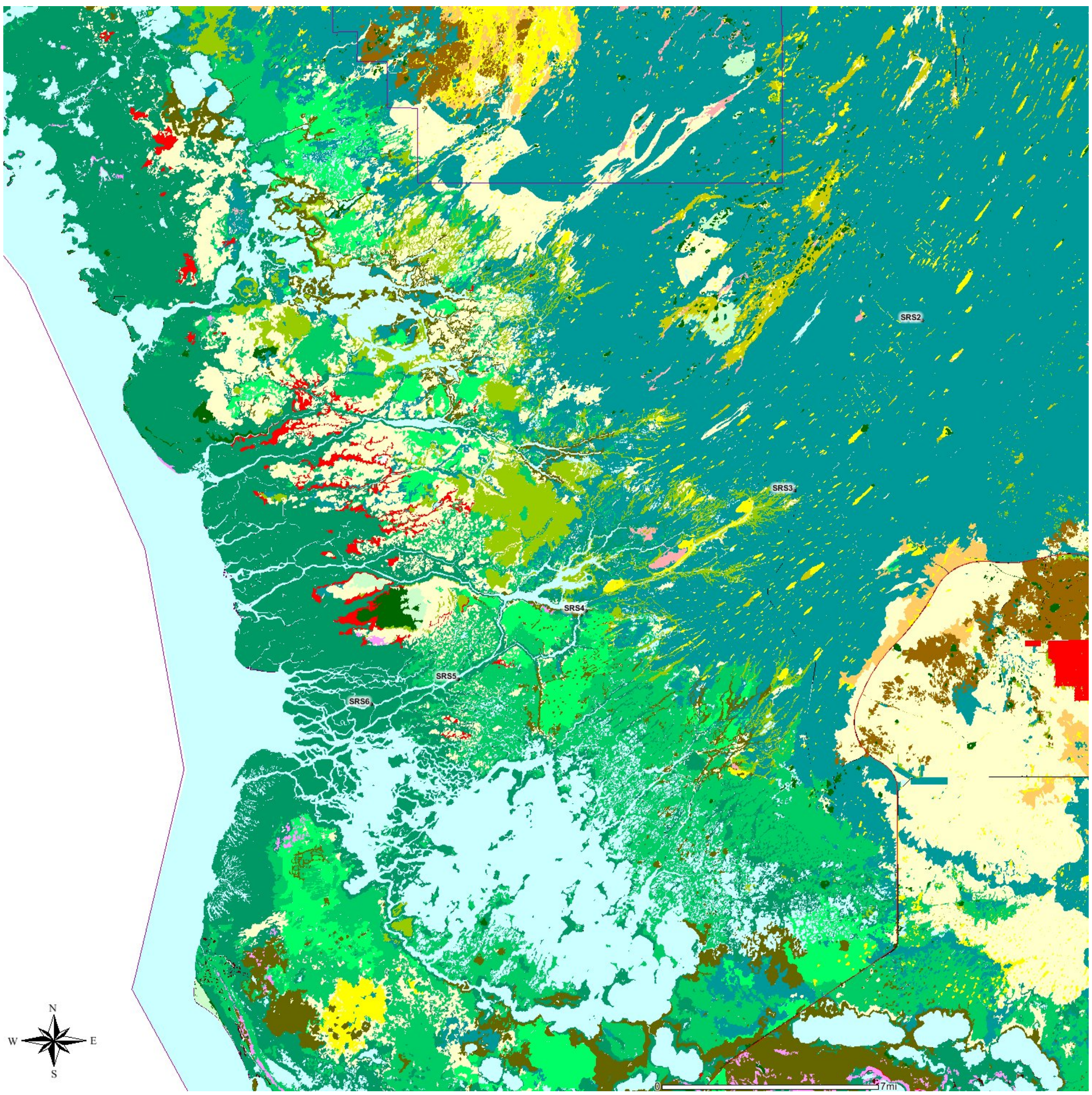
INDICATORS FOR RESTORATION

SOUTH FLORIDA ECOSYSTEM RESTORATION

REPORT TO THE
SOUTH FLORIDA ECOSYSTEM RESTORATION TASK FORCE

FROM THE
SCIENCE COORDINATION GROUP
2006



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INDICATORS FOR RESTORATION:
SOUTH FLORIDA ECOSYSTEM RESTORATION

An Ecological Indicator is a metric that is designed to inform us easily and quickly about the conditions over time and space of an ecosystem (Bennet 2000).

A useful Ecological Indicator must produce results that are clearly understood and accepted by scientists, policy makers, and the public (Jackson et al., 2000)

Introduction

Scientists have long sought a system for measuring the general health, ecological integrity (sensu Parrish et al. 2003) and restorative capabilities and trends of ecosystems (Griffith and Hunsaker 1994, Karr and Chu 1997). National Indicators for pollution and the economy have been used for many years to convey complex scientific and economic principles and data into easily understandable concepts (Bennett 2000).

There are many ecological restoration initiatives globally and nationally that are either currently using or developing Ecological Indicators to assist them in grading ecological conditions (i.e. integrity). A few of the larger US restoration/preservation programs that are developing and using Ecological Indicators include Chesapeake Bay Maryland, San Francisco Bay-Delta-River System California, Fort Benning Military Reservation Georgia, Eglin Air Force Base Florida, Blue Marsh Conservation Area-St. John's River Florida, Yellowstone National Park Montana, Great Smokey Mountains National Park North Carolina, Seneca Creek Watershed Maryland, Prairie Pothole Region North Dakota, Columbia River Oregon and the South Florida Ecosystem Restoration Program.

Background

The South Florida Ecosystem Restoration Task Force (Task Force), established by section 528(f) of the Water Resources Development Act (WRDA) of 1996 consists of 14 members. There are seven federal, two tribal, and five state and local government representatives. The duties of the Task Force include: 1) Coordinate the development of consistent policies, strategies, plans, programs, projects, activities, and priorities addressing the restoration, preservation, and protection of the South Florida ecosystem; 2) Exchange information regarding programs, projects and activities of the agencies and entities represented on the Task Force to promote ecosystem restoration and maintenance; 3) Facilitate the resolution of interagency and intergovernmental conflicts associated with the restoration of the South Florida ecosystem among the agencies and entities represented on the Task Force; 4) Coordinate scientific and other research associated with the restoration of the South Florida ecosystem; and 5) Provide assistance and support to agencies and entities represented on the Task Force in their restoration activities.

Recognizing that the execution of many of its duties requires accurate and timely synthesis and coordination of science information, in 2004, the Task Force initiated the development of a *Plan for Coordinating Science (Plan).* In the *Plan,* the Task Force defines science application as:

> *[Ensuring] that relevant scientific information is synthesized and conveyed in formats that facilitate management decisions, and that this is done in a timely manner. This type of activity includes the development of metrics, such as indicators of restoration success and associated performance measures.*

In 2005, the Task Force directed the Science Coordination Group (SCG; see www.sfrestore.org) to develop a “suite” of system-wide indicators for restoration.

The Task Force will use these system-wide indicators to judge the performance of the CERP and non-CERP restoration projects toward achieving restoration goals that are outlined in both the Comprehensive Everglades Restoration Plan (CERP), and the goals and projects included in the Task Force Strategic Plans, see respectively:

- http://www.usace.army.mil/inet/functions/cw/hot_topics/everglades.htm
- http://www.sfrestore.org/documents/2004_strategic%20plan_volume%20I.pdf

In addition, these indicators will help evaluate the ecological changes resulting from the implementation of the restoration projects and provide information and context by which to adapt and improve, add, replace or remove indicators as new scientific information and findings become available.

Scope of This Report

Ecological systems are complex and efforts to select and implement easily understood indicators of change are extremely difficult. In seeking indicators of significant ecological change for management information purposes, there is a need to consider the many steps involved in producing and conveying a scientifically sound report to policy makers. For example, producing ‘top-of-the-mountain’ ecological information requires such tasks as identifying and quantifying information objectives, designing a sampling network, selecting methods to perform the sampling, establishing a transparent and documented data management/data quality system, detailing how data will be analyzed, interpreted accessed and shared, and designing reports to convey the resulting information. This report focuses primarily on two dimensions of System-wide Indicator design and development – 1) identification of indicators and associated variables to be measured and, 2) how to communicate information about them and the information they are intended to convey about restoration, to managers and policy makers.

We have applied a narrow focus to this report not because the SCG considers these other aspects of indicator development, data collection, use, and application less critical, but, because the larger ecosystem restoration efforts, particularly through CERP and RECOVER and the SCG, already incorporate these other elements or are in the process of developing and implementing these other aspects. For further details, please see:

- RECOVER comprehensive plan for monitoring (RECOVER MAP I & II) (http://www.evergladesplan.org/pm/recover/recover_map.cfm);
- An Adaptive Assessment Strategy for the Comprehensive Everglades Restoration Plan (March 2000) (http://www.evergladesplan.org/pm/recover/recover_docs/aat/032700_aat_strategy.pdf);
- Information & Data Management Program Management Plan (PrMP) Sept 2003 Draft Revision/Update v0.24 (http://www.evergladesplan.org/pm/progr_data_mgmt_plan.cfm);
- Interagency Modeling Center Program Management Plan, Final - January 2004 (http://www.evergladesplan.org/pm/progr_imc_plan.cfm);
- CERP Quality Assurance Systems Requirements (QASR), (http://www.evergladesplan.org/pm/program_docs/qasr.cfm);
- Independent Scientific Review Panel (http://www.evergladesplan.org/pm/ind_review.cfm);
- Additional RECOVER and CERP projects (http://www.evergladesplan.org/pm/landing_program.cfm)
- Science Coordination Group Indicator Reports and Plan for Coordinating Science http://www.sfrestore.org/scg/index.htm

It is not the purpose of this report to provide such details. It is limited to indicator selection and communication only, with the other details available elsewhere as noted above. It is important that the reader understand that the development, application and communication of the suite of System-wide Indicators discussed in this report is occurring within in this larger and comprehensive congruent effort. Without the larger restoration effort as the framework, this System-wide Indicator endeavor by the Task Force would not be possible.

We recognize that production of information about restoration performance, outlined in very broad terms in this report, will require considerable effort. There is no discussion of implementation mechanisms, agencies, timelines or staffing because, again, not only are these aspects beyond the scope of this report, but also because they are being developed and implemented through other aspects of the restoration program that these indicators are integrated with. However, we understand that the development of a successful performance measure system is critical to successful use and application of these indicators for managers and policy makers. The SCG is working with the CERP RECOVER process and is already developing performance measures for these indicators that will be available for the first assessment in 2008.

Large, complex regional restoration programs must include a means for measuring how well they meet their goals. We view indicators as a critical part of goal measurement. Scientists involved in south Florida restoration have developed a process known as Adaptive Management—Adaptive Assessment that will help measure responses of natural and human systems as the CERP is implemented, and will quantify how well the restoration plan is meeting its desired objectives. Adaptive Assessment also will provide a scientific basis for making improvements to the indicators, if and when the need or opportunities for such improvements are identified. The primary role of Adaptive Assessment is to have an on-going process for increasing the probability that restoration will be successful. The terms “Adaptive Assessment” and “Adaptive Management” are currently used interchangeably by many managers and resource professionals. Because Adaptive Management in its original meaning described a designed process for testing hypotheses, the term Adaptive Assessment is used here to describe a protocol for collecting and interpreting new information specifically for the purpose of improving the design of the Comprehensive Plan that includes the use and communication of indicators.

Adaptive Assessment provides an organized process for confronting and reducing uncertainties that exist about how the natural and human systems in south Florida will respond to a long-term restoration program. Some uncertainties are inevitable, in that we are dealing with systems that are highly complex, not thoroughly understood, and difficult to predict. The systems are complex in their detail (i.e., in the number of different components that they include) and their dynamics (i.e., the number and scales of relationships that drive responses). The current level of uncertainty has prompted a range of professional opinions regarding the comparative importance and use of different ecosystem indicators and variables, and of the linkages among them.

Although these debates are essential steps for focusing and prioritizing future science, the purpose of the indicators is to provide an integrated approach to determine the progress of restoration efforts. The SCG recognizes that integration of all the indicators in the System-wide suite should remain a top priority in order to ensure that the indicators are applicable to, and used and communicated in a manner consistent with the “System-wide” assessments that are preferred. We also note that while the report is focused heavily on South Florida, other regions require attention as well.

In short, this report, while limited in scope to the identification of a process and application of that process in developing a suite of indicators that collectively will provide for a System-wide assessment of restoration, it still addresses a critical need in any modern ecosystem management effort. That is to provide scientifically sound information regarding changes in ecosystem health resulting from management actions and, in the case of South Florida, a major restoration program.

Development of System-Wide Indicators

Ecological indicators come in many different formats, forms, levels of detail or resolution, organizational schemas, and environmental metrics. They also have many different purposes and applications and no one set or method of application or means of developing indicators seems to work or apply in all situations or ecosystems. However, each individualized set of indicators is designed to capture an “essence” or defining set of “features” of the ecosystem that they are intended to indicate something about. The “features” of the Greater Everglades—South Florida

Ecosystem includes characteristics distinctive of the Everglades' landscape, trophic constituents, biodiversity, and physical properties.

The Task Force requested that a system-wide suite of indicators for Greater Everglades's restoration be developed and available for inclusion in their 2006 biennial report with the first assessment scheduled no later than the 2008 biennial report. The SCG recognized that this short timeline might result in "indicator gaps" and may require the development and inclusion of additional indicators in the future.

The SCG developed this initial suite of South Florida system-wide indicators of restoration success through the execution of a 4-step process.

Step 1. Evaluate existing restoration efforts from various sources for indicators for possible application to the Task Force suite of system-wide indicators (see Table 1)

Step 2. Using established guidelines, (see Table 2) select relevant indicators for Everglades Ecosystem applicability, evaluate the list of Indicators for individual and collective value and coverage of Everglades' ecosystem Regions, Characteristics, Trophic Interactions, and Functions

Step 3. Identify "indicator gaps", and where feasible for the 2006 report, develop new indicators to fill identified gaps

Step 4. Select final system-wide suite of indicators for the 2006 biennial report and develop indicator documentation and communication proposal and identify "indicator gaps" to be filled by 2008 or beyond

Step 1. Evaluate Existing Restoration Efforts for Indicators

Since much work on indicator development for south Florida Ecosystem Restoration has already been accomplished under CERP the SCG's leading source for indicators was the Restoration Coordination and Verification (RECOVER) team's *Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan* and the RECOVER Monitoring & Assessment Plan (MAP) see: http://www.evergladesplan.org. RECOVER's (2005) Interim Goals and Targets report includes 31 different indicators specific to south Florida restoration projects, and responsive to the CERP Programmatic Regulations published in 68 FR 218 (12 November 2003). The RECOVER MAP (2005) included over 90 parameters (reduced from several hundred in the first draft) that will be included in restoration monitoring and used as "indicators" for restoration. For details on all the monitoring elements in the RECOVER MAP, see:

http://www.evergladesplan.org/pm/recover/recover_map.cfm

Table 1. Existing restoration programs evaluated by the SCG included those from the following agencies and programs.

