WY2015. Numbers in bold are lower.

<table>
<thead>
<tr>
<th>Region</th>
<th>Parameter</th>
<th>WY2014</th>
<th>WY2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern</td>
<td>Chla (µg/L)</td>
<td>0.47 ± 0.38</td>
<td>0.27 ± 0.16</td>
</tr>
<tr>
<td></td>
<td>TDN (µM)</td>
<td>46.5 ± 7.1</td>
<td>50.8 ± 6.7</td>
</tr>
<tr>
<td></td>
<td>TDP (µM)</td>
<td>0.11 ± 0.04</td>
<td>0.08 ± 0.04</td>
</tr>
<tr>
<td></td>
<td>Turbidity (NTU)</td>
<td>5.2 ± 3.5</td>
<td>2.5 ± 1.2</td>
</tr>
<tr>
<td>Central</td>
<td>TDP (µM)</td>
<td>0.31 ± 0.14</td>
<td>0.22 ± 0.07</td>
</tr>
<tr>
<td>Western</td>
<td>TOC (µM)</td>
<td>415 ± 163</td>
<td>321 ± 77</td>
</tr>
</tbody>
</table>

Key to units: µg/L – micrograms per liter, µM – micromoles, and NTU – nephelometric turbidity units.
Figure 6-28. Mean Chla concentrations in micrograms per liter (μg/L) in the three regions of the bay studied during WY2013–WY2015 (solid symbols) compared to the monthly median and the interquartile range for the entire period of record, WY1992–WY2012 (solid line and blue shading).
Figure 6-29. Mean TDP concentrations in micromoles per liter (μM/L) in the three regions of the bay studied during WY2013 through WY2015 (solid symbols) compared to the monthly median and the interquartile range for the entire period of record, WY1992–WY2012 (solid line and blue shading).

[Note 1.0 μM = 31 μg/L = 31 parts per billion.]
Figure 6-30. Mean TDN concentrations in micromoles per liter (μm/L; μM) in the three regions of the Bbay studied during WY2013 through WY2015 (solid symbols) compared to the monthly median and the interquartile range for the entire period of record, WY1992–WY2012 (solid line and blue shading). [Note 100 μM = 1.4 micrograms per liter = 1.4 parts per million.]
Table 6-9. Deviation of WY2015 from the period of record (WY1992–WY2014) averages. Numbers in bold are statistically different (p < 0.05).

<table>
<thead>
<tr>
<th>Region</th>
<th>TDN (µM)</th>
<th>DIN (µM)</th>
<th>TDP (µM)</th>
<th>Chla (µg/L)</th>
<th>TOC (µM)</th>
<th>Salinity</th>
<th>Turb (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern</td>
<td>109 %</td>
<td>61 %</td>
<td>38 %</td>
<td>56 %</td>
<td>86 %</td>
<td>125 %</td>
<td>30 %</td>
</tr>
<tr>
<td>Central</td>
<td>114 %</td>
<td>44 %</td>
<td>39 %</td>
<td>21 %</td>
<td>94 %</td>
<td>118 %</td>
<td>28 %</td>
</tr>
<tr>
<td>Western</td>
<td>92 %</td>
<td>86 %</td>
<td>62 %</td>
<td>55 %</td>
<td>77 %</td>
<td>104 %</td>
<td>35 %</td>
</tr>
</tbody>
</table>

Key to units: µg/L – micrograms per liter, µM – micromoles, and NTU – nephelometric turbidity units.

ECOHYDROLOGY IN THE COASTAL LAKES OF CENTRAL FLORIDA BAY

Christopher Madden, Dean Whitman¹ and Rene’ Price¹

The coastal lakes area of northern central Florida Bay is currently of intense interest due to the newly initiated C-111 Spreader Canal Western Project, which will establish more natural flows to Taylor Slough by creating a hydrologic ridge along the eastern margin of the slough. The project is designed to reduce seepage and retain more water in the slough to improve the timing, distribution, and quantity of water in central Florida Bay. The lakes region is also expected to benefit from the additional fresh water as a result of C-111 Spreader Canal Western Project operations. The West Lake chain, including West Lake, Long Lake, and Cuthbert Lake, lies on the western edge of Taylor Slough. The Seven Palm Lake chain in central Taylor Slough includes Seven Palm Lake, Middle Lake, Monroe Lake, and Terrapin Bay. These water bodies are of great importance to Florida Bay because they support large seagrass meadows and mangrove forests, provide critical nekton and bird habitat and they supply fresh water to central Florida Bay. The shallow (1-m depth), connected lakes are expected to benefit from C-111 Spreader Canal Western Project operations due to increased freshwater flow, which will reduce dry season salinities and increase water transparency, improving habitat conditions for fauna such as birds and fish. The lakes are also often high in nutrients and algal biomass that can exceed 100 µg/L Chla. Increases in freshwater flow may alter nutrient dynamics in as yet unknown ways, which could impact phytoplankton and benthic vegetation in the lakes and that could be transported downstream to sensitive Florida Bay waters. The District, in collaboration with Florida International University, initiated a study in September 2013, with the objectives of understanding water and nutrient flows into the lakes, developing a hydrologic budget and determining downstream impacts on Florida Bay.

The initial measurements taken for this study include geophysical measurements of conductivity/resistivity of lake waters and subsurface waters to determine the salinity distributions in surface water and groundwater and to monitor potential changes during the course of C-111 Spreader Canal Western Project operations. This report describes geophysical data collected in the West Lake and Seven Palm Lake drainage systems in May 2014. Data included marine electromagnetic (EM) profiles and soundings, water depth measurements, surface water conductivity and salinity measurements, and a set of coincident EM and direct current (DC) resistivity soundings along the main park road.

Methods

A towed instrument was used to provide spatial coverage of subsurface conductivity in West Lake on May 19, 2014, and in Seven Palm Lake and south into Middle Lake and Monroe Lake on
May 27, 2015. In total, over 30,000 three-frequency measurements were collected. A multi-frequency EM sounding was collected at the northern end of Seven Palm Lake at the beginning of the deployment. This sounding consisted of EM measurements at discrete frequencies ranging between 1 and 15 kilohertz (KHz) and was collected in 6 steps by recording three frequencies at a time, with the higher frequency giving conductivity data on the overlying water column and lower frequencies penetrating progressively deeper into the groundwater. The marine EM profile data were processed to calculate apparent conductivities. This survey will be repeated twice more during the study and data will be integrated with continuous tracking of wells drilled into the soil to measure water depth, salinity, and nutrients at fixed points in the system (Figure 6-31).

**Figure 6-31.** Location of marine EM transects and soundings and coincident EM and DC resistivity sounding measurements.

**Results**

Maps of apparent conductivity profile data collected in West Lake are shown in Figure 6-32 with apparent conductivities ranging from 1,000 to 2,500 millisiemens per meter (mS/m). The highest conductivities (>2,000 mS/m) were at the eastern end of the lake. Conductivity values were generally higher than observed during a scoping survey in August 2013, and this is consistent with higher salinities expected at the end of the dry season compared to the wet season. Also, in August 2013, there was a gradient of increasing conductivity from east to west in West Lake whereas in May 2014, the gradient was opposite with conductivity increasing from west to east. In the McCormick system, conductivities increased from 1,500 mS/m in the northwestern end of Seven Palm Lake to over 6,000 mS/m in Monroe Lake (Figure 6-33). In deeper groundwater layers, conductivity decreased in both lake chains, indicating that during the wet season, a significant source of lower salinity water may be coming from the groundwater. This is consistent with hypothesis that groundwater may provide a significant flow into the lakes and downstream into Florida Bay. The issue requires further study to track seasonal changes and to follow the effects of C-111 Spreader Canal Western Project operations on the nature of groundwater inputs to central and western Taylor Slough.
Figure 6-32. Apparent conductivities at 1, 8, and 15 KHz measured by the Profiler instrument on May 19, 2014, in West Lake. Conductivity probe measurements of the surface water are also shown.
Relevance to Water Management

The hydrology of the southern Everglades, especially in the transition zone, is largely unknown. It is of high importance to understand the flows and budgets of water in this region, particularly with the commencement of restoration action that will direct more water to the area so as to understand impacts to the ecotone region and to Florida Bay. It is also critically important to know groundwater movement to investigate the hypothesized mechanism for release of P from limestone bedrock with the influx of saline groundwater from the bay. This zone, where fresh groundwater encounters saline water, is an important zone of high biogeochemical activity that bears on the P delivery to Florida Bay and may be implicated in the phytoplankton biomass encountered in the area.

FLORIDA BAY BENTHIC VEGETATION

Joseph Stachelek and Amanda McDonald

Benthic vegetation, composed of seagrass and benthic macroalgae, provides habitat structure in Florida Bay and its associated creeks, ponds, swamp forests, and marshes of the mangrove transition zone. Monitoring and research of benthic vegetation is critical to understanding the effects of water management and restoration on wetland and estuarine ecosystems. Results from these efforts are used in assessing the effectiveness of the current Florida Bay MFL rule, which is based on the salinity tolerance of *Ruppia maritima*. These surveys are used to provide ecosystem status updates for RECOVER, assessments of District operations, and calibrate and verify the Florida Bay Seagrass Community Model (SEACOM).
Methods

Benthic vegetation is monitored regionally in select locations using a randomized design where several 0.25-square meter quadrats are assessed for benthic vegetation using indices of percent cover. Three separate monitoring programs cover different areas in Florida Bay: Audubon, Miami-Dade County Department of Environment Resource Management (DERM), and South Florida Fish Habitat Assessment Program (FHAP). The FHAP and Miami-Dade DERM programs provide estimates of benthic vegetation cover using a visual index of bottom occlusion. FHAP monitors 17 basins throughout Florida Bay and along the southwestern coast every May while Miami-Dade DERM monitors the nearshore embayments of northeastern Florida Bay quarterly. Audubon of Florida monitors benthic vegetation using a point-intercept method every other month at sites along nine transects extending from the freshwater marshes of the southern Everglades to Florida Bay. A more complete description of the monitoring programs and the methodologies are presented in Chapter 12 of the 2011 South Florida Environmental Report – Volume I (Alleman, 2011).

Results

Despite near average or above average water levels in WY2015, salinities were well above average during the dry season throughout the upper transition zone and well above average during the entire water year within Florida Bay.

Two notable trends in benthic vegetation cover were carried over from previous water years into WY2015. First, cover of \textit{R. maritima} has still not rebounded from the dramatic decreases observed following record high cover in WY2011 and WY2012. In Taylor River, these decreases were tracked by the cover of other saltwater intolerant species such as \textit{Chara hornemanni}. However, along the eastern transects of the Audubon monitoring program (Joe Bay and Highway Creek), cover of \textit{C. hornemanni} has remained relatively stable and even increased at some sites.

Second, \textit{Thalassia testudinum} continues to be alive and healthy at the downstream end of the many monitoring transects. Increases were particularly evident at Taylor River and Highway Creek. Average cover at Taylor River reached a record high near 20 percent for WY2015.