- California Bay-Delta Authority Restoration and Adaptive Management Program of the San Francisco Bay and Sacramento-San Joaquin Delta ecosystem (CALFED Bay-Delta Program; see:

  - http://science.calwater.ca.gov/sci_tools/performance_measures.shtml
- Corps of Engineers-Jacksonville District, South Florida Water Management District, and the Everglades National Park Modified Water Deliveries to Everglades National Park and South Dade Canals (C-111) Projects (ModWaters;
  - see: http://www.sfwmd.gov/org/pld/hsm/reg_app/mwd/).
- Southwest Florida Feasibility Study
  - (see: http://www.evergladesplan.org/pm/studies/swfl.cfm)
- Florida Bay / Florida Keys Feasibility Study
  - (see: http://www.evergladesplan.org/pm/studies/fl_bay.cfm)
- Chesapeake Bay Program Indicators Workgroup
  - (see: http://www.chesapeakebay.net/irw.htm)
- Ecological Indicators for the Nation
  - (see: http://www.nap.edu/catalog/9720.html)

Summary of Findings from Step 1.

Most of the projects and programs we evaluated for indicators either had no indicators that were reasonably applicable to our purpose or where indicators might have been useful in providing insight for development of our indicators, they included either variables or metrics that did not apply to the Everglades. Even so, where possible we utilized conceptual and strategic aspects of these other project indicators, and tried to ensure that concepts regarding effective approaches and uses of indicators were incorporated into the selection, design, development and application of our suite of indicators. One of the most important benefits all these programs provided was a large array of indicators and types of indicators that in retrospect provided us with the ability to use this framework and a process of elimination to help us prospectively identify “gaps” among our preliminary “sets” of indicators and to guide us in identifying errors of omission and errors of commission with regard to our selected suite.

Additionally, the indicators from the final six programs we more thoroughly evaluated provided us with several important findings beyond just lists of possible individual indicators.

1. California Bay Delta Program
   a. Did not consider an integrated system-wide approach to indicators and suggested to us the need for such integration.
   b. Indicators were predominantly water supply or water quality (for consumption) oriented even where additional indicators were biological in nature suggesting a need on our part to clearly separate

biological from built system sets of indicators to ensure we did not confuse findings related to the different Task Force goals.

c. Provided important written organizational examples for succinctly and unambiguously justifying the use of and describing individual indicators, their metrics, and research findings and gaps related to the individual indicator.

2. Modified Water Deliveries Program
    a. While not formally considered a “CERP” program many assumptions in CERP are based on this program being implemented prior to CERP projects and thus provided key guidance on the importance of good spatial coverage for Task Force indicators.
    b. Significant hydrological research and modeling have been done for this particular region, which provided insights into indicators where hydrological criteria were critical to indicator responses.
    c. Provided direct information regarding the impacts that CERP projects may have on some invasive exotic species and helped guide our development of the invasive exotic plant and future invasive exotic animal indicator(s).
3. Southwest Florida Feasibility Study
    a. Provided numerous examples of indicators applicable to the built system for the development of our “compatibility” indicators.
    b. It also provided numerous concepts related to compatibility of the human and natural sides of restoration offering us insight into selecting “compatibility” indicators that could be integrated.
4. Florida Bay Florida Keys Feasibility Study
    a. Provided key indicator examples with definitive research findings and process links to Florida Bay and estuarine indicators that provided “big picture” evaluations for estuarine and coastal areas.
5. Chesapeake Bay-Delta Program
    a. Provided clear examples of possible communication tools using graphs with targets.
    b. Provided valuable insights into target development and justifications and the complexity and non-trivial aspects of setting and communicating meaningful targets.
    c. Because the GAO report (GAO 2005) criticized their program for having too many un-integrated indicators this provided reinforcement of our decision to reduce the number of indicators to an “elegant few”, and ensure their integration to be able to “tell the bigger story”.
    d. Provided reinforcement of our decision to integrate the indicators and provide assessments in a straightforward, uncomplicated manner.

   e. Confirmed the need to be able to devolve big-picture assessments back through the more detailed data in order to provide transparency of findings.

6. Ecological Indicators for the Nation
   a. Provided a frame of reference to help ensure that our indicators fell within the general guidelines, concepts and recommendations for nationally accepted approaches related to ecological measurement and appraisal.

Step 2. Use Guidelines to Select Relevant Indicators

To objectively evaluate existing indicators that were potentially applicable to the Task Force's directives and interests, and to also determine that the suite collectively provided sufficient "coverage" of the regions, characteristics, trophic interactions, properties and functions of the ecosystem (see Figures 1a and 1b and Table 3) the SCG assembled two sets of guidelines (see Table 2). One is for ecological indictors and the other for indicators of compatibility of the built-system elements of CERP (those CERP projects intended to provide water and maintain levels of flood protection to the human dominated developed areas) with restoration . The SCG used these sets of guidelines to evaluate the individual indicators from the restoration plans and programs noted in Table 1.

Table 2. Restoration Indicator Guidelines developed by South Florida Ecosystem Restoration Task Force, Science Coordination Group (SCG)	
Ecological Indicator Guidelines	***Restoration Compatibility Guidelines***
1. Is the indicator relevant to the ecosystem and does it respond to variability at a scale that makes it applicable to the entire system or a large or important portion of it?	1. Does the indicator provide a measure of compatibility of the built system with ecological restoration?
2. Is the indicator feasible to implement (is someone collecting data already)?	2. Is the indicator feasible to implement (is someone collecting data already)?
3. Is the indicator sensitive to system drivers?	3. Is the indicator sensitive to system drivers (stressors, operations of water management)?
4. Is the indicator interpretable in a common language?	4. Is the indicator interpretable in a common language?
5. Are there situations where even an "optimistic" trend with regard to the indicator might suggest a "pessimistic" restoration trend?	5. Is the indicator scientifically defensible?
6. Are there situations where a "pessimistic" trend with regard to the indicator may be unrelated to restoration activities?	6. Are clear measurable targets established for the indicator to allow for assessments of success of affects of management actions and operations on ecological restoration?
7. Is the indicator scientifically defensible?	7. Does the indicator have specificity? Does it indicate a feature specific enough to result in management action or corrective action?
8. Are clear, measurable targets established for the indicator to allow for assessments of success of ecological restoration and effects of management actions?	
9. Does the indicator have specificity? Does it indicate a feature specific enough to result in management action or corrective action?	
10. What level of ecosystem process or structure does the indicator address?	

Through application of the guidelines listed in Table 2, the SCG narrowed the number of indicators to a sub-set of candidate indicators that met the criteria and were deemed suitable for inclusion in the system-wide suite of indicators for the Task Force.

Table 3. List of South Florida Ecosystem "Features"

Landscape Characteristics

- Hydropatterns
- Vegetation Pattern & Patchiness
- Productivity
- Native Biodiversity

- Oligotrophy
- "Pristine-ness"
- "Intactness" (connectivity)
- Trophic Balance
- Habitat Balance

Trophic Constituents & Biodiversity

- Primary producers (autotrophs, detritus)
- Primary consumers (herbivores)
- Secondary consumers (primary & secondary carnivores)
- Tertiary consumers (tertiary carnivores)

Physical Properties

- Water quality
- Water depth
- Water duration
- Water timing
- Water management (when, where, & how much water is moved)
- Exotics
- Salinity
- Nutrients (Nitrogen, Phosphorus, Sulphur)
- Contaminants

Ecological Regions (see Figure 1a)

- Greater Everglades
- Southern Estuaries & Florida Bay
- Northern Estuaries (east & west)
- Big Cypress
- Kissimmee River Basin
- Lake Okeechobee
- Florida Keys

Temporal Scales (See Figure 1b)

- Indicators that respond rapidly to environmental changes
- Indicators that respond more slowly to environmental changes

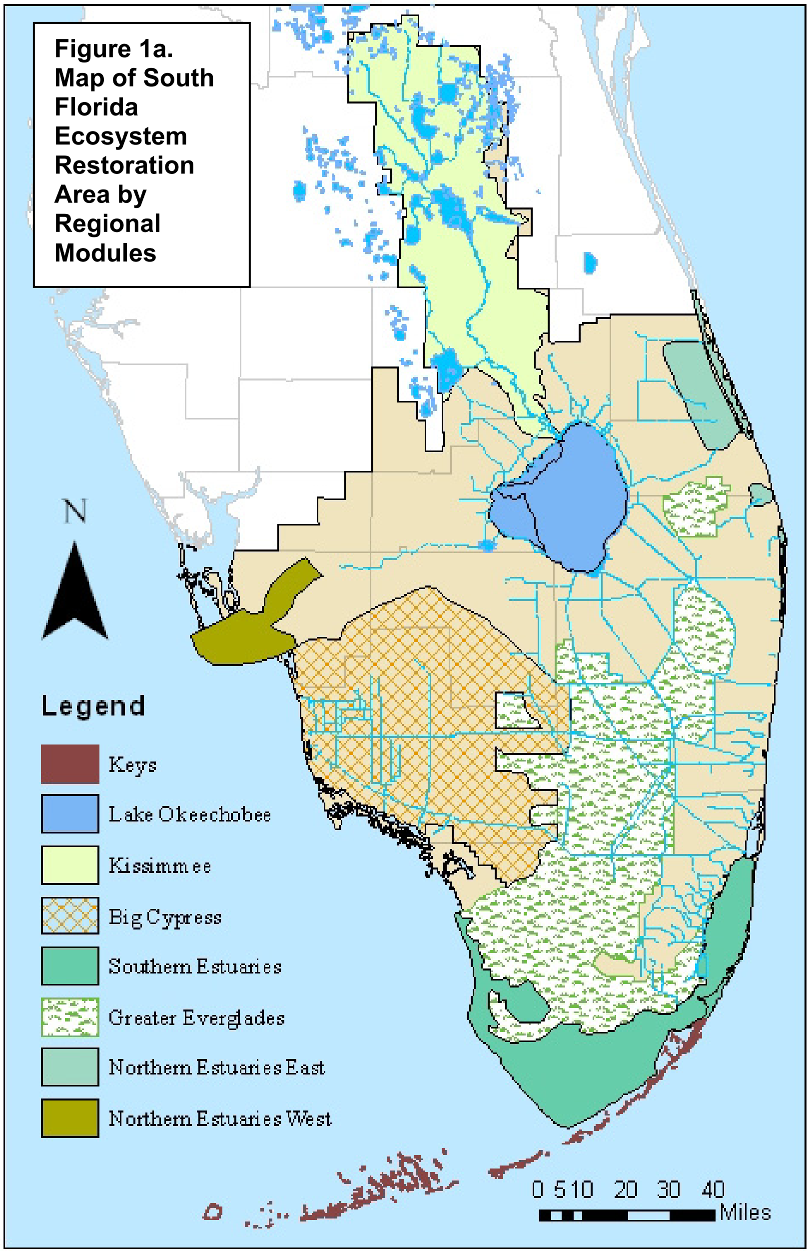


Figure 1a. Map of South Florida Ecosystem Restoration Area by Regional Modules

To determine if the existing indicators evaluated during Step 2 provided relatively comprehensive coverage of present day South Florida geography and ecosystem properties and functions (See Tables 3 & 4), the SCG matched applicability of the candidate indicators to the eight regional modules (see Figures 1a and 1b). The regional modules were developed by scientists involved with RECOVER and the CERP Monitoring and Assessment Program (MAP), see: http://www.evergladesplan.org/pm/recover/recover_map.cfm), the Science Coordination Group and other monitoring and restoration efforts underway in South Florida.

These modules organized the ecosystem into broad eco-regional elements in order to aid in the development of Conceptual Ecological Models (CEMs), as serve as assessment areas for the key eco-regions of the ecosystem.

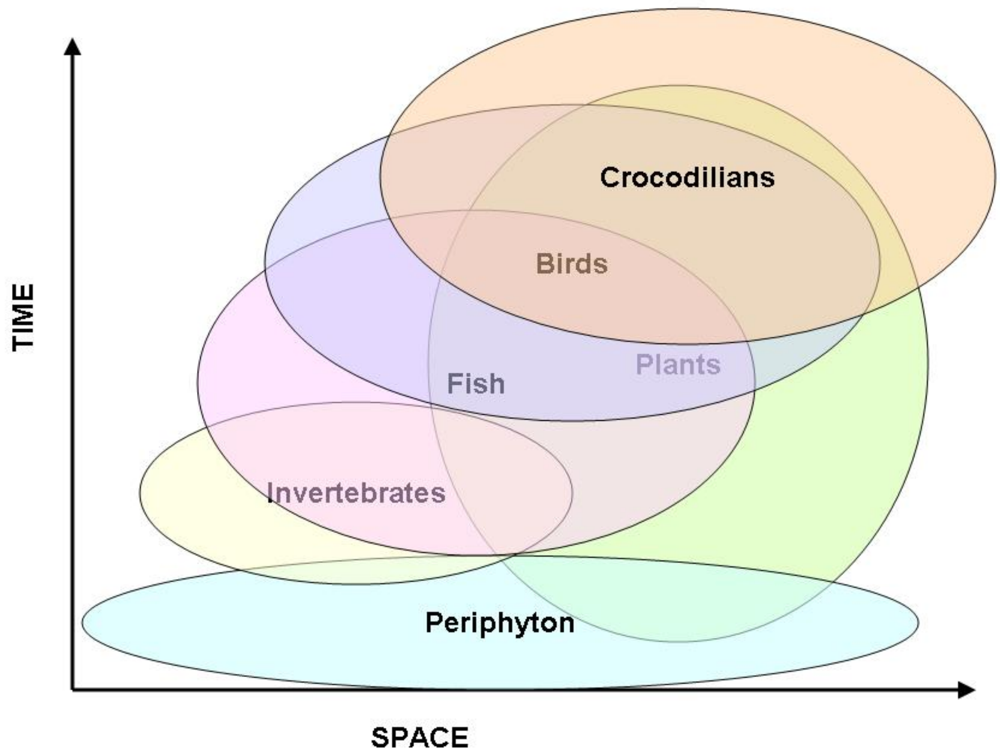


Figure 1b. Figure 1b is a graphical representation of how the individual indicators (only 6 indicators are used in the example) interrelate with the temporal and spatial aspects of the ecosystem and the drivers that affect these indicators. The indicators collectively integrate ecological information on all the temporal and spatial scales at which drivers operate within the ecosystem. Periphyton for example responds to environmental drivers very rapidly and covers both small and large spatial scales of the ecosystem, whereas crocodilians respond more slowly to environmental drivers and generally affect and are affected at larger spatial scales. This figure is not meant to capture the literal aspects of spatial and temporal interactions with any precision, but is meant only to illustrate how the indicators collectively help to integrate different spatial and temporal components of the ecosystem and why we considered this factor in our selection process.