A new development in WY2015 was a significant decrease in \textit{Halodule wrightii} cover within the central and western Florida Bay basins compared to the previous two years. Rankin Lake, which had \textit{H. wrightii} presence in more than 80 percent of quadrats sampled during WY2006–WY2014, had the estuarine species in only 64 percent of the quadrats during WY2015 (Figure 6-34). To the southeast, Whipray Basin, which had averaged \textit{H. wrightii} presence in 51 percent of quadrats from WY2008 to WY2014, decreased to presence in only 30 percent of quadrats in WY2015. Twin Key Basin, to the south, had experienced an increase in \textit{H. wrightii} presence to 42 percent of quadrats by WY2014, but decreased in WY2015 to presence in only 25 percent of sampled quadrats. Rabbit Key Basin, which had \textit{H. wrightii} presence in an average of 61 percent of sampled quadrats from WY2006 through WY2012, experienced an increase to presence in 79 percent of sampled quadrats in WY2013 and WY2014, but has also experienced a decline back to presence in 62 percent of quadrats in WY2015. Sampling within Florida Bay occurs at the beginning of the water year, so the impacts of the elevated salinity in WY2015 will not be seen until the WY2016 data.

Relevance to Water Management

Increases in the cover of salt-tolerant \textit{T. testudinum}, decreases in \textit{H. wrightii}, and the near complete absence of \textit{R. maritima} throughout the transition zone in WY2015 is a signal that, due to drought conditions and hypersalinity, the overall benthic vegetation community is under stress. Elevated salinity continuing into WY2016 and a dry start to the beginning of the WY2016 wet season is an indication that the benthic vegetation community will continue to be stressed in WY2016. The way in which a rebound of the benthic vegetation community takes place will be a
good indicator of the resilience of this community, and it will provide a real-world test of the Florida Bay MFL criteria.

Figure 6-34. Frequency of *H. wrightii* presence in sampled quadrats in the central and western basins of Florida during WY2006–WY2015 with standard deviation denoted by the error bars. These basins experienced a significant decline in *H. wrightii* presence in WY2015.
FLORIDA BAY SYSTEMWIDE INDICATORS FOR SUBMERGED AQUATIC VEGETATION

Christopher Madden and Amanda McDonald

An indicator was developed that expresses and tracks the status and trends of SAV for Florida Bay (Madden et al. 2009). The indicator uses monitoring data to assess four metrics capturing the status of abundance (areal extent and density) and species diversity (species dominance and target species). The four indicators are combined to give an overall score for the bay each year. For WY2014, a bay-wide composite score of yellow (fair) summarizes the overall system status, unchanged from the previous assessment. Broken down by individual zones, the combined indicator remained good in the Northeast, Central, and Western zones, and fair in the Southern Zone for both 2013 and 2014 (Figure 6-35). The SAV indicator for the Transition Zone (the mangrove ecotone, embayments, creeks, and lakes in the southern Everglades wetland) improved to good in WY2014 from fair. Data for the unusually hypersaline WY2015 will be evaluated as part of the 2016 assessment and is expected to show a seagrass community under severe stress.

Florida Bay SAV Community Overall Status

Figure 6-35. SAV Indicator scores for 2013 and 2014 for each of five indicator zones in Florida Bay. Indicator stoplights combine abundance and diversity indexes. All zones remain unchanged from 2012 except the Transition Zone, which improved to good in 2014 from fair in 2013.
Methods

Based on species composition and monitoring data from Braun-Blanquet assessments of cover, scores are calculated relative to historical potential for each of five bay zones. The ranges determining system status and the basic methodology for calculating the SAV Indicator are detailed in Madden et al. (2009). A new step in the protocol has been introduced to aggregate SAV scores from all five zones to create a single system status indicator for the entire bay. The minimum score for the five zones is assigned as the bay-wide score.

Results

The abundance index showed that SAV cover and density was good in the Northeast Zone, fair in the Transition, Central, and Western zones, and poor in the Southern Zone. The spatial extent component of the abundance index expresses the proportion of bay bottom area covered by seagrass and reflected good SAV cover for all zones of the bay. No significant die-off events occurred during the assessment period. Despite good areal cover, the abundance index was reduced in some zones due to the second underlying component, density, reflecting sparseness of SAV in several areas.

Notably, density remained poor in Madeira Bay, Long Sound, and Joe Bay in the Transition Zone and Twin Key Basin in the Southern Zone, dropped to fair in Rankin in the Central Zone, and remained fair in Rabbit Key Basin in the Western Zone. As a result, the aggregated abundance index was at a good status only in the Northeast Zone, with the others being fair or poor.

The diversity index, which combines indicators for species dominance and presence of desirable target species, showed continued good status in the Northeast, Central, and Western zones. The Transition Zone diversity index improved to good in WY2014, reflecting underlying improvement from poor to fair species dominance and the recovery of SAV habitat leading to *R. maritima* expansion. The Southern Zone maintained its diversity index status of fair through WY2014, reflecting excessive dominance by *Thalassia* in the underlying species dominance score of fair. Lack of community diversity in the Southern Zone yielded a continuing fair score for target species.

The SAV status has either remained steady or improved, notably with improvement in the Transition Zone. The bay-wide score for Florida Bay is yellow (fair) for 2014, given that there is at least one yellow in one zone. Trends in the underlying components of the Northeast Zone have been positive, reflecting continued improvement since the mid-2000s when hurricanes and a prolonged algal bloom negatively impacted the SAV community. Although the Western Zone remains in good overall condition, there are declines in some component scores that bear watching and improvement is required in the perennially fair status of the overall score in the Southern Zone.