Conceptual Ecological Models exist for five eco-regional modules, including; Lake Okeechobee, Greater Everglades, Northern Estuaries – east and west, and Southern Estuaries). The CEMs describe and illustrate the drivers, processes and attributes and the links among them that explains how each of these ecological sub-regions functions within the larger landscape (see Wetlands; the Journal of the Society of Wetland Scientists, special issue, Volume 25, No. 4, December 2005). Additional sub-models are available for individual ecological elements within the regional CEMs (e.g. Florida Panther, Wood Stork, and Complex Landscapes-

Vegetation). CEMs for the remaining modules and for invasive exotic animals are planned. A CEM for invasive exotic plants is currently under development.

TABLE 4. SYSTEM-WIDE ECOLOGICAL INDICATORS

LANDSCAPE CHARACTERISTICS	Fish & Macroinvertebrates	Wood Stork & White Ibis	Roseate Spoonbills	Florida Bay SAV	Florida Bay Algal Blooms	American Alligators & Crocodiles	American Oysters	Periphyton & Epiphyton	Pink Shrimp	Lake Okeechobee Littoral Zone	Invasive Exotic Plants
HYDROPATTERN	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Yellow
VEGETATION INTEGRITY	Yellow	Yellow	Yellow	Green	Yellow	Orange	Orange	Green	Green	Green	Green
PRODUCTIVITY	Green	Green	Green	Green	Green	Yellow	Green	Green	Green	Green	Yellow
NATIVE BIODIVERSITY	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Green	Green	Yellow
TOTAL BIODIVERSITY	Green	Yellow	Yellow	Green	Yellow	Yellow	Green	Green	Yellow	Green	Yellow
OLIGOTROPHY	Green	Yellow	Yellow	Green	Green	Orange	Yellow	Green	Yellow	Green	Yellow
PRISTINE-NESS	Yellow	Yellow	Yellow	Green	Green	Yellow	Yellow	Green	Yellow	Green	Yellow
INTACTNESS / CONNECTIVITY	Green	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Green	Yellow	Green	Yellow
TROPIHIC BALANCE	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow	Orange	Orange	Black
HABITAT BALANCE	Green	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow	Orange	Orange	Black
TROPHIC LEVELS											
AUTOTROPHS	Green	Orange	Orange	Green	Green	Yellow	Green	Green	Green	Green	Yellow
DETRITUS	Green	Orange	Orange	Green	Green	Yellow	Green	Green	Green	Green	Yellow
HERBIVORES	Green	Green	Green	Yellow	Yellow	Yellow	Green	Green	Green	Yellow	Yellow
PRIMARY CARNIVORES	Green	Green	Green	Yellow	Orange	Green	Yellow	Yellow	Yellow	Yellow	Yellow

SECONDARY CARNIVORES											
TERTIARY CARNIVORES											
DRIVERS / STRESSORS											
WATER - DEPTH											
WATER - DURATION											
WATER - TIMING											
WATER MANAGEMENT											
WATER QUALITY											
EXOTICS											
SALINITY											
PHOSPHORUS											
NITROGEN											
SULFUR											
CONTAMINANTS											
GEOGRAPHIC REGIONS											
GREATER EVERGLADES											
SOUTHERN ESTUARIES											
NORTHERN ESTUARIES											
BIG CYPRESS											
KISSIMMEE RIVER											
LAKE OKEECHOBEE											
FLORIDA KEYS											

Table 4. Table 4 represents the relative coverage of the indicators among the different Ecosystem Characteristics, Properties, Spatial Coverage and Drivers/Stressors. **Green** indicates either a) research has been done establishing a direct statistical correlation or b) the area or regions are directly monitored for this indicator. **Yellow** indicates either a) a link identified by the Conceptual Ecological Model exists but may not be a research established statistical correlation, or b) the region is only partially covered or represented by the indicator. **Orange** indicates either a) an assumed ecological link suggesting the indicator integrates information about this feature of the ecosystem but that no research-based links have been demonstrated or b) the region is not well monitored for this indicator but the indicator could apply to this region with expanded monitoring. **Black** indicates either a) that this feature is not being studied or monitored and the indicator is presumed not to include this ecological feature in the information it provides about the ecosystem or b) that this region is not included for this indicator in any monitoring.

Step 3. *Identify Indicator Gaps*

Our indicator evaluation process included careful screening of each indicator for its application to the many "everglades' features" we identified, and cross-comparisons of the "features" of each indicator to ensure we did not overlook a key feature (see Tables 3 and 4) or where our indicators did not cover a key feature, our process allowed us to determine that in order to identify and where possible be able to fill that particular gap. In addition, we used the huge assortment of indicators from the many disparate projects we evaluated, to help us determine key themes to ensure that our suite of indicators was complete from that larger perspective. While we were comfortable that the suite would at least to some degree, unavoidably include errors of commission simply due to the nature of the process and the indicators themselves; we wanted to be sure that we avoided errors of omission whenever possible.

Key Gaps That Were Identified

1. No indicators exist for the impacts of the development and operation of restoration projects on anthropogenic contaminants such as pesticides and medical wastes (there are some preliminary research studies by the USGS on pesticides)
2. There are no indicator(s) related to the spread of exotic species (plants or animals)
3. There are no vegetation pattern/mosaic/integrity/patchiness indicators that covers a sufficiently large geographic region and includes uplands (there are vegetation indicators for specific regions and habitats that may serve as starting points)
4. Only one indicator of restoration compatibility (Water Volume) covers large portions of the Everglades system and several modules. The other two currently included indicators of restoration compatibility (Salinity Intrusion and South Dade Flood Protection) cover only the southeastern Florida area (i.e. Palm Beach, Broward and southwestern Miami-Dade Counties)

To help fill these gaps the SCG sought technical assistance and direction from numerous ecologists, biologists, chemists, hydrologists, and natural resource managers to help fill the indicator gaps.

After evaluation of the gaps, the SCG determined that an exotic plant indicator and three existing RECOVER restoration compatibility indicators would be able to be incorporated in the 2006 Task Force biennial report. The Vegetation Pattern/Integrity, Contaminants, Exotic Animals, and additional restoration compatibility indicators were not feasible for development and inclusion until at least the 2008 biennial report. In the case of the vegetation pattern and contaminants indicators significant additional work is required to produce Conceptual Ecological Sub-Models for these indicators, and develop and peer review them. In the case of additional compatibility indicators, the SCG was not able to reach a consensus on their applicability and thinks further evaluation is required.

Step 4. ***Select Final 2006 Indicators***

The final recommended suite of 13 indicators for the 2006 biennial reporting period that collectively will help the Task Force to assess restoration goals and targets are in Table 5. Twelve of the 13 indicators are existing RECOVER indicators and are included in the RECOVER Interim Goals and Interim Targets Report and RECOVER MAP I and II. The exotic indicator is not currently included as a RECOVER indicator but is identified as important by RECOVER (2005). Detailed write-ups of the individual indicators are provided in Parts II and III of this document.

Table 5. List of Task Force System-wide Indicators for 2006	
1.	Fish & Macroinvertebrates
2.	Wading Birds (Woodstork, White Ibis & Roseate Spoonbill)
3.	Florida Bay Submerged Aquatic Vegetation
4.	Florida Bay Algal Blooms
5.	Crocodilians (Alligators & Crocodiles)
6.	American Oysters
7.	Periphyton-Epiphyton
8.	Juvenile Pink Shrimp
9.	Lake Okeechobee Littoral Zone
10.	Invasive Exotic Plants
11.	Water Volume
12.	Salinity Intrusion in the Biscayne Aquifer
13.	Flood Protection – C-111 Basin

Limitations and Gaps

We clearly recognize the limitations of this proposed suite of indicators (see Table 4). Only four modules (see Figure 1) have had CEMs developed for them. Some of the indicators are regional in nature and do not reflect broader ecological or physiographic provinces, even though they may represent important bioregions (e.g. Roseate Spoonbill for Southern Estuaries, Oysters for Northern Estuaries). Some of the modules (i.e. geographic regions of the ecosystem, see Figure 1a) are not included in the monitoring area for some of the selected indicators, and there are some identified "indicator gaps" that will not be filled until at least the 2008 Task Force Report and perhaps the 2010 report. However, since the strategy and planning process for restoration incorporate adaptive management and adaptive assessment, we feel comfortable that the indicators will remain quite valuable for the purposes stated, and through additional research and assessment, they can be further refined and improved without compromising any interim findings and applications of the indicators.

For modules that are not covered, or are only partially covered, by the monitoring programs associated with this suite of indicators, the limitations and gaps in the regional coverage will be discussed and represented in any assessments. A lack of information for an indicator—due for example from the lack of geographic coverage—is considered to be a serious deficit in our ability to assess and evaluate restoration success and will be noted in all biennial assessments.

In spite of these limitations however, these indicators offer an opportunity to regularly inform key policy makers and managers on the performance of the restoration program and provide insight into the individual and collective results of restoration activities on important components of the Greater Everglades' ecosystem.

One Example Under Consideration of How The SCG Plans To Communicate The Findings From These Indicators To The Task Force

How much, what kind and what quality information does a manager or policy maker need before he or she can make a decision? Much of the answer may relate to the background of the individual manager or policy maker, but much also depends on the quality of the information and the manner of its communication (Durnil 1999). The quality of the information and the method of communication are especially critical where scientific information is involved because the majority of people making management or policy decisions using this information are usually not scientists themselves (Durnil 1999).

Effective communication of indicator results to the Task Force and Congress is as important as the performance of the indicators themselves. When assessing the performance of an indicator, scientists collect data related to the metrics that statistically link environmental parameters to indicator performance. These data are usually detailed and complex requiring various levels of analysis and interpretation even for use by other scientists. The role of RECOVER and the SCG is to work with the scientists involved in monitoring these indicators and interpret their results into a more common framework and language. Because indicators provide discrete pieces of information about one (or perhaps a few) constituents of the ecosystem that is intended to "reflect" the status of the larger system (Schiller *et al.* 2001), we will need to interpret that "reflection" in a way that is integrative but simple and unambiguous yet does not compromise the integrity of the individual findings.

Schiller *et al.* (2001) conducted a study that developed and tested processes for translating indicators of regional concern into a common language for communication with the public and decision-making audiences. The study found that people did not want to know what the indicators measured or how the indicators performed. Rather, the audiences wanted "to know what such measurements can tell them about environmental conditions." Furthermore, the researchers found that the indicator results that were most positively received "were descriptions of the kinds of information that various combinations of indicators provide about broad ecosystem conditions." Schiller et al. (2000) also found that study participants preferred to let scientists decide what should be measured as long as these measures could be communicated in a way the participants could understand. Because the SCG concurs with Schiller *et al.* (2001) and others that describing environmental conditions is a key attribute of indicator use and application, determining how to describe and communicate indicator results to the Task Force is integral to their development, application, and acceptance.

At regular intervals, RECOVER and the SCG will jointly assemble data from the many south Florida monitoring and research programs related to all of the indicators (see www.evergladesplan.org), including this suite of indicators for the Task Force. The SCG and RECOVER will coordinate with individual scientists using an expert panel-based approach (Oliver 2002) to asses the results and indicator performance for the Task Force. To be effective we must condense the detail of the data from the many monitoring elements and then summarize and abbreviate these details into an accurate reflection of the status of the ecosystem in as simple and straightforward a manner as possible.

The SCG has not finalized a communication tool(s) yet because we will not be reporting on the performance of the indicators to the Task Force until 2008 and plan to use this additional time to refine ideas and options. We have evaluated other communication tools (see

http://www.complianceconsortium.org/ECCPresentations/PresentationtoEPARegion1.ppt).

Because the exotic plant indicator is a new indicator, we were required to produce a communication tool for it for a RECOVER technical review. We based it on a similar approach that has been successful in communicating the results of complex hydrological modeling and exotic species information to south Florida environmental policy makers. We provide this communication tool as an example of a method and approach we intend to explore for use in communicating results from the entire suite of indicators.

The Independent Scientific Review (Jordan et al. 2006) of this communication tool provided several recommendations and some points for consideration.

1) The reviewers felt the tool was too complicated and ambiguous because of the use of numerical rankings for question responses (Jordan et al. 2006 see pages 16 & 17).
    a. To address this we eliminated the numerical responses to the questions and made them simply color responses based on expert panel evaluations of the possible outcomes related to the questions asked of the data from the five monitoring programs.
    b. We also simplified the questions by eliminating or simplifying the numerous possible response categories.
2) The reviewers felt the stoplight format obscured the basis for decisions leading to the conclusions about CERP progress, and prevented independent evaluations by the reader (Jordan et a. 2006, see page 17).
    a. We tried to address this concern by providing a table that clearly delineated the individual responses to each question for each module and species. We could further address this by providing the actual data from the monitoring programs in a data appendix to the assessment reports. The panel process of taking the individual color responses and combining them into summary stoplight colors will need further clarification and documentation of the decision rules (questions) to improve that element of the process.
    b. We also simplified the questions in order to make sure that the questions we asked of the results from the monitoring programs were insensitive to methodological differences among the monitoring programs.
3) The reviewers recommended a stacked column or line chart for the indicator performance measure (e.g. fish abundance) with a target line as the communication tool (Jordan et al. 2006 see page 18).
    a. We agree that such a chart system may be preferable and possible for most if not all the other indicators. However, there are four issues with developing such a tool at this time.
        i. The possible performance measures for exotic plants (e.g. acres, cover, abundance, etc.) are not direct measures in the monitoring programs so there would be no target against which to measure change.
        ii. There are no well-established targets at this point for most of the indicators.
        iii. A target for invasive exotic plants is probably not feasible, at least until a quantifiable measure can be developed for the current concept of "maintenance control" as used in invasive exotic plant management.
        iv. We are developing a performance measure for vegetation integrity related to exotic plants and do not consider the stoplight tool to be a concise quantifiable performance measure but instead a form of an "Invasive Species Report Card" (sensu Harwell et al. 1999).

4) The reviewers felt that a positive (green) response due to the decrease in a species extent from an herbicide program or a biological control program did not address the issue of long-term herbicide exposure and possible harm to the environment, or possible harm from biological control agents on non-target species.
    a. This is an issue that has been discussed in numerous venues. No satisfactory solution to the concern regarding herbicides (and the development of resistance in the target weeds) has been found. The alternative, no use, or only limited use of chemical control leaves invasive exotics free to spread.
    b. We disagree with the reviewers regarding biological control agents when biocontrol agents are developed using "classical" biocontrol techniques where they are carefully screened to be host specific. This is the method used by the biocontrol scientist for south Florida restoration (see: Louda et al. 2003, Thomas and Willis 1998).