Relevance to Water Management

Data from the indicator analysis are used in a variety of ways: (1) to communicate SAV status internally within the District and to its Governing Board; (2) to communicate with research collaborators and interagency partners, including the USGS, National Oceanic and Atmospheric Administration, Department of Interior, FDEP, Miami-Dade DERM, ENP, United States Environmental Protection Agency, RECOVER, and others; (3) to provide a visual status report to the United States Congress and to the public via presentations; (4) to formally document and report SAV status in such publications as the *South Florida Environmental Report*, the System Status Report, the C-111 Ecological Status Report, the C-111 Spreader Canal Western Features Project Monitoring and Assessment Report, the Minimum Flows and Levels for Florida Bay Review and Update report and other published documents. The indicator and components are also used to evaluate progress in and success of restoration activities in the southern Everglades and Florida Bay. The SAV Indicator and components are used to monitor and assess the success of MFL rulemaking and assess how violations of the rule affect the SAV resource that may trigger
requirement of an MFL recovery strategy (Strasizar et al. 2013). CERP and Central Everglades Planning Project evaluations of restoration strategies use the SAV indicator in evaluating potential management strategies and performance targets.

SOUTHERN EVERGLADES PEAT COLLAPSE

Joseph Stachelek, Stephen Kelly, Carlos Coronado–Molina, Tiffany Troxler\(^1\), Laura Bauman\(^1\), Fred Sklar, John Kominoski\(^1\), Shelby Servais\(^1\), Benjamin Wilson\(^1\), Viviana Mazzei\(^1\), Evelyn Gaiser\(^1\), Christopher Madden and Stephen Davis\(^5\)

Conservative estimates predict that sea levels will rise by 0.6 m in South Florida over the next century (Zhang et al. 2011, Obeysekera et al. 2015). Sea level rise and increased saltwater intrusion is likely to result in some measure of inland shoreline transgression. The extent of this transgression depends in part on the resilience of brackish and freshwater ecosystems. One possibility is that saltwater intrusion into formerly fresh marshes will cause a decrease in belowground plant productivity and an increase in microbial breakdown of stored carbon. Taken together, this may cause brackish and freshwater peat soils to "collapse", degrade rapidly, and cause changes in local land elevations. There is some evidence that peat collapse is already occurring in some areas of the southern Everglades (Figure 6-36, panels A and B).

![Figure 6-36](image)

**Figure 6-36.** Evidence of peat collapse in ENP marshes (A, B). Field mesocosms in ENP marshes (C) and concurrent experiments at the Florida Bay Interagency Science Center (FBISC) outdoor mesocosm facility in Key Largo (D).

Methods and Results

District scientists in collaboration with ENP, Florida International University, and the Everglades Foundation are investigating the likelihood of widespread peat collapse by simulating saltwater intrusion into brackish and freshwater marshes. Experiments are being conducted by adding saltwater to containers of sawgrass peat marsh soil at the Florida Bay Interagency Science Center (FBISC) outdoor mesocosm facility as well as into large field mesocosms in the fresh and brackish marshes of ENP (Figure 6-36, panels C and D). Salinity dosing occurs continuously at the outdoor mesocosm facility and monthly at the field mesocosms.

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\(^5\) Everglades Foundation, Palmetto Bay, Florida
Results so far suggest that saltwater intrusion into these areas will cause changes in soil water chemistry, increased loss of peat, and increases in microbial enzymes that break down peat. Specifically, saltwater dosing in the ENP field mesocosms has increased porewater chloride and sulfate concentrations (Figure 6-37). In order to avoid repeated destructive sampling of the experimental plots soil carbon dioxide (CO₂) and methane (CH₄) efflux data were used as a proxy for changes in peat mass (measurements supplement biannual destructive sampling). Efflux measurements in the FBISC mesocosms show that peat soils subjected to exposure and elevated salinity have a more positive C net-ecosystem-exchange rate as they become a net source of C to the atmosphere rather than a net sink (Figure 6-38). Peat soils that act as a net source of C over the long-term will lose mass and likely decrease in elevation.

One of the primary controls on peat C balance is microbial enzyme mediated breakdown of organic matter. Microbial enzymes enable the breakdown of organic macromolecules (cellulose, lignin, and phenols) into products that are small enough for assimilation (Mann et al. 2014, Sinsabaugh et al. 2013). Changes in enzyme activity are regarded as signals of a change in the bioavailability of C and nutrients. However, these changes can also be caused by fluctuations in microbial community composition and biomass (Sinsabaugh 1992). Previous studies have shown a negative relationship between elevated salinity and the enzymes responsible for P bioavailability (Freeman et al. 2001). Thus, it is possible that the addition of marine P with saltwater intrusion will reduce the demand for phosphatase production. In order to assess potential changes in microbial processes occurring as result of saltwater intrusion and peat collapse, changes in potential enzyme activity were tracked within the soils of the experimental plots. The activity of one enzyme in particular, cellulase, has increased in the subsurface peat layers of the FBISC mesocosms following exposure to elevated salinity (Figure 6-39).

Figure 6-37. Porewater chloride and sulfate concentrations in manipulations at the FBISC outdoor mesocosm facility (top) and ENP field mesocosms (bottom).
Figure 6-38. Net ecosystem exchange measured as carbon (CO₂) flux in freshwater (FW) and brackish water (BW) marsh sites. Both sites were a source of C to the atmosphere (positive CO₂ flux) in the dry season and this effect was amplified with increased salinity in the brackish marsh. [Note: AW – ambient water; mg C m⁻² d⁻¹ – milligrams carbon per square meter per day; and SW – saltwater.]
Figure 6-39. Cellulase activities increased within FBISC mesocosm soils following exposure to elevated salinity and submergence at 10–20 cm soil depth (p < 0.05). [Note: µmol g⁻¹ h⁻¹ – micromoles per gram per hour]

Relevance to Water Management

A critical concern for the management of freshwater and coastal habitats in coastal ENP is the potential for inland marshes exposed to increasing sea level rise to collapse (CISREP 2014). If salt-tolerant communities cannot adapt to the salinity changes associated with increasing sea levels, then significant coastal wetland loss may occur, dramatically increasing the vulnerability of the South Florida coastline. Collapsing peat may release nutrients into the water column that are eventually transported downstream. This may result in algal blooms and increased turbidity that would have cascading effects throughout Florida Bay and other adjacent coastal embayments. The results of this research will improve predictions of the resilience of coastal marshes and allow for better planning with respect to the quantity and timing of freshwater deliveries necessary to support the coastal Everglades. In addition, results will provide the South Florida coastal community and water managers with new information that allows for the assessment of the environmental consequences of storms, hydrologic restoration, sea level rise and changing rainfall and runoff on the coastal zone.
LANDSCAPE ECOLOGY

This section examines: (1) the development of a model to predict the necessary hydrologic targets for maintaining and/or restoring the Everglades ridge and slough landscape features, and (2) the initial results of the Decomp Physical Model (DPM). A more complete description and evaluation of the hydrologic, biogeochemical, and biological results of the DPM is documented in Appendix 6-1 of this volume.

AN INITIAL MULTISTATE TRANSITION PROBABILITY MODEL FOR RIDGE, WET PRAIRIE AND SLOUGH

Christa Zweig and Sue Newman

The ridge and slough landscape was a dominant landscape type of the central portion of the Everglades and is an example of a patterned peatland with parallel drainage topography whose patterning was stable for thousands of years (Bernhardt and Willard 2009). Water management for flood control and water supply began in the early twentieth century (McVoy et al., 2011) and has had a dramatic impact on the patterning. The ridge and slough landscape consists of long, linear strands of sawgrass, longer hydroperiod sloughs, and occasional tree islands oriented parallel with the slow moving flow of water from northwest to southeast. This landscape has been fragmented by compartmentalization, impoundment, and reduced flows (Ogden 2005) and is now in a degraded form (Nungesser 2011, Wu et al. 2006, Zweig et al. 2011, McVoy et al. 2011). A new multistate probability model (Figure 6-40) was designed to explore the effect altered hydrology may have had on the ridge and slough landscape—causing changes between ridge, wet prairie, and slough states—and how hydrology may be used in its restoration.

Figure 6-40. Representation of multistate model for ridge, wet prairie, and slough, which models transition probabilities ($\psi$) from one state to the other, or the probability of staying in the same state.
Multistate models were originally developed to deal with multiple states of wildlife (physiological or spatial states) in survival analyses (Hestbeck et al. 1991, Nichols et al. 1994), but have been applied in a limited way to vegetative habitats (Zweig and Kitchens 2014, Breininger et al. 2010, Hotaling et al. 2009). They use a likelihood-based approach to model transition probabilities between discrete states over time and can accommodate missing data (Lebreton and Pradel 2002). Multistate models can directly estimate environmental parameters, past and present, connected with state/community changes (Breininger et al. 2010).

**Methods**

The data for this analysis were collected between 2002 and 2013 (n = 867) in southern WCA-3A (see sampling details in Zweig and Kitchens 2014; Figure 6-41). The data was clustered for three different repeated samples (2002/2010, 2003/2012, 2004/2013) into three ‘states’, sawgrass, wet prairie, and slough, using a hierarchical cluster analysis on the biomass/density data with a Sorenson distance measure and flexible beta of -0.25 in PC-ORD (McCune and Mefford 1999).

**Figure 6-41.** Study sites in southern WCA-3A. Black squares are 1-square kilometer study plots and yellow dot is the Site 65 hydrologic gauge.

The three states were used in a likelihood-based multistate analysis in Program MARK [version 6.1, (White and Burnham 1999)] to model transition probabilities between ridge, slough, and wet prairie. The ‘multistate recaptures only’ model in MARK estimates survival (S), detection (p), and annual transition probabilities (ψ). Both S and p were constrained to be equal to 1, as it was assumed perfect detection of a sample and that a sample always survived from one sample event to the next.
Models were constructed to test for the effect of environmental covariates, or a combination thereof, on conditional transition probabilities (conditional on the state at \( t \) for \( t+1 \)) between vegetation communities and tested them against a null model. The null model assumed that the transition probabilities were constant through time and the same between transitions (slough to ridge, ridge to prairie, etc.). The environmental parameters tested were local elevation (cm), peat depth, and tailored hydrology for each site. For hydrology, a global hydrology was used from the gauge with the longest hydrologic record (USGS Site 65) to test if local or global effects are more important on the landscape. For the annual minimum and maximum water depths and amplitudes, 5- and 15-year average means were used (maximum - minimum annual water depth). The hydrology was tailored to each sample by its elevation subtracted from the stage of a local well (see details in Zweig and Kitchens 2008), so samples near each other could have a hydrology that varied by centimeters according to the local microtopography. The most supported model is chosen by the lowest Akaike information criterion (AICc) (Burnham and Anderson 2002) and highest AICc weight, which represents the relative likelihood of the model.

**Results**

The most supported model included 15-year hydrologic amplitude, 15-year hydrological maximum, elevation, and peat depth (Table 6-10). The effect of 15-year hydrology on ridge and slough landscape transitions was more supported than 5-year hydrology, with a 14.0388 difference in AICc (\( \Delta \text{AICc} \)) between 15-year mean minimum and 5-year mean minimum. A \( \Delta \text{AICc} \) greater than 2.0 indicates a strong difference between two models (Burnham and Anderson 2002). Between single environmental factors, peat depth was the most important, differing between 9 and 26 \( \Delta \text{AICc} \) from other variables. Site-specific hydrology (from local elevation) was a better indicator of state transitions than a global hydrology (Site 65). The \( \Delta \text{AICc} \) between the model with Site 65 global hydrology and tailored water depths was 20.1272.