The SCG will continue to explore the communication examples provided by the reviewers. Particularly toward working with RECOVER to develop quantifiable goals and simple and direct performance measures in addition to the possible use of 'report card' systems in concert with performance measures.

EXOTIC PLANT INDICATOR COMMUNICATION TOOL EXAMPLE

The Science Coordination Group has reviewed and approved this method of communicating the results for the exotic plant indicator. The SCG is developing analogous tools and sets of rating questions (decision rules) for the other individual indicators and for the suite of indicators and use the results of those rankings to fill out similar tables to the one below (see Table 6).

THE METRICS THE QUESTIONS AND THE "INDICATOR"

It is important to remember that this assessment of invasive exotic plants is only a synthesis of what we know or are able to know from existing sources of information. The questions and their application toward assessing restoration in relation to invasive exotic plants are designed with this in mind and are unable to answer any questions outside of these parameters. In addition, the individual questions are collated into a single response in the "Stop-Light" tables. We used an expert panel-based approach to the assessment of the vegetation condition identified in the individual question responses to the data (*sensu* Oliver 2002).

We will collect data from each of the five monitoring/surveying projects identified in the Invasive Exotic Plant Indicator Report (available at www.sfrestore.org). The goal is to utilize the collective set of metrics from these five programs to develop an assessment of the "indicator" condition to determine the status of invasive exotic plants collectively and individually. Modules will be assessed individually and each species will be assessed by module (see Figure 1 and Tables 6 & 7), using the following set of questions and weightings to evaluate and report the status of invasive exotic species. Because the data collected by each program varies spatially, temporally and in precision each data set will have to be evaluated individually using the questions below and then integrated after an individual evaluation using an expert panel-based approach (*sensu* Oliver 2002).

RATINGS AND RANKING

The ratings used in each of the questions do not represent actual data or measurements or any absolute valuation. They are only a relative valuation for helping expert panel members coalesce the individual parameters (the actual information) from the five different monitoring/surveying programs. Because the data from the individual monitoring programs cannot collectively be statistically integrated or correlated it was necessary to develop objective questions that could be asked of the data either collectively or individually by project, but that would not step beyond the ability of the data to give accurate and objective information. It was equally important that the individual responses (red, yellow or green) could be related directly back to the data from the monitoring programs in order that the process was repeatable and objective (see Table 7). The synthesis of the individual questions into the "Stop-Light" tables was done using the expert panel-based approach previously noted (see Oliver 2002).

<u>THE QUESTIONS</u>

MODULE LEVEL QUESTIONS. These questions apply to the species that have been identified as high priorities for control based on the information in the South Florida Environmental Report (SFWMD 2006) by module. Results from these three questions are reflected in the module level results in Tables 6 & 7 and are examples from the Greater Everglades Module. These questions are intended to reflect the general state or condition of the ecological region represented by the module.

1. How many species identified as high priority for control have been found in this module?
   1.1. none = green
   1.2. can't determine = yellow
   1.3. less than 10 = yellow
   1.4. 10 or more = red

2. How many previously undetected species (new species never found in this module before) have been found within this module?
   2.1. None = green
   2.2. Can't determine = yellow
   2.3. 5 or less = yellow
   2.4. more than 5 = red

3. Do the four monitoring programs reasonably cover the entire spatial area or region within the module?
   3.1. Yes = green
   3.2. Can't determine = yellow
   3.3. No = red

SPECIES LEVEL QUESTIONS. These questions apply to each species known to be present within the module. Only collectively do the five monitoring programs collect information on all the species identified as high priority for control, so these results are based on the cumulative information from the five individual data sets and the expert panel results from the annual South Florida Environmental Report. Results from these questions reflect species level results (see Tables 6 & 7).

1. In how many acres within the module does this species occur?
   - 1.1. Undetected = green
   - 1.2. Can't determine = yellow
   - 1.3. less than 1000 acres = yellow
   - 1.4. more than 1000 acres = red

2. Within the module is the extent of the species documented to be increasing, decreasing or static?
   - 2.1. Increasing = red
   - 2.2. Static = yellow
   - 2.3. Can't determine = yellow
   - 2.4. Decreasing = green

3. If the species is decreasing in extent, is it a direct result of an active biocontrol or chemical / mechanical control program?
   - 3.1. Yes = green
   - 3.2. Can't determine = yellow
   - 3.3. No (program is in place but too early to tell) = yellow
   - 3.4. No (no program in place) = red

RESPONSES TO THE QUESTIONS

The **Greater Everglades' Module** is being used as the example for the individual question responses (see below), however, individual responses for all modules and species are presented in Table 7. High priority species included in the Greater Everglades' Module are: *Ardisia elliptica* (shoe button Ardisia), *Casuarina* spp. (Australian pine), *Lygodium microphyllum* (Old World climbing fern), *Melaleuca quinquenervia* (melaleuca), *Schinus terebinthifolius* (Brazilian pepper), *Colubrina asiatica* (lather leaf).

GE Module Level Question 1.	Six	=	red
GE Module Level Question 2.	None	=	green
GE Module Level Question 3.	Yes	=	red

GE Species Level Question 1.

Ardisia elliptica	> 1000	=	red

Causarina spp.	< 1000	=	yellow
Lygodium microphyllum	> 1000	=	red
Melaleuca quinquenervia	> 1000	=	red
Schinus terebinthefolius	> 1000	=	red

Species Level Question 2.

Ardisia elliptica	increasing	=	red
Casuarina spp.	decreasing	=	green
Lygodium microphyllum	increasing	=	red
Melaleuca quinquenervia	decreasing	=	green
Schinus terebinthifolius	increasing	=	red

Species Level Question 3.

Ardisia elliptica	No Program	=	red
Casuarina spp.	Yes	=	green
Lygodium microphyllum	No – too early	=	yellow
Melaleuca quinquenervia	Yes	=	green
Schinus terebinthifolius	Can't Det.	=	yellow

Red = Severe Negative Condition, or one is expected in near future, with out-of-control situation that merits serious attention

Yellow/Red = Problem was previously localized or not too severe but is or appears to be progressing toward a Severe Negative Condition generally due to inaction; without attention and resources the situation may develop or become Red

Red/Yellow = Currently a Negative Condition but there are reasonable control efforts under way; however, without continued or improved efforts, this species may revert to a severe situation or become a future serious invader and revert to Yellow/Red or Red

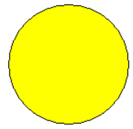
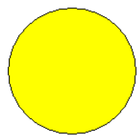
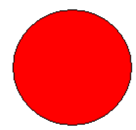
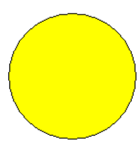
Yellow = Situation is improving due to reasonable control program and either is stable or moving toward stabilizing, or the species is still very localized but is expected to spread if sufficient resources or actions are not continued or provided; the situation could still reverse

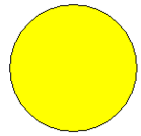
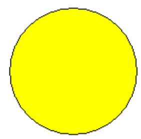
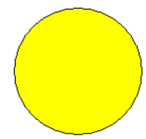
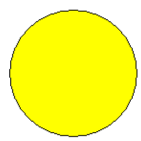
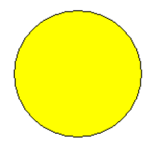
Green/Yellow = Situation is generally good and under control but still needs regular, even if low-level, attention to continue progress to Yellow/Green or Green

Yellow/Green = Significant progress is being made and situation is moving toward good maintenance control and is expected to continue improving as long as resources are maintained

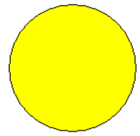
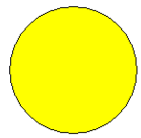
Green = Situation is under control has remained under control for several years, particularly where biocontrol is found to be effective; where chemical maintenance control is in place, continuation of control efforts is essential to maintain Green status

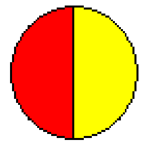
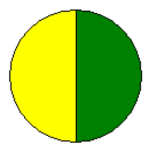
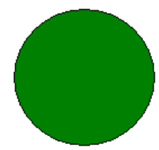
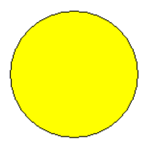
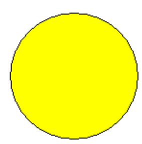
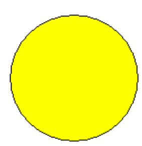
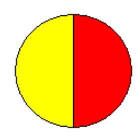
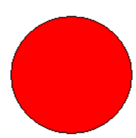
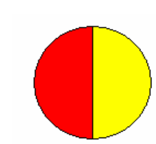
Tables 6 a - h. Legend for the Individual Module Stop-Light Reports:

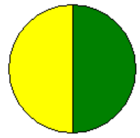
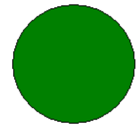
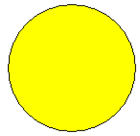
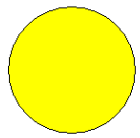
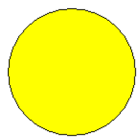
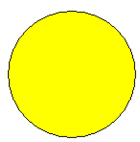
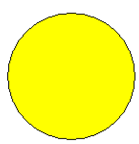
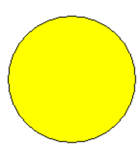
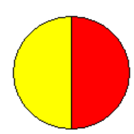
	CURRENT STATUS		1-2 YEAR PROGNOSIS	
SOUTHERN ESTUARIES & FLORIDA BAY MODULE (results in this row reflect only the 3 module level questions not species level questions)	Australian pine and Brazilian pepper control programs have been underway for many years and significant control has been achieved. However many species have invaded in recent years and their possible effects are unclear. Most of Florida Bay is not included in any monitoring program for invasive plants.		Some species, such as Latherleaf have been serious invaders of rare habitats along the southern coast of Everglades National Park. Other new species are simply off the radar as far as their inclusion in a systematic control or monitoring program and are serious unknowns.	
Australian Pine (Casuarina spp.)	Effective control program is in place in the southern and western coastal areas of the Park. Surrounding seed sources make continuous long-term management necessary in these areas. Impacts endangered species.		Chemical control effective and most coastal habitats are clear, but ongoing control still needed in coastal areas due to (floating) seed pressure from other areas. Biocontrol research underway.	
Latherleaf (Colubrina asiatica)	The spread of latherleaf has been documented for over a decade. Overall distribution and impacts in coastal habitats are increasing. It is difficult to detect remotely and especially problematic to rare coastal habitats. Not part of a systematic monitoring program.		This species has been spreading north along the Park's west coast, east along Florida Bay and south into the Florida Keys. This species poses a serious threat to the natural areas of north Key Largo. Herbicidal control logistically challenging. Seed viability poorly understood. No biological control programs underway.	
Sapodilla (Manilkara zapota)	It is scattered throughout coastal hardwood habitats. It is difficult to detect remotely and is not included in an Indicator systematic monitoring program.		Because it is intermixed in native tropical hardwood communities, its detection and control are difficult and logistically challenging. Likely spread by animals. No biological control program underway.	

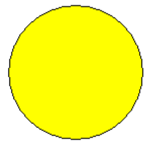
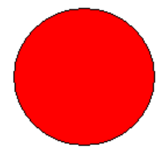
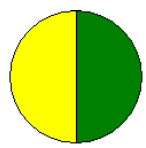
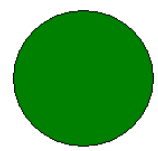
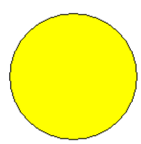
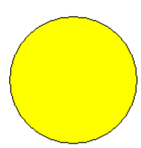
Half Flower (Scaevola taccada)	This species is limited to coastal habitats. It is easy to detect but is not part of an Indicator systematic monitoring program.		Effectively controlled along beaches in most locations in the Module, but surrounding seed sources from ornamental plantings make long-term control problematic. No biological control program underway. Prospects poor, given native Scaevola species.	
Brazilian Pepper (Schinus terebinthifolius)	Invades most habitats, including coastal communities, very destructive. Chemical control ineffective in reducing Moduleecosystem-wide spread so far, however, localized control programs are proving effective in the Module.		Control programs in southern areas of the Park have been effective in reducing local populations. Most Brazilian pepper populations limited so far in this region but coastal mangroves still threatened. New biocontrol agents under study for future release 2007-2008.	
Seaside Mahoe (Thespesia populnea)	Invades coastal habitats, forms dense monocultures. Not part of a systematic monitoring program.		Control of this species is ongoing in Elliot Key, and scattered locales in Florida Bay. Surrounding seed sources from wild populations and ornamental plantings. Floating seeds are spread into natural areas with high tide, and make longterm control difficult.	

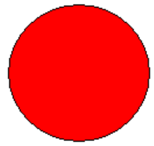
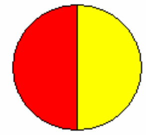
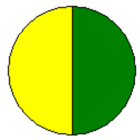
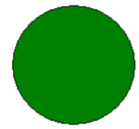
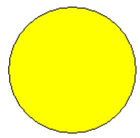
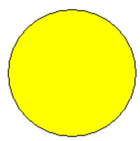
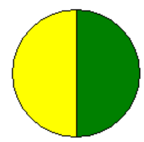
	CURRENT STATUS		1-2 YEAR PROGNOSIS	
FLORIDA KEYS MODULE **(results in this row reflect only the 3 module level questions not species level questions)**	Restoration efforts have been underway in this Module for some time and much progress has been made on Casuarina and Brazilian Pepper. However, systematic monitoring of the Keys has been insufficient to determine the distributions of all the species present or their locations in natural areas.		This module has had a significant control program effort underway for several years. Progress on many species is evident, but continued monitoring and control efforts will be needed to prevent serious reinvasions of the many species still threatening this region and new species that may arrive.	
Australian Pine (Casuarina spp.)	Effective removal program is in place and Casuarina is not a serious problem in the natural areas of the keys anymore.		Chemical control effective, most natural areas clear or clearable with modest effort. Biocontrol research underway.	
Latherleaf (Colubrina asiatica)	Know little about its spread or distribution throughout the region. It is not included in Indicator systematic monitoring program.		Increases in spread and distribution are occurring but not well documented. May become a serious pest moving into areas where other exotics have been controlled. A potentially serious pest of the Crocodile Refuge in north Key Largo.	
Sickle Bush (Dichrostachys cinerea)	A relatively new species. Know little about its spread or distribution throughout the region. It is not included in Indicator systematic monitoring program.		Increases in spread and distribution may be occurring but unable to confirm. May become a serious pest moving into areas where other exotics have been controlled. A known and serious pest in Cuba.	
Laurel Fig (Ficus microcarpa)	Limited distribution throughout the region. It is not included in Indicator systematic monitoring program.		Problematic because it grows epiphytically on native tree species, making control difficult. Biological control probably not an option given native Ficus species.	
Sapodilla (Manilkara zapota)	Know little about its spread or distribution throughout the region. It is not included in Indicator systematic monitoring program.		Localized problem. May become a serious pest moving into areas where other exotics have been controlled. Invades natural forests and difficult to control.	