**Table 6-10.** Results for multistate models indicating hypotheses about the effect of environmental variables on vegetation community transitions. The dot model (.\) assumed that the transition probabilities were constant through time and between state transitions.

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>( \Delta \text{AIC} )</th>
<th>AICc Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S(1)p(1)\psi(\text{transitions + peat + elevation + 15-year mean maximum + 15-year mean amplitude}) )</td>
<td>791.8254</td>
<td>0</td>
<td>0.49705</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{transitions + peat + elevation + 15-year mean minimum + 15-year mean amplitude}) )</td>
<td>791.8254</td>
<td>0</td>
<td>0.49705</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{peat}) )</td>
<td>885.5214</td>
<td>93.6960</td>
<td>0</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{elevation}) )</td>
<td>894.1254</td>
<td>102.3000</td>
<td>0</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{15-year mean amplitude}) )</td>
<td>895.0095</td>
<td>103.1841</td>
<td>0</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{15-year mean minimum}) )</td>
<td>896.2999</td>
<td>104.4745</td>
<td>0</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{5-year mean minimum}) )</td>
<td>910.3387</td>
<td>118.5133</td>
<td>0</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{15-year mean maximum}) )</td>
<td>911.8656</td>
<td>120.0402</td>
<td>0</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(\text{15-year mean maximum from Site 65}) )</td>
<td>931.9928</td>
<td>140.0548</td>
<td>0</td>
</tr>
<tr>
<td>( S(1)p(1)\psi(.) )</td>
<td>986089.8146</td>
<td>985297.9892</td>
<td>0</td>
</tr>
</tbody>
</table>
Model output provided decadal transition probabilities for each state (slough, wet prairie, and ridge) as a function of changes in hydrology. Parameters for each transition and environmental variable were used to help distinguish the effect of the variable on each transition (Table 6-11) and were considered significant if their confidence intervals did not include 0. These parameters suggested that deeper peat makes sloughs more resilient to transition to drier communities, and that both ridge and slough are more stable in deep peat. Higher amplitudes lead to increased transitions to drier communities, but lower amplitudes do not necessarily lead to more ridge-to-slough transitions. Sloughs are most vulnerable to higher amplitudes than wet prairies.

Table 6-11. Parameter estimates, standard error, and confidence intervals for the ridge, prairie, and slough multistate model. Significant parameters are listed in bold. [Note: P = wet prairie, R = ridge, and S = slough.]

<table>
<thead>
<tr>
<th>Beta</th>
<th>Standard Error</th>
<th>Lower 95% Confidence Interval</th>
<th>Upper 95% Confidence Interval</th>
<th>Environmental Variable</th>
<th>Transition</th>
</tr>
</thead>
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<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>survival/detection</td>
<td>constant</td>
</tr>
<tr>
<td>26.74</td>
<td>20.84</td>
<td>-14.11</td>
<td>67.59</td>
<td>intercept</td>
<td>P to S</td>
</tr>
<tr>
<td>-30.72</td>
<td>21.20</td>
<td>-72.27</td>
<td>10.83</td>
<td>intercept</td>
<td>R to S</td>
</tr>
<tr>
<td>3.25</td>
<td>30.54</td>
<td>-56.62</td>
<td>63.11</td>
<td>intercept</td>
<td>R to P</td>
</tr>
<tr>
<td>-0.93</td>
<td>21.50</td>
<td>-43.08</td>
<td>41.21</td>
<td>intercept</td>
<td>S to R</td>
</tr>
<tr>
<td>-32.38</td>
<td>22.53</td>
<td>-76.54</td>
<td>11.78</td>
<td>intercept</td>
<td>S to P</td>
</tr>
<tr>
<td>-13.06</td>
<td>36.78</td>
<td>-85.15</td>
<td>59.03</td>
<td>intercept</td>
<td>P to R</td>
</tr>
<tr>
<td>-0.25</td>
<td>0.09</td>
<td>-0.42</td>
<td>-0.08</td>
<td>amplitude</td>
<td>P to S</td>
</tr>
<tr>
<td>0.16</td>
<td>0.18</td>
<td>0.35</td>
<td>0.59</td>
<td>amplitude</td>
<td>R to S</td>
</tr>
<tr>
<td>0.24</td>
<td>0.18</td>
<td>-0.11</td>
<td>0.59</td>
<td>amplitude</td>
<td>R to P</td>
</tr>
<tr>
<td>0.54</td>
<td>0.10</td>
<td>0.33</td>
<td>0.74</td>
<td>amplitude</td>
<td>S to R</td>
</tr>
<tr>
<td>0.53</td>
<td>0.15</td>
<td>0.24</td>
<td>0.82</td>
<td>amplitude</td>
<td>S to P</td>
</tr>
<tr>
<td>0.33</td>
<td>0.17</td>
<td>0.01</td>
<td>0.66</td>
<td>amplitude</td>
<td>P to R</td>
</tr>
<tr>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
<td>0.07</td>
<td>peat</td>
<td>P to S</td>
</tr>
<tr>
<td>-0.04</td>
<td>0.02</td>
<td>-0.07</td>
<td>0.00</td>
<td>peat</td>
<td>R to S</td>
</tr>
<tr>
<td>-0.12</td>
<td>0.05</td>
<td>-0.21</td>
<td>-0.03</td>
<td>peat</td>
<td>R to P</td>
</tr>
<tr>
<td>-0.05</td>
<td>0.02</td>
<td>-0.09</td>
<td>-0.02</td>
<td>peat</td>
<td>S to R</td>
</tr>
<tr>
<td>-0.08</td>
<td>0.02</td>
<td>-0.12</td>
<td>-0.04</td>
<td>peat</td>
<td>S to P</td>
</tr>
<tr>
<td>-0.07</td>
<td>0.04</td>
<td>-0.15</td>
<td>0.01</td>
<td>peat</td>
<td>P to R</td>
</tr>
<tr>
<td>-0.04</td>
<td>0.08</td>
<td>-0.20</td>
<td>0.12</td>
<td>elevation</td>
<td>P to S</td>
</tr>
<tr>
<td>0.05</td>
<td>0.08</td>
<td>-0.11</td>
<td>0.21</td>
<td>elevation</td>
<td>R to S</td>
</tr>
<tr>
<td>-0.07</td>
<td>0.11</td>
<td>-0.29</td>
<td>0.16</td>
<td>elevation</td>
<td>R to P</td>
</tr>
<tr>
<td>-0.10</td>
<td>0.08</td>
<td>-0.27</td>
<td>0.06</td>
<td>elevation</td>
<td>S to R</td>
</tr>
<tr>
<td>-0.01</td>
<td>0.09</td>
<td>-0.19</td>
<td>0.17</td>
<td>elevation</td>
<td>S to P</td>
</tr>
<tr>
<td>0.00</td>
<td>0.13</td>
<td>-0.26</td>
<td>0.26</td>
<td>elevation</td>
<td>P to R</td>
</tr>
<tr>
<td>-0.02</td>
<td>0.07</td>
<td>-0.17</td>
<td>0.12</td>
<td>15-year maximum</td>
<td>P to S</td>
</tr>
<tr>
<td>0.10</td>
<td>0.08</td>
<td>-0.05</td>
<td>0.25</td>
<td>15-year maximum</td>
<td>R to S</td>
</tr>
<tr>
<td>-0.05</td>
<td>0.13</td>
<td>-0.31</td>
<td>0.21</td>
<td>15-year maximum</td>
<td>R to P</td>
</tr>
<tr>
<td>-0.20</td>
<td>0.08</td>
<td>-0.36</td>
<td>-0.04</td>
<td>15-year maximum</td>
<td>S to R</td>
</tr>
<tr>
<td>-0.05</td>
<td>0.09</td>
<td>-0.23</td>
<td>0.12</td>
<td>15-year maximum</td>
<td>S to P</td>
</tr>
<tr>
<td>-0.12</td>
<td>0.11</td>
<td>-0.35</td>
<td>0.10</td>
<td>15-year maximum</td>
<td>P to R</td>
</tr>
</tbody>
</table>