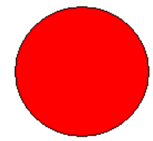
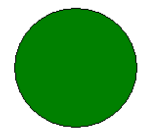
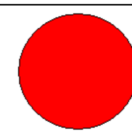
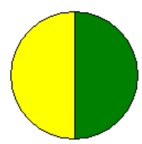
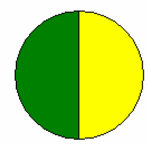
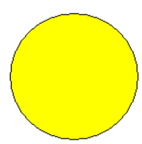
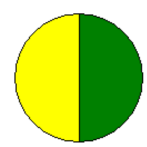
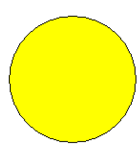
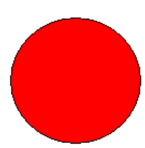
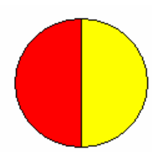
Half Flower (Scaevola taccada)	Coastal species, distributed throughout this Module. It is not included in aIndicator systematic monitoring program, although it is fairly easy to detect.		Seeds float making long term management of this coastal species problematic. Biological control probably not an option given closely-related native Scaevola species.	
Brazilian Pepper (Schinus terebinthifolius)	Invades most habitats, very destructive. Chemical control ineffective in reducing system-wide spread so far, however, local control programs are proving effective in the Keys.		Control programs effective in the Keys, most populations limited. New biocontrol agents under study for future release 2007-2008.	

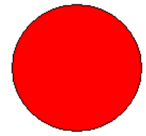
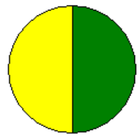
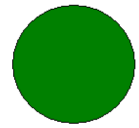
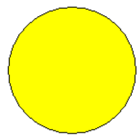
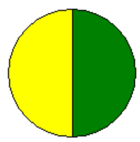
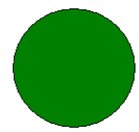
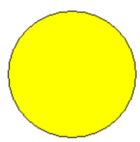
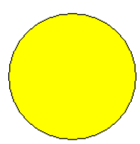
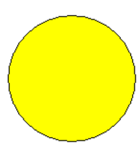
	CURRENT STATUS		1-2 YEAR PROGNOSIS	
NORTHERN ESTUARIES MODULE – WEST COAST (results here reflect only the 3 module level questions not species level questions)	While much progress has been made with Melaleuca, Brazilian pepper and Australian Pine, other species seem to be gaining a foothold and most of these species are not included in any of the Indicator monitoring programs. We know very little about the large majority of invaders and are not able to assess their status in an objective or repetitive way to determine trends.		Good control of Melaleuca, Schinus and Casuarina. Biocontrol for Melaleuca showing effectiveness. First biocontrol releases for Lygodium; new biocontrol for Schinus under study. Other species still localized, but numerous, and potentially serious invaders exist for which little is know about their biology or spread.	
Australian Pine (Casuarina spp.)	Populations exist along roadsides, canals and a few natural sites, but removal programs are in place and are considered effective.		Chemical control effective, most natural areas clear or clearable with modest effort. Biocontrol research underway.	
Air Potato (Dioscorea bulbifera)	Know little about its spread or distribution. Not included in Indicator systematic monitoring program.		Control efforts are not coordinated, no biocontrol effort underway.	
West Indian Marsh Grass (Hymenachne amplexicaulis)	Distributed in wet areas. Not included in Indicator systematic monitoring program.		Species problematic because it is difficult to control with herbicides in wetlands. No biocontrol effort underway.	
Cogon Grass (Imperata cylindrica)	Know little about its spread or distribution beyond roadside-type infestations. Not included in Indicator systematic monitoring program.		Species problematic because it is difficult to control with herbicides. No biocontrol effort underway.	
Old World Climbing Fern (Lygodium microphyllum)	Serious invader, rapid spread throughout Module, invades most habitats, very destructive.		No significant and population wide effective controls yet but biocontrol release made with additional release expected 2006. Chemical control studies continuing.	

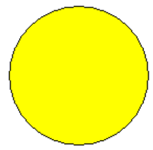
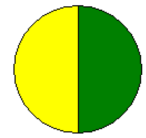
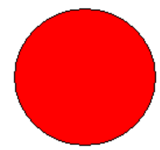
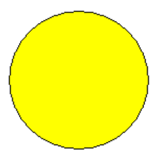
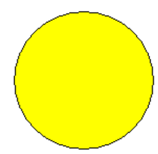
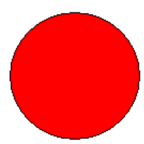
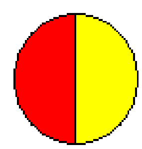
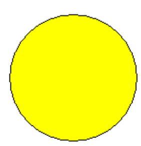
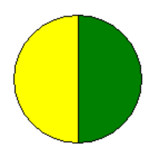
Melaleuca (Melaleuca quinquenervia)	Still abundant on private lands but biocontrol reducing cover and spread and agents establishing throughout Module.		Chemical control effective on most public lands, biocontrol agents effective and additional spread of existing agents and new agents expected 2006.	
Burma Reed (Neyraudia reynaudiana)	Know little about its spread or distribution in the Module. Not included in Indicator systematic monitoring program.		Species problematic because it is difficult to control with herbicides. No biocontrol effort underway.	
Guinea Grass (Panicum maximum)	Know little about its spread or distribution in the Module. Not included in Indicator systematic monitoring program.		Species problematic because it is difficult to control with herbicides. No biocontrol effort underway.	
Itch Grass (Rottboellia cochinchinensis)	Spreading in wetland areas. Not included in Indicator systematic monitoring program.		Species problematic because it is difficult to control with herbicides in wetlands. In tropical America this species is a serious invader of agricultural and abandoned or disturbed lands often leading to abandonment of the land for agricultural use.	
Half-flower (Scaevola taccada)	Coastal species, easy to detect, but not included in Indicator systematic monitoring program.		Control efforts effective where implemented. Seed source from surrounding ornamental plantings makes long term control necessary. No biocontrol effort underway. Prospects limited due to native Scaevola species.	
Brazilian Pepper (Schinus terebinthifolius)	Serious invader, with rapid spread throughout Module, invades most habitats and is very destructive. Local control programs are proving effective where resources are available.		Control programs in the Module are effective in natural areas where management programs are underway. New biocontrol agents under study for future release 2007-2008.	
Para grass (Urochloa mutica)	Distributed in wetland areas. Not included in Indicator systematic monitoring program.		No coordinated control efforts in place for the Module, No biocontrol effort underway although local populations can be eliminated.	

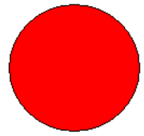
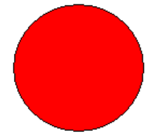
	CURRENT STATUS		1-2 YEAR PROGNOSIS	
NORTHERN ESTUARIES MODULE – EAST COAST **(results here reflect only the 3 module level questions not species level questions)**	While much progress has been made with Melaleuca, Brazilian pepper, and Australian Pine, other species seem to be increasing and most are not included in Indicator monitoring programs. Little is known about the large majority of invaders. Unable to assess status in an objective or repetitive way to determine trends.		Good control of Melaleuca, Schinus, and Casuarina. Biocontrol for Melaleuca showing effectiveness. First biocontrol releases for Lygodium; new biocontrol for Schinus under study. Other species still localized, but numerous, and potentially serious invaders exist for which little is know about their biology or spread.	
Shoebutton Ardisia (Ardisia elliptica)	May be entering exponential spread phase in this Module. Moving into floodplain communities and dominating understory. Not included in Indicator systematic monitoring program. Difficult to monitor remotely.		No coordinated, significant control efforts or biocontrol efforts underway.	
Australian Pine (Casuarina spp.)	Remnant populations exist along canals and a few natural sites, but removal program is in place and effective.		Chemical control effective, most natural areas clear or clearable with modest effort. Biocontrol research underway.	
Caulerpa (Caulerpa brachypus)	Know little about its spread or distribution. Not included in Indicator systematic monitoring program.		Caulerpa is a marine alga that is an extreme problem in other parts of the world. It is now spreading rapidly across Florida's coral reefs. It has the potential to eliminate most other species on Florida's "hard bottom" coastal areas. No significant control efforts or effectiveness, no biocontrol effort underway.	
Air Potato (Dioscorea bulbifera)	Know little about its spread or distribution. Known populations appear to be increasing despite some control efforts. Not included in Indicator systematic monitoring program.		Control programs in the Module have limited success in natural areas, no biocontrol effort underway.	

Old World Climbing Fern (Lygodium microphyllum)	Serious invader, rapid spread throughout Module, invades most habitats, very destructive.		No effective, Module-wide control programs yet but biocontrol release made and additional release expected 2006. Chemical control studies continuing.	
Melaleuca (Melaleuca quinquenervia)	Still abundant on private lands but biocontrol reducing cover and spread and agents establishing throughout Module.		Chemical control effective on most public lands, biocontrol agents effective and additional spread of existing agents and new agents expected 2006.	
Torpedograss (Panicum repens)	Know little about its spread or distribution, but appears to be increasing in several managed natural areas. Not included in Indicator systematic monitoring programs.		No coordinated control efforts in place. No biocontrol efforts underway.	
Brazilian Pepper (Schinus terebinthifolius)	Serious invader, with rapid spread throughout Module, invades most habitats. Chemical control ineffective in reducing system-wide spread so far, however, local control programs in Module are proving effective where resources are available.		Control programs in the Module are effective. New biocontrol agents under study for future release 2007-2008.	

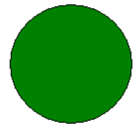
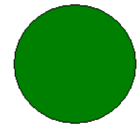
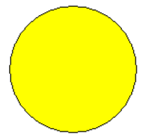
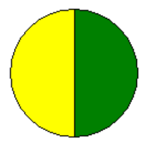
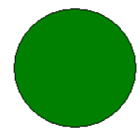
	CURRENT STATUS		1-2 YEAR PROGNOSIS	
KISSIMEE MODULE **(results in this row reflect only the 3 module level questions not species level questions)**	Restoration efforts have been underway in this Module for some time and much progress has been made However, many very serious exotics occur in this region for which little in know about how invasive they may become.		Many of the species occur only in this region of the and little is known about their biology, yet some of them are very serious weeds in other parts of the world. Re-hydrated habitat is providing new habitat for some aquatic species including hydrilla	
Water Hyacinth (Eichhornia crassipes)	Significant control efforts and biocontrol programs have been underway for many years. Control programs are achieving good results.		Systematic control and monitoring programs are in place and have been achieving good results.	
Limpograss (Hemarthria altissima)	Know little about its spread or distribution. Observations indicate this species is increasing in scope. Is included in DEP aquatic plant surveys.		No significant control efforts or effectiveness, no biocontrol effort underway.	
Hydrilla (Hydrilla verticillata)	Limited control efforts and biocontrol programs have been underway for many years. Control programs are mixed results.		Systematic control and monitoring programs are in place and have been achieving good results but recent herbicide resistance is creating new control problems along with increased habitat on the re-hydrated floodplain.	
West Indian Marsh Grass (Hymenachne amplexicaulis)	Know little about its spread or distribution throughout the system. It is included in DEP aquatic plant surveys.		Efforts at control in this Module have been good and most populations in natural areas appear to be under reasonable control.	
Cogon Grass (Imperata cylindrica)	Know little about its spread or distribution. Not included in Indicator systematic monitoring program.		Has been controlled to varying degrees on public lands in the module. No biocontrol effort underway.	
Old World Climbing Fern (Lygodium microphyllum)	Serious invader, rapid spread throughout Module, invades most habitats, very destructive.		Chemical control has brought populations to maintenance control on public land. Biocontrol release made with additional release expected 2006. Chemical control studies continuing.	

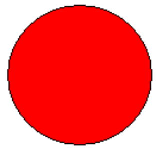
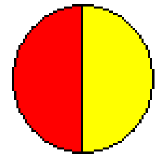
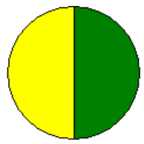
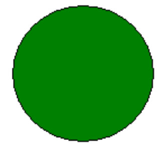
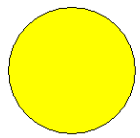
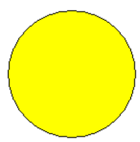
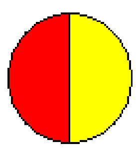
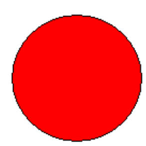
Japanese Climbing Fern (Lygodium japonicum)	Little is known about its potential impacts in Module.		Populations being controlled so far however, distribution and spread unknown and no biological control program underway.	
Melaleuca (Melaleuca quinquenervia)	Still abundant on private lands but biocontrol reducing cover and spread and agents establishing throughout Module.		Chemical control effective on most public lands, biocontrol agents effective and additional spread of existing agents and new agents expected 2006.	
Torpedograss (Panicum repens)	Know little about its spread or distribution. Included in DEP aquatic plant surveys.		No significant control efforts or effectiveness, no biocontrol effort underway although local populations can be eliminated.	
Water Lettuce (Pistia stratiotes)	Significant control efforts and biocontrol programs have been underway for many years. Control programs are achieving good results. Included in DEP aquatic plant surveys.		Systematic control and monitoring programs are in place and have been achieving good results.	
Chinese Tallow (*Sapium sebiferum)*	Distributed along many lake edges in the Kissimmee Chain of Lakes. Not included in Indicator systematic monitoring program.		Problematic wetland tree species. That forms dense monocultures. No significant control efforts or effectiveness, no biocontrol effort underway although local populations can be eliminated	
Brazilian Pepper (Schinus terebinthifolius)	Serious invader, with rapid spread throughout SFL, invades most habitats, very destructive. Chemical control ineffective in reducing system-wide spread so far, however, local control programs are proving effective where resources are available.		Control programs effective in natural areas where management programs are underway. New biocontrol agents under study for future release 2007-2008.	
Tropical Soda Apple (Solanum viarum)	Know little about its spread or distribution. Not included in Indicator systematic monitoring program.		Control efforts limited, although local populations can be eliminated. Biological control underway.	

	CURRENT STATUS		1-2 YEAR PROGNOSIS	
GREATER EVERGLADES MODULE **(results here reflect only the 3 module level questions not species level questions)**	Lygodium and Schinus still widespread and serious threats to Module. Continued rapid spread of these two species with little results from control efforts. Still several other species present with little or no control effort or effectiveness.		Good control of Melaleuca and Casuarina. Biocontrol for Melaleuca effective. First biocontrol releases for Lygodium; new biocontrol for Schinus under study. Other species still localized, no new serious invaders detected.	
Shoebutton Ardisia (Ardisia elliptica)	Was a localized problem in the Park but now is infests tree islands and bayheads throughout the WCAs. Difficult to detect and not part of a systematic monitoring program.		No significant control program, no biocontrol effort underway. Now found in WCA tree islands and bayheads, poses a serious threat. May be entering exponential spread phase. Difficult to monitor remotely and resembles several native species making detection and control difficult.	
Australian Pine (Casuarina spp.)	Still common in northeast portions of the Park and on District canal banks.		Chemical control effective, most natural areas clear with the exception of northeast part of the Park where significant control is still needed. Biocontrol research underway.	
Old World Climbing Fern (Lygodium microphyllum)	Serious invader, rapidly spreading throughout Module, invades most habitats, very destructive. Long-term management difficult given the variety of habitats it infests.		No effective control yet but biocontrol release made with additional release expected 2006. Chemical control studies continuing.	
Melaleuca (Melaleuca quinquenervia)	Large portions of the Module are under maintenance control and biocontrols showing promising results. However, some areas in the east Everglades, Refuge and Corbett still need significant work.		Chemical control effective on most public lands, biocontrol agents effective and additional spread of existing agents and new agents expected 2006.	

Brazilian Pepper (Schinus terebinthifolius)	Serious invader, with rapid spread throughout the Module. Invades most habitats, very destructive. Chemical control effective in limited areas but ineffective in reducing overall spread. Significant portions of the Park, particularly the mangroves are seriously impacted.		No effective regionwide controls yet. Chemical control programs effective in limited areas where significant resources can be applied. New biocontrol agents under study for possible release 2007-2008.	

	CURRENT STATUS		1-2 YEAR PROGNOSIS	
LAKE OKEECHOBEE MODULE **(results in this row reflect only the 3 module level questions not species level questions)**	Restoration efforts have been underway in this module for some time and much progress has been made, including on exotic species. However, several serious species occur in this module and continued disturbance of the littoral zone may increase chances of new invasions.		This module has had a significant and well funded control program effort underway for many years. Progress on many species is evident, but continued monitoring and control efforts will be needed to prevent serious reinvasions of the many species threatening this region.	
Alligator Weed (Alternanthera philoxeroides)	Effective biocontrol program has been underway for many years. Control programs have achieving complete control in most areas.		Biocontrol and monitoring programs are in place and have been achieving good results.	
Australian Pine (Casuarina spp.)	Effective removal program is in place and Casuarina is not a serious problem in the Module anymore.		Chemical control effective, most natural areas clear or clearable with modest effort. Biocontrol research underway.	
Water Hyacinth (Eichhornia crassipes)	Chemical and biocontrol control programs have been underway for many years. Maintenance control (less than 300 acres of treatable plants lake-wide) has been the goal of the program: due to funding shortfalls in FY06 and the active 2004 and 2005 hurricane seasons this goal has not been consistently met.		On-going control and monitoring programs are in place. Maintenance Control is expected to be maintained.	
Hydrilla (Hydrilla verticillata)	Although programs are in place for control, no control activities have been necessary in recent years. Hurricanes, hydrologic conditions and flocculent substrate have prohibited wide spread expansion.		Effective control and monitoring programs, are in place and have been achieving good results.	
West Indian Marsh Grass (Hymenachne amplexicaulis)	Know little about its spread or distribution throughout the system. It is not included in Indicator Indicator systematic monitoring program.		Increases in spread and distribution may be occurring but unable to confirm. May become a serious pest moving into areas where other exotics have been controlled.	

Melaleuca (Melaleuca quinquenervia)	Effective chemical control program underway for several years with excellent effectiveness.		Chemical control effective, biocontrol agents becoming effective and additional spread of existing agents and new agents expected 2006.	
Torpedograss (Panicum repens)	It covers almost 20,000 acres of lake wetlands. Spread seems to be increasing. Not included in Indicator systematic monitoring program.		Control efforts are underway and appear to be effective. However, lake management and drawdowns may increase spread in spite of control program.	
Water Lettuce (Pistia stratiotes)	Chemical and biocontrol control programs have been underway for many years. Maintenance control (less than 300 acres of treatable plants lake-wide) has been the goal of the program: due to funding shortfalls in FY06 and the active 2004 and 2005 hurricane seasons this goal has not been consistently met.		On-going control and monitoring programs are in place. Maintenance Control is expected to be maintained.	

	CURRENT STATUS		1-2 YEAR PROGNOSIS	
BIG CYPRESS MODULE (results in this row reflect only the 3 module level questions not species level questions)	While much progress has been made with Melaleuca, Brazilian pepper and Giant Salvinia other species seem to be gaining a foothold and most of these species are not included in any of the monitoring programs for exotics.		Good control of Melaleuca and Casuarina. Biocontrol for Melaleuca showing effectiveness. First biocontrol releases for Lygodium; new biocontrol for Schinus under study. Other species still localized, but one new and potentially serious invader has been documented by Park Service personnel.	
Australian Pine (Casuarina spp.)	Remnant populations exist along canals and a few natural sites, but removal program is in place and effective.		Chemical control effective, most natural areas clear or clearable with modest effort. Biocontrol research underway.	
Air Potato (Dioscorea bulbifera)	Know little about its spread or distribution. Not included in Indicator systematic monitoring program.		Treated as encountered by contract crews in some areas of the Module such as BCNP, but there are no coordinated control programs in the Module and no biocontrol effort underway.	
Cogon Grass (Imperata cylindrica)	Mainly distributed along roadsides, canals and levees. Not part of a systematic monitoring program.		Treated as encountered in BCNP. No significant coordinated control efforts in place for the Module. No biocontrol effort underway.	
Old World Climbing Fern (Lygodium microphyllum)	Serious invader, rapid spread throughout Module. Invades most habitats, very destructive. Chemical control in module so far effective due to small localized populations but concern over rate of spread still serious.		Contract crews are treating populations as part of "find and treat" operations in some areas. Module-wide controls are not coordinated. Biocontrol release made with additional release expected 2006. Chemical control studies continuing	
Japanese Climbing Fern (Lygodium japonicum)	Southernmost extent of species (so far). Little is known about its impacts in the Module.		Populations have been controlled in the Module so far however, distribution and spread are unknown and no biological control is program underway.	

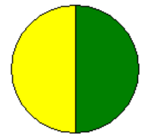
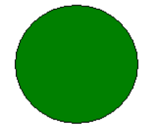
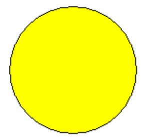
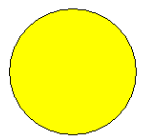
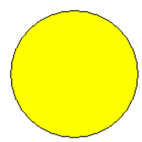
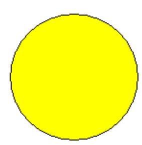
Melaleuca (Melaleuca quinquenervia)	Coordinated efforts to control species, but it is still abundant on private lands. Biocontrol reducing cover and spread and agents establishing throughout Module.		Chemical control effective on most public lands, biocontrol agents effective and additional spread of existing agents and new agents expected 2007-2008.	
Downy Rose-myrtle (Rhodomyrtus tomentosa)	Know little about its spread or distribution within the Module. Not included in Indicator systematic monitoring program.		No fully coordinated control efforts in Module, although local populations are being controlled. No biological control programs underway.	
Giant Salvinia (Salvinia molesta)	Small populations but seems to be under control in Module. Not included in Indicator systematic monitoring program.		Serious aquatic weed in many parts of the world and southern US. Module populations do not appear to present a serious threat at this time due to active control efforts and presence of effective biological control agent.	
Brazilian Pepper (Schinus terebinthifolius)	Serious invader, with rapid spread throughout Module, invades most habitats, very destructive. Chemical control ineffective in reducing Module-wide spread so far, however, local control programs are proving effective where resources are available.		BCNP control program effective, most populations limited or slated for control. New biocontrol agents under study for future release 2007-2008.	
Tropical Soda Apple (Solanum viarum)	Know little about its spread or distribution. Not included in Indicator systematic monitoring program.		Controlled when encountered in BCNP. Distribution poorly understood. It has been introduced in contaminated sod and is widespread on some Tribal lands. Biological control program is underway.	

TABLE 7. Responses from individual questions for all Modules

SE & FB Module Questions	1	2	3
	YELLOW	YELLOW	RED
SE & FB Species Questions	1	2	3
Australian Pine (Casuarina spp.)	YELLOW	GREEN	GREEN
Latherleaf (Colubrina asiatica)	YELLOW	RED	RED
Sapodilla (Manilkara zapota)	YELLOW	YELLOW	YELLOW
Half Flower (Scaevola taccada)	YELLOW	YELLOW	RED
Brazilian Pepper (Schinus terebinthifolius)	YELLOW	YELLOW	YELLOW
Seaside Mahoe (Thespesia populnea)	YELLOW	YELLOW	YELLOW
FK Module Questions	1	2	3
	YELLOW	YELLOW	RED
FK Species Questions	1	2	3
Australian Pine (Casuarina spp.)	YELLOW	GREEN	GREEN
Latherleaf (Colubrina asiatica)	YELLOW	RED	YELLOW
Sickle Bush (Dichrostachys cinerea)	YELLOW	YELLOW	YELLOW
Laurel Fig (Ficus microcarpa)	YELLOW	YELLOW	YELLOW
Sapodilla (Manilkara zapota)	YELLOW	YELLOW	YELLOW
Half Flower (Scaevola taccada)	YELLOW	YELLOW	YELLOW
Brazilian Pepper (Schinus terebinthifolius)	YELLOW	GREEN	GREEN
NE – W Module Questions	1	2	3
	RED	YELLOW	RED
NE – W Species Questions	1	2	3
Australian Pine (Casuarina spp.)	YELLOW	GREEN	GREEN
Air Potato (Dioscorea bulbifera)	YELLOW	YELLOW	YELLOW
West Indian Marsh Grass (Hymenachne amplexicaulis)	YELLOW	YELLOW	YELLOW
Cogon Grass (Imperata cylindrical)	YELLOW	YELLOW	YELLOW
Old World Climbing Fern (Lygodium microphyllum)	YELLOW	RED	YELLOW
Melaleuca (Melaleuca quinquenervia)	YELLOW	GREEN	GREEN
Burma Reed (Neyraudia reynaudiana)	YELLOW	YELLOW	YELLOW
Guinea Grass (Panicum maximum)	YELLOW	YELLOW	YELLOW
Itch Grass (Rottboellia cochinchinensis)	YELLOW	YELLOW	YELLOW
Half-flower (Scaevola taccada)	YELLOW	YELLOW	YELLOW
Brazilian Pepper (Schinus terebinthifolius)	YELLOW	GREEN	GREEN
Para grass (Urochloa mutica)	YELLOW	YELLOW	YELLOW

NE - E Module Questions	1	2	3
	YELLOW	YELLOW	RED
NE - E Species Questions	1	2	3
Shoebutton Ardisia (Ardisia elliptica)	YELLOW	RED	RED
Australian Pine (Casuarina spp.)	YELLOW	GREEN	GREEN
Caulerpa (Caulerpa brachypus)	YELLOW	RED	YELLOW
Air Potato (Dioscorea bulbifera)	YELLOW	RED	YELLOW
Old World Climbing Fern (Lygodium microphyllum)	YELLOW	RED	YELLOW
Melaleuca (Melaleuca quinquenervia)	YELLOW	GREEN	GREEN
Torpedograss (Panicum repens)	YELLOW	RED	YELLOW
Brazilian Pepper (Schinus terebinthifolius)	YELLOW	GREEN	GREEN

Kissimee Module Questions	1	2	3
	RED	YELLOW	RED
Kissimee Species Questions	1	2	3
Water Hyacinth (Eichornia crassipes)	YELLOW	GREEN	GREEN
Limpograss (Hemarthria altissima)	YELLOW	RED	YELLOW
Hydrilla (Hydrilla verticillata)	YELLOW	GREEN	GREEN
West Indian Marsh Grass (Hymenachne amplexicaulis)	YELLOW	GREEN	GREEN
Cogon Grass (Imperata cylindrical)	YELLOW	YELLOW	YELLOW
Old World Climbing Fern (Lygodium microphyllum)	RED	RED	YELLOW
Japanese Climbing Fern (Lygodium japonicum)	YELLOW	YELLOW	YELLOW
Melaleuca (Melaleuca quinquenervia)	YELLOW	GREEN	GREEN
Torpedograss (Panicum repens)	YELLOW	YELLOW	YELLOW
Water Lettuce (Pistia stratiotes)	YELLOW	GREEN	GREEN
Brazilian Pepper (Schinus terebinthifolius)	YELLOW	GREEN	GREEN
Chinese Tallow (Sapium sibiferum)	YELLOW	RED	YELLOW
Tropical Soda Apple (Solanum viarum)	YELLOW	YELLOW	YELLOW
GE Module Questions	1	2	3
	YELLOW	GREEN	GREEN
GE Species Questions	1	2	3
Shoebutton Ardisia (Ardisia elliptica)	RED	RED	RED
Australian Pine (Casuarina spp.)	YELLOW	GREEN	GREEN
Old World Climbing Fern (Lygodium microphyllum)	RED	RED	YELLOW
Melaleuca (Melaleuca quinquenervia)	RED	GREEN	GREEN
Brazilian Pepper (Schinus terebinthifolius)	RED	RED	RED

LAKE O. Module Questions	1	2	3
	YELLOW	YELLOW	RED
LAKE O. Species Questions	1	2	3
Alligator Weed (Alternanthera philoxeroides)	GREEN	GREEN	GREEN
Australian Pine (Casuarina spp.)	GREEN	GREEN	GREEN
Water Hyacinth (Eichornia crassipes)	YELLOW	GREEN	GREEN
Hydrilla (Hydrilla verticillata)	YELLOW	GREEN	GREEN
West Indian Marsh Grass (Hymenachne amplexicaulis)	YELLOW	RED	YELLOW
Melaleuca (Melaleuca quinquenervia)	GREEN	GREEN	GREEN
Torpedograss (Panicum repens)	RED	RED	YELLOW
Water Lettuce (Pistia stratiotes)	YELLOW	GREEN	GREEN
BICY Module Questions	1	2	3
	RED	YELLOW	RED
BICY Species Questions	1	2	3
Australian Pine (Casuarina spp.)	YELLOW	GREEN	GREEN
Air Potato (Dioscorea bulbifera)	YELLOW	YELLOW	YELLOW
Cogon Grass (Imperata cylindrical)	YELLOW	YELLOW	YELLOW
Old World Climbing Fern (Lygodium microphyllum)	YELLOW	GREEN	GREEN
Japanese Climbing Fern (Lygodium japonicum)	YELLOW	RED	YELLOW
Melaleuca (Melaleuca quinquenervia)	YELLOW	GREEN	GREEN
Downy Rose-myrtle (Rhodomyrtus tomentosa)	YELLOW	YELLOW	YELLOW
Giant Salvinia (Salvinia molesta)	YELLOW	GREEN	GREEN
Brazilian Pepper (Schinus terebinthifolius)	YELLOW	GREEN	GREEN
Tropical Soda Apple (Solanum viarum)	YELLOW	YELLOW	YELLOW

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PART II

ECOLOGICAL INDICATORS

FISH & CRUSTACEANS

WADING BIRDS (WOOD STORK, WHITE IBIS & ROSEATE SPOONBILLS)

FLORIDA BAY SUBMERGED AQUATIC VEGETATION

FLORIDA BAY ALGAL BLOOMS

CROCODILIANS (AMERICAN ALLIGATOR & AMERICAN CROCODILE)

AMERICAN OYSTERS

PERIPHYTON & EPIPHYTON

PINK SHRIMP

LAKE OKEECHOBEE LITTORAL ZONE

INVASIVE EXOTIC PLANTS

Fish and Crustaceans

Author: Joel Trexler

What Is This Indicator?