The probability that a community would stay in the same state for a range of amplitudes and 15-year mean maximum water depth values was calculated to determine the hydrology that creates the most stable ridge and slough landscape (varying depths and amplitudes while holding elevation
and peat depth constant). Wet prairie was not considered for now, as it is heavily influenced by peat depth. The most stable ridge and slough landscape would be under conditions where water management creates a 75–80 cm 15-year average amplitude (Figure 6-42) and a 15-year average maximum between 80 and 90 cm (Figure 6-43).

**Figure 6-42.** Probabilities that ridge, wet prairie, or slough states will remain stable over a range of mean 15-year hydrologic amplitude (cm). Best stability for both states is a 75–80 cm 15-year average amplitude.

**Figure 6-43.** Probabilities that ridge or slough states will remain stable over a range of mean 15-year maximum water depths. Best stability for both states is between an 80 and 90 cm 15-year average maximum.
Relevance to Water Management

Models such as this can help guide water management decisions, particularly since the ridge and slough landscape is an indicator of Everglades restoration in CERP and the Central Everglades Planning Project and this area in WCA-3A is the ‘heart of Everglades restoration’. This model can specifically be used for the RECOVER high-low performance measure, and provides tangible water depth targets for a stable ridge and slough landscape. It also provides guidance on hydrology that can be used to transition one type of community to another in areas that are dominated by one community and in need of active restoration measures.

EXPERIMENTAL EFFECTS OF SHEETFLOW ON SEDIMENT REDISTRIBUTION IN THE RIDGE-AND-SLOUGH AND CANAL BACKFILLING – INTERIM FINDINGS OF THE DECOMP PHYSICAL MODEL

Carlos Coronado-Molina, Judson Harvey6, Jay Choi3, Brendan Buskirk3, Jesus Gomez-Velez3, Allison Schwartz2, David Ho7, Ben Hickman4, Laurel Larsen8, Joel Trexler1, Mike Bush1, Michael Manna, Susan Newman, Colin Saunders, Fred Sklar, Christopher Madden, Fabiola Santamaria2 and Michelle Blaha2

Background and Summary

The DPM is a landscape-scale adaptive management study to evaluate the benefits of restoring sheetflow in the ridge-and-slough landscape. Project objectives include (1) evaluating the extent to which flow moves sediment from sloughs to ridges and builds microtopography and patterning and (2) determining the ecological benefits of backfilling canals, completely or partially, to maintain natural sediment transport while reducing downstream eutrophication. A detailed description of the hydrological, biogeochemical, and biological studies conducted for the DPM is presented in Appendix 6-1 of this volume.