Marsh and estuarine aquatic fauna, including small fishes and crustaceans, are critical in the food web as primary and secondary consumers and as a prey for focal Everglades' predators such as wading birds (RECOVER 2005). This indicator uses the density (how many animals per unit area), biomass (mass of animals per unit area), and community composition (how many of each species per unit area) of a suite of native fishes (e.g., eastern mosquitofish, bluefin killifish, sheepshead minnows, sailfin molly) and crustaceans (slough and Everglades crayfish, riverine grass shrimp) to describe trends in their populations related to hydrology. Their density and community composition are correlated with hydrological conditions including depth, duration, timing, spatial extent, and water quality. Salinity is a critical parameter in estuarine habitats.

Fish and macroinvertebrates integrate biological impacts of hydrological operations affecting their local communities at all life stages (Ruetz, C., et al. 2005). This is important because research has linked three key aspects of Everglades' ecology to this indicator: 1) Top predators such as wading birds are directly dependent on prey density, especially fish and crustaceans (Frederick and Spalding 1994); 2) Prey population structure, standing crop, and density are directly dependent on water depth, duration, timing, distribution, quality and periphyton biomass (Ruetz et al. 2005, Trexler et al. 2002, Turner et al. 1999); 3) Prey availability is directly dependent on prey density, water depth, duration and timing (Gawlik 2002).

Fish and macroinvertebrate responses are linked to the suitability of environmental conditions. Correlations between biological responses and environmental conditions contribute to an understanding of the species' status and trends over time. The positive or negative trends of this indicator relative to hydrological changes (Trexler et al. 2005) permit an assessment of positive or negative trends in restoration. Restoration success or failure would be evaluated by comparing recent and future trends and status of the fish and macroinvertebrate populations with historical population data and model predictions; as stated in the CERP hypotheses related to the food web (CERP Monitoring and Assessment Plan section 3.1.2.4, 2004).

CERP MAP Hypotheses related to Fish and Macroinvertebrates Indicator

- Restore the density, community characteristics, size structure, and taxonomic composition of marsh fishes and other aquatic fauna to levels that support sustainable breeding populations of higher vertebrates;
- Shift the distribution of high density populations of marsh fishes and other aquatic fauna from artificially-pooled areas (i.e. water conservation areas) to restored wetlands in the southern Everglades;
- Shift the foraging distribution of wading birds in response to expected trends in the density, distribution, and concentration of prey organisms.

What Has Happened To Affect The Indicator?

Concerns about fish and crustaceans relate primarily to their use as food by organisms considered as essential to restoration by scientists, managers and policy makers, (e.g. wading birds, alligators). Reproduction of higher vertebrates (e.g. large fish, wading birds and alligators) is dependent on food availability—fish and macroinvertebrates, and periphyton that sustains them—that, in turn is entirely dependent on hydrological conditions. Because of relatively dry hydrological conditions resulting from water management over the past several decades, and a loss of habitat (due partly to reduced areas of inundation and increased dry downs) in the Everglades, fish and macroinvertebrate densities have decreased and community structure changed, when compared to wetter conditions [as defined in CERP performance measures (Trexler et al. 2003, Trexler et al. 2005, RECOVER 2005)]. Research indicates that fish and crustacean populations need sufficient time to build up numbers of animals and biomass following drought. Accumulating adequate numbers and biomass for sufficient prey requires a number of years (Trexler et al. 2005). Once populations are sufficient, they must become available to the predators for general sustenance and breeding, and this requires appropriate water depths and timing of depth fluctuations to support large populations of different predators that need different water conditions to access the prey (Gawlik 2002).

What Areas of the Everglades Does This Indicator Cover?

Fish and macroinvertebrates cover virtually all of the Everglades freshwater wetlands and the southern estuarine areas. These areas include the following RECOVER & SCG regional modules; Greater Everglades, Florida Bay and Southern Estuaries, Big Cypress, Lake Okeechobee, and the Kissimmee River Basin. These modules are shown in Figure 1.

What Does The Research Say?

Because of the unique geological history and oligotrophy of the Everglades, native fish communities are relatively species poor and have low standing stocks compared to other wetland systems (Loftus and Kushlin 1987, Trexler 1995, Turner et al. 1999). However, the most important factors affecting fish abundances regionally are the loss of habitat (including extent of areas inundated), hydroperiod, water depth and frequency of drying events (Trexler et al. 2005). Increasing drought frequency and below-ground depth of drying also increases the time required for fish and crustacean populations to recover to levels considered representative of the historical Everglades (Trexler et al. 2003). It takes from three to eight years following each drying event in a long-hydroperiod marsh for fish and macroinvertebrate populations to stabilize (Turner et al. 1999, Trexler et al. 2005). When drying events occur repeatedly at less than a 3-8 year interval, fish and crustacean populations are continually recovering from past droughts and may fail to reach densities sufficient to sustain large predators (Loftus and Eklund 1994, Turner et al. 1999, Trexler et al. 2005).

Water quality also affects fish and crustacean populations. Phosphorus enrichment increases fish populations, at least for a period of time (Turner et al. 1999, Gaiser et al. 2005). This is linked to an increase in macroinvertebrates the fish consume (McCormick et al. 2004, Smith 2004) and breakdown of the periphyton mat, possibly permitting greater access to food sources in the mat (Liston 2005). However, this appears to be a temporary phenomenon because as the eutrophication develops, the overall food source is ultimately reduced (Turner et al. 1999, McCormick et al. 2002). Macroinvertebrate community composition, including crustaceans, is similarly affected by nutrient enrichment (McCormick et al. 2004, Smith 2004).

In a particularly encouraging finding, Trexler et al. (2005) observed that when water management created wetter conditions in areas of Everglades National Park previously over-dried, but not nutrient enriched, fish and macroinvertebrate populations recovered to the numbers and community structure that are indicative of historical conditions.

Models of different levels of complexity have been developed for assessment of hydrological alternatives using small fish. The ATLSS model ALFISH simulates fish density dynamics across the entire Everglades' landscape based on hydrological drivers (Gaff et al. 2000). Recent work has found good correspondence between ALFISH output and field collections (Gaff et al. 2004). Simple statistical models have also been developed for assessments comparing observed data to hydrological model output, including the Natural System Model (Trexler et al. 2003).

Why Is This Indicator Important?

1. <u>The Indicator is relevant to the Everglades Ecosystem and Responds To Variability At A Scale That Makes It Applicable To the Entire Ecosystem or Large Portions Of The Ecosystem:</u>

- It contains an abundant community of species typical of the Everglades ecosystem;
- They are characteristic of all Everglades' freshwater wetlands;
- They are primary and secondary consumers that rely primarily on periphyton productivity (the base of the Everglades' food chain);
- Productivity and community structure are directly linked to hydrology;
- Fish and crustaceans provide the critical prey for secondary and tertiary carnivores such as wading birds;
- Fish densities are linked to periphyton production and wading bird nesting success, which are also being used as indicators (integration);
- Productivity measures (abundance and standing stock) are key outcomes (performance measures) in most RECOVER Conceptual Ecological Models and in CERP Interim Goals.

2. <u>The Indicator is Feasible to Implement and is Scientifically Defensible:</u>

- There are existing, funded cooperative research and monitoring programs with FIU, Florida Coastal LTER Program, USGS, and the NPS;
- There is a long term data base covering over 25 years for some sites;
- There are reliable models available to determine the impacts of water management on these populations;
- Reliable models exist for estimating historical fish densities in regions where historical databases do not exist;
- Pattern metrics (e.g. abundance, community structure) are statistically correlated to Ecosystem Drivers;
- It is being developed as part of the CERP ALFish Landscape Model;
- There are numerous peer reviewed journal articles;
- This indicator is already part of the CERP RECOVER interim goals and Food-Web Monitoring Component of the CERP MAP.

3. <u>The Indicator is Sensitive to System Drivers (Stressors)</u>

- Key environment Drivers (Rainfall, Water Quantity, Water Quality) are statistically correlated to species abundance and community composition;
- Short and Long hydroperiod wetlands have distinct fish density and community composition;
- Fish density and community composition are causally linked to hydrological factors (water depth, days since last dry-down, and length of dry-down);

<u>4. The Indicator is Integrative</u>

- Fish and crustacean production are linked to periphyton production and, in turn, wading bird nesting success is linked to fish and macroinvertebrate production;
- Community responses are representative of hydrological improvement (i.e. Water Management);
- Fish and crustaceans are included in the CERP Food-Web Monitoring Component that includes an index of food-web function and landscape connectivity (“intactness”);

4. <u>Goals and Performance Measures are established in the RECOVER MAP for the Indicator and the following metrics are being monitored:</u>

- Number of animals per meter
- Frequency of dry-downs
- Duration of dry-downs
- Community composition in both short- and long-hydroperiod wetlands

Discussion

The RECOVER Conceptual Ecological Models identify three major stressors to wetlands that are affecting the critical populations of fish and crustaceans: water management practices (affecting hydrology and water quality); agricultural and urban development (affecting habitat loss, hydrology and water quality); and invasive exotic species (affecting habitat loss, abundance and community composition) (CERP Monitoring and Assessment Plan 2004).

Conversions of large areas of short-hydroperiod wetlands (marl prairies) east of Everglades National Park and the Water Conservation Areas into agricultural and urban uses represents a large regional loss that populations of fish and crustaceans and other aquatic fauna once inhabited. This loss due to irreversible land-use changes has had a major impact on both the abundance and structure of these communities.

Animal density (animals per unit area), relative abundance (proportion of each species in a community), standing stock (grams of animal per unit area), and community composition are affected by the duration, and frequency of droughts. The reduction of hydroperiod resulting from long-term water management changes has artificially limited fish densities, size structure and community structure in Everglades' wetlands for many decades. Areas of the southern Everglades (eastern portions of Everglades National Park) that were over-drained for many decades have shown marked improvement in fish and crustacean populations with improvements r in water management (i.e. increases in duration of flooding and depth of water; Trexler et al. 2005). Further restoration is needed.

Additional hydrological restoration is expected to improve habitat for fish and crustaceans in both long and short hydroperiod-wetlands. In long-hydroperiod wetlands, it is expected to reduce the incidence and severity of drying and enhance populations acting as source areas for dispersal. In short-hydroperiod wetlands, improved water management is expected to provide sufficient water level to maintain more aquatic refuges in solutions holes, which also serves as dispersal sites during the wet season.

Exotic species, both plants and animals, may impact the populations of fish and crustaceans. Exotic fish predators, such as the black acara, can affect populations through direct predation (Kobza et al. 2004, RECOVER 2005). This could be particularly dramatic during the dry season when populations are congregated in refuges (e.g. alligator holes, solution holes), thus reducing the ability of the population to recover because of reduced numbers of animals dispersing after early wet-season flooding events. Exotic plants may affect these populations by altering the native vegetation and hydrological characteristics of wetland areas. For example, melaleuca can replace open grassy wetlands with forest; and it is documented to raise soil levels thus reducing the area of inundation and water flow.

Longer-Term Science Needs

Basic biology of fish and crustaceans in the Everglades, and ways to monitor their responses to hydrological management effectively, is relatively well worked out.

Continued work is needed to improve monitoring techniques in Rocky Glades-like habitats, delineate and track non-native taxa, and better understand the implications of canals and levees for improved assessments of de-compartmentalization. Existing monitoring programs and projects need to be continued to capitalize on the developing time-series information on these animals that can be used in impact assessment.

Current monitoring techniques for fishes use a throw-trap to sample in freshwater habitats and drop-trap in mangrove environments. While these techniques are excellent for much of the Everglades, there are limitations. In particular, neither technique can be used effectively in the Rocky Glades where soil is absent and the rocky ground surface is highly uneven. Alternative techniques for sampling fish and macroinvertebrates in this landscape are not well established by studies of their sampling efficiency and bias. This is unfortunate because these habitats are found in important areas for restoration and management, and monitoring of aquatic communities is valuable for assessment and evaluation.

Response to Review Panel

Several of the comments from Independent Scientific Review by Jordan et al. are beyond the scope of this document are thoroughly addressed in other technical documents, particularly those pertaining to the mechanics of performance measure preparation.

Individual comment responses

1. List species in indicator: The current document was prepared to provide a framework for choice of performance measures used as system-wide indicators, rather than discuss the details of these performance measures. We felt that it was appropriate to discuss total fish density and biomass as indicators in this document, and leave discussion of nuances of how the values will be calculated and reported to other documents.

2. I disagree with the goal of including diversity indices. The technical reasons are varied and beyond the scope of this discussion, but would be happy to elaborate in person if necessary. Suffice it to say that there are technical and conceptual difficulties regarding application of such indices in general, and in the Everglades in particular. We do plan to report some simple measures related to the dynamics of native versus non-native species that may fulfill the intent of this comment.

3. All performance measures (fish and crustaceans) will be calculated to indicate deviation from expectation given targeted hydropattern (probably similar to those generated by the Natural System Model or a successor) and water quality.

4. We agree with the goal of improving monitoring techniques for habitats in the Rocky Glades. In fact, we are working on this and funding has been provided

by agencies (more could always be used, of course). It would be a pleasure to discuss this topic and our ongoing efforts in detail, but this isn't the forum.