The study uses a before-after-control-impact (BACI) experimental design, with additional sites for synoptic surveys (Figure 6-44) to evaluate hydrological and ecological response variables to flow conditions and canal backfill treatments. Ten gated culverts (S-152) are used to move water from L-67A into an area known as “the pocket” between L-67A and L-67C canal/levee features. Several of the findings from the first flow event (documented in the 2015 South Florida Environmental Report, Sklar and Dreschel 2015) were again observed in the second flow event. In both flow events, dye injected at the S-152 spread radially across the pocket, moving preferentially eastward. High flow velocities (> 3 centimeters per second) were achieved primarily in sloughs, but limited to areas within 500 m of the S-152 structure. Velocities and shear stress measured at the sediment-water interface in sloughs were above the critical thresholds required to resuspend sediments. Several independent field measurements (e.g., traps, synthetic tracers, and water samples) demonstrated sediment transport increased, more so in sloughs than in ridges. In both

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6 United States Geological Survey, Reston, Virginia
7 University of Hawaii, Manoa, Hawaii
8 University of California, Berkeley, California
flow events, water velocities and sediment transport in the RS1 slough (nearest the S-152) increased substantially over the duration of flow despite relatively constant S-152 discharges.

Figures 6-44. (Top left) DPM experimental site, located in “the pocket” between the L-67A and L-67C canal/levee structures. Hydrologic and biological response variables are measured at 11 marsh sites and 5 canal sites using a BACI experimental design. Site RS1 includes an upstream and downstream boardwalk, RS1U and RS1D, respectively. (Top right) Additional sites (pink) were added to analyze changes in spatial gradients along the north-to-south flow path in a subset of response variables. (Bottom) Location of a 3-m x 100-m created slough, used to assess the benefits of active management in restoring flow and sediment redistribution.

For this year’s chapter, the focus is more narrowly on observed changes in the chemical and physical properties and the fate of transported sediments. Differences in the physical and chemical nature of transported sediments have implications for how structures are operated in the interest of maximizing sediment redistribution. For example, if nutrient content and sediment transport during initial flow pulses (from structure openings) are several-fold greater than during steady-state flows, then optimal structure operations might include a combination of both pulse flows and steady-state flows. In both flow events, changes in sediment chemistry and physical properties indicated that transport of sediments (per day) was greater and consisted of finer (< 45 micrometer diameter), phosphorus-rich particles during the initial pulse than during steady-state flow conditions.
Periphyton-derived sediments may explain the initial increase in sediment transport and water column TP. Particle size analysis indicated that fine particles are periphyton-derived, and in addition, high-resolution aerial imagery showed rapid break-up of metaphyton in sloughs where velocities significantly increased. Analysis of floc biomarkers and synthetic floc experiments provided evidence of slough-sediments moving and settling in ridges under high flow, a critical mechanism in rebuilding topography. Biomarker analysis of sediments accumulating in canals also showed widespread sources changes with flow. Finally, initial findings of a pilot study to create a small, narrow slough (Figure 6-44, bottom panel), showed that flow and sediment transport can be increased and that active management may accelerate the process of restoring the ridge/slough pattern.

**Relevance to Water Management**

Although water column TP and suspended sediment concentrations (SSC) remain relatively low during most of the high-flow period (below 10 parts per billion and 1 milligram per liter, respectively), high-temporal resolution data indicated water TP and SSC were briefly elevated during initial pulse releases, mainly in sloughs. The tenfold increases in SSC suggest such short-term pulses could be an effective operational tool for water management in redistributing sediments and rebuilding topography, particularly if water supply is limited. Some uncertainties remain in this regard, namely (1) how much time is required to replenish the fine sediments that contribute the majority of the SSC spikes; and (2) the magnitude of particles (and P) transported and redistributed during pulses compared to longer-term flows. Both structure operations and sampling during the third flow event will be modified accordingly to evaluate the importance of pulse flows compared to steady state flows.

Results from the created slough indicated that active management of vegetation, combined with high flow conditions, can be successful in generating high slough velocities. Such an approach is likely needed to accelerate ridge-and-slough landscape restoration given the limited spatial extent of high velocities observed to date. An important next step in DPM will be to increase the areal expanse of sloughs that have been invaded by sawgrass as a result of drainage.

Canal velocities roughly doubled under high flow, reaching 7–8 centimeter per second, above critical erosion thresholds for Everglades sediments. Therefore, the widespread changes in canal sediment sources, as evidenced by molecular biomarkers, may be caused by velocity changes in the canal itself. Given the high TP of canal sediments, this process could potentially alter P cycling in the canal. Specific impacts include (1) increased water column TP in both canals and the marshes downstream of the levee gap, (2) changes in the vegetation growth and vegetation types within canals (e.g., exotics that further reduce through-flow of natural (low-TP) sediments, promote anoxic conditions, or produce high-TP sediments), and (3) changes in marsh vegetation downstream of canal/levee gaps (e.g., cattails). To address these questions, subsequent flow events will place greater emphasis on quantifying the sources (biomarkers) of advected sediments entering canals from adjacent ridges and sloughs; evaluating biomarker signatures and nutrient contents of benthic sediments within the canal; recording vegetation changes within and adjacent to canal treatments; and conducting more focused analysis of water column TP (including sediment TP) in canal and downstream marshes. The extent to which partial or complete backfilling interacts with these ecosystem responses will also be evaluated.
LITERATURE CITED


SFWMD. 2014b. Updated Habitat Improvement Plan for the Cape Sable Seaside Sparrow in Designated Critical Habitat Unit 3 (Subpopulation D), FY2015–2019. South Florida Water Management District, West Palm Beach, FL.


Virzi, T. and M.J. Davis. 2014. C-111 Project and Cape Sable Seaside Sparrow Subpopulation D Annual Report 2014. Rutgers University, New Brunswick, NJ, and Ecotudies Institute, Mount Vernon, WA.


Wanless, H.R. 2008. Statement on Sea Level in the Coming Century. Report from the Miami-Dade County Climate Change Advisory Task Force to the Board of County Commissioners, Miami, FL.