5. Elimination of macroinvertebrates is contrary to the conceptual model underlying these performance measures. In this case, crayfish (two species) and grass shrimp (one species) are important components of Everglades' food webs leading to wading birds and alligators.

6. The document already points out that we have models to generate the values and that there is no single target expectation for the Everglades. In particular, targets are dependent upon the rainfall and hydrological history of a particular site; some or all of the Everglades should dry in drought years (such as the two year interval 1989-1990) and all places that dry should have depleted aquatic animal populations for one or more years following such events.

7. Sustainable breeding populations of 'higher vertebrates' in the aquatic portion of the ecosystem are not a factor in Everglades management (does this mean otters and muskrats?). Perhaps this comment was intended for another section? There are no higher vertebrates relevant to this report except wading birds, and they are addressed elsewhere.

8. Shifting fishes from the pooled areas has indeed been considered in the conceptual model. We are well aware that this has the potential to diminish foraging opportunities for upper trophic-level consumers. However, the details are hard to predict because they depend on multiple factors in the implementation of SERC. Discuss of this level of details is beyond the scope of this report, but I'd really enjoy discussing it with anybody who wants to. This is an important target for modeling work, however.

9. Extending our monitoring to northern estuaries would be a good idea if resources are available.

10. Yes, we intend to include indices of relative abundance of native and non-native fishes, as well as size-based measures of community structure linked to threshold sizes consumed by birds. The ultimate assessment tool will be multi-variable, similar to the stoplight system proposed for non-native plants.

11. A bar chart with stacked columns could be used, but must report deviation of observed from expected, given target hydrology (NSM-like hydrology).

12. Current monitoring of fishes and macroinvertebrates is by throw trap. The usefulness of that technique has been evaluated and calibrated in many papers. Though imperfect, it appears to be less imperfect that all other alternatives. Fyke nets are a case in point. This is an example of an encounter sampling device, meaning that it is stationary and fish must move into it to be captured. We have documented that interpretation of results from such devices (also includes minnow traps, gill nets) deployed in the Everglades is challenging at best, because fish movement is seasonally

variable and species-specific. It is clear that data gathered from these methods cannot be used as measures of density or local abundance in the Everglades. Another example is instructive: crayfish capture rates in ponds has been shown to be dependent on the presence or absence of largemouth bass (a predator) because predator presence influences their movement rate. In a monitoring context, changes of operations may change the abundance of predators or susceptibility of animals to predators (vegetation density) in ways that alter movement rates. Also, operations and patterns of marsh drying also affect movement rate independent of local density. This is further complicated by the large-size and open nature of the Everglades, where operations at some distant point could cause animals to move into areas not directly affected, changing movement rates of their prey. This need not lead to a change in local density of an animal to alter the capture rate in an encounter-type sampler. In summary, interpretation of these devices must be made with caution, even more than is needed to interpret data from drop nets and throw traps.

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WADING BIRDS (White Ibis and Wood Storks)

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What is this Indicator?

Extremely large numbers of colonial wading birds were one of the defining characteristics of the pre-drainage wetlands of south Florida (Ogden et al. 2005). Of particular relevance in understanding the population dynamics of wading birds in the pre-drainage system, are the combined features of large spatial extent and highly variable hydrological conditions that created and maintained a mosaic of wetland habitats. This combination is what made it possible for the region to support large nesting colonies of two species of wading birds with quite different foraging strategies and prey requirements, White Ibis and Wood Storks.

White Ibis forage for small fish and crayfish in very shallow water in wetlands that dry annually in most years. Ibis tend to forage close to nesting colonies (<20 km) and, therefore, relocate their colony sites and change the timing of nesting from year to tear in response to shifting locations of high densities of prey (Frederick and Ogden 1997). In contrast, Wood Storks tend to forage on the larger sizes of marsh fishes, often in deeper pools that do not dry annually. Storks routinely soar great distances from colony sites (25-75 km) and are able to reuse traditional colony sites for many years, irrespective of shifting locations of prey. Historically, ibis initiated nesting in most years in mid- to late dry seasons when water levels were low, while storks initiated nesting early in dry seasons when water levels were higher. With a comparatively short nesting cycle for ibis, and a much longer cycle for storks, both species fledged young in the late dry season when prey concentrations were generally highest.

The broad restoration goals for ibis and storks are about recovering the kind of ecosystem with the spatial and temporal variability to support large numbers of both of these behavioral and habitat specialists. The specific restoration goals for these two species include targets for numbers of nesting pairs, location of colonies, timing of nesting, and an increase in the size and frequency of the larger nesting assemblages ("super colonies").

- An initial numerical goal for ibis and storks is to recover and/or sustain nesting populations of 50,000 and 5,000 birds, respectively. Long-term numerical goals have yet to be set.
- The restoration goal for location of stork colonies is a return of large nesting colonies in the southern, mainland estuaries of Everglades National Park, and a return to multiple colony sites in the Big Cypress basin.
- The restoration goal for timing of nesting by storks is a recovery of the historical pattern of colony formation in the early dry season months, November-January.
- An increase in the size of ibis super colonies, and an increase in the frequency to not less than two super colony events per 10 years.

CERP MAP Hypotheses related to Wading Bird Indicators (RECOVER 2004):

- Restoration of the density, seasonal concentrations, size structure, and taxonomic composition of marsh fishes and other aquatic fauna to levels that support sustainable breeding populations of higher vertebrates,
- Shift the distribution of high densities populations of marsh fishes and other aquatic fauna from artificially-pooled areas (WCAs) to the restored natural pools in the southern Everglades,
- Shift the foraging distribution of wading birds in response to expected trends in the density, distribution, and concentration of prey organisms,
- Re-establish wading bird nesting colonies in the coastal regions of the southern Everglades and an increase in the numbers of nesting pairs and colony sizes in response to desired trends in populations of prey organisms.
- Increase nesting success/survival rates of wading birds

What Has Happened To Affect The Indicator?

The drainage of extensive areas of short-hydroperiod wetlands, large-scaled alterations in water depth and distribution patterns due to compartmentalization of wetlands in the central Everglades, and the reduction of freshwater flows into the formerly more productive estuaries, are the anthropogenically-induced stressors that have substantially impacted ibis, storks and other wading birds in south Florida (Ogden 1994). Both ibis and storks have responded to these stressors by largely abandoning former nesting and roosting sites in the southern Everglades and Big Cypress basins, by delaying the initiation of nesting by several months (storks), and by rarely forming the “super-colonies” that once characterized the south Florida wetlands (ibis) (Frederick and Ogden 2001). The number of ibis nesting in south Florida has declined from an estimated 100,000 – 200,000 birds in the 1930s - 1940s (years of super colonies) to 20,000 – 60,000 birds since the late 1990s. The number of nesting storks has declined from 14,000 – 20,000 birds prior to 1960 to about 2,000 – 5,000 birds since the late 1990s (Ogden 1994). The loss of early-dry-season foraging habitats has caused storks to delay the initiation of nesting by 2-3 months in many years, which has often resulted in young birds still being in nests when summer rains begin, and prey concentrations are lost. The disruption of natural hydrological patterns has substantially disrupted natural wet-dry patterns, thought to be of major importance in organizing the production pulses that supported super-colony formation (citation).

What Areas of the Southern Florida Ecosystems Does This Indicator Cover?

White Ibis and Wood Storks, and other associated species of wading birds in south Florida (e.g., Great Egrets, Snowy Egrets, Tricolored Herons), are system-wide indicators for the south Florida wetlands. The areas used by these birds include the following RECOVER & SCG regional modules: Greater Everglades, Florida Bay and Southern Estuaries, Northern Estuaries, Big Cypress, Lake Okeechobee, and the Kissimmee River Basin (see Figure 1). On seasonal, annual, and multi-year periods, these species of wading birds move about over large spatial scales in locating and utilizing good foraging habitats. The seasonal and annual variability in rainfall that characterizes south Florida means that the optimum foraging conditions for wading birds also vary both temporally and spatially. Wading birds are integrating information from many different regions in determining when and where they forage and form nesting colonies. In addition, individual wading birds may fly long distances daily, between roosts or nesting colonies and optimum foraging sites. The daily, seasonal, and annual patterns of movement by wading birds often occur at multi-landscape scales, and can cross among freshwater and estuarine communities.

Why Is This Indicator Important?

1. The Indicator is relevant to the Everglades ecosystem and responds to variability at a scale that makes it applicable to the entire ecosystem or large portions of the ecosystem:

    - White Ibis and Wood Storks and other species of colonial-nesting wading birds are well adapted to be successful in a healthy Everglades-type ecosystem;
    - These species are characteristic of the freshwater and estuarine greater Everglades system;
    - Ibis and storks are top predators in Everglades aquatic food chains;
    - The distribution and abundance of ibis, storks and other wading birds is determined by temporal and spatial scales of production and availability of aquatic prey;
    - Ibis and storks and other species of wading birds move about over large spatial scales in response to variable seasonal and annual patterns in the quality of foraging habitat;
    - The quality of good foraging habitat is directly linked to regional and system-wide hydrological patterns.

2. The indicator is feasible to implement and is scientifically defensible:

    - Survey protocols for foraging and nesting patterns for ibis and storks and other species of colonial-nesting wading birds are well developed in south Florida;
    - Major portions of the Everglades ecosystem are currently being surveyed for nesting colony patterns;
    - Many surveys of nesting colonies and foraging patterns have previously been conducted, providing a strong record of past patterns;
    - There is a strong body of research and published information for wading birds in the Everglades system, providing a solid, base-line understanding of the linkages between hydrological patterns and the ecology and biology of wading birds;
    - Wading birds have already been established as indicators for CERP success, and are included in the RECOVER Monitoring and Assessment Plan, and as a recommended CERP Interim Goal.

3. The indicator is sensitive to system drivers (stressors):

- Wading birds show sensitivities to anthropogenically-induced altered hydropatterns in the Everglades by changing the location, timing and magnitude of nesting and foraging at system-wide scales;
- A strong set of working hypotheses have been developed to explain how and why wading birds have been adversely affected by drainage and management practices in the Everglades system, as a basis for predicting wading bird responses to restoration programs.

4. The indicator is integrative.

- The nesting and foraging patterns of ibis and storks and other species of wading birds is strongly influenced by patterns of abundance and availability of aquatic prey, which in turn are influenced by the production and density of prey, which are determined by past and current hydrological patterns;
- Ibis and storks feed on different prey, and have different foraging strategies, therefore the collective responses of these two species, and other species of wading birds, reveal broad system-wide conditions of aquatic production and availability;
- The high levels of mobility of wading birds, both in time and space, can reveal how wading birds are integrating information of foraging and nesting conditions over large temporal and spatial scales.

5. Goals and performance measures are established in the RECOVER MAP for the indicator and the following metrics are recommended for monitoring:

- Numbers of nesting colonies
- Locations of nesting colonies
- Timing of nesting
- Species composition of nesting colonies
- Frequency of occurrence of “super colonies”.

Discussion

Large numbers of showy wading birds were a conspicuous feature of the pre-drainage wetlands of south Florida. Single nesting colonies that contained an estimated 100,000 to 200,000 birds were reported in some early years. Although most of the early colonies were decimated by plume hunters in the late 19th Century, protective legislation and good remaining habitat conditions during the early 20th Century allowed most of the nesting species to fully recover by the 1930s. The huge “rookery” that was located along the extreme headwaters of Shark River was estimated in 1934 to have been a mile long and several hundred feet wide, and was so packed with nests and young birds that it was difficult to walk through the colony without pushing into nests (R.P.Allen, field notes). These bird cities were symbolic of the richness and abundance of the former south Florida wetlands, and they had largely disappeared by the end of the 1960s.

The location and size of colonies, the species composition, and the timing of nesting by wading birds in the pre-drainage south Florida wetlands were largely determined by the physical and ecological characteristics of these wetlands. It is predicted that the recovery of these historical nesting patterns will be a strong indicator that the mainland wetlands in south Florida have been successfully restored to an Everglades-type of ecosystem that much more closely resembles the pre-drainage system than do the current wetlands. Successful recovery of historical White Ibis and Wood Stork nesting patterns will be especially indicative of restoration success because of the special and contrasting behavioral and habitat characteristics between these two species. Recovery of wetland systems that can support large numbers of both of these two species will be an ultimate measure of Everglades' restoration success.

Longer-Term Science Needs

The White Ibis and Wood Stork indicators are based on patterns of nesting for these two species. For these patterns to be properly measured and evaluated over time, a comprehensive, system-wide program of monitoring nesting colonies is required (locations, species composition, numbers of nesting pairs, measures of success). Currently, no such system-wide survey of nesting colonies is in effect (Gawlik 2002). The regions of south Florida that are being systematically surveyed are the three WCAs, plus mainland Everglades National Park. Important regions that are not being systematically surveyed include Lake Okeechobee, the Big Cypress basin, and portions of the Caloosahatchee and St. Lucie estuaries.

Much information on the basic biology, food habits, movement patterns for ibis and storks has been researched and reported. In the context of restoration, several key questions remain unaddressed. These include:

- A more complete understanding of the biology and ecology of the two species of freshwater crayfish, key prey species for the ibis. An especially important question pertains to the ecological conditions that supported the tremendous numbers of crayfish that were reported in the pre-drainage Everglades basin.
- The natural pattern of high water and drought that are hypothesized to have organized pulses of production in an otherwise oligotrophic system, and which may have supported the periodic formation of super colonies, is poorly understood. Key questions have to do with the role of multi-year droughts in nutrient and production dynamics in the greater Everglades.
- Although systematic surveys of wading bird foraging patterns have been conducted for many years, the relationships between wading bird abundance and foraging patterns, and the location, size and timing of nesting colonies is still poorly understood.

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WADING BIRDS (Roseate Spoonbills)

Author: Jerry Lorenz

South Florida Ecosystem Restoration: Roseate Spoonbills

What Is This Indicator?

Monitoring of Roseate Spoonbills (*Platalea ajaia*) in Florida Bay over the past 70 years have shown that this species responds markedly to changes in hydrology and corresponding changes in prey abundance and availability (Powell et al. 1989, Lorenz et al. 2002). This indicator uses nesting location, nest numbers and nesting success in response to food abundance and availability. In turn, prey density and availability are functions of hydrological conditions including depth, and salinity. These relationships are well documented and spoonbills responses can be directly related to changes in hydrology and hydrography.

There is a 70-year database of spoonbill nesting activity in Florida Bay. Lorenz et al. (2002) demonstrated that nesting patterns are highly dependant on hydrologic conditions on the foraging ground most proximal to the nesting colonies. Other species of concern (e.g. Bald Eagle, Osprey, Brown Pelican, Great White Heron, and American Crocodile) have been observed to follow similar trends and dependence on adequate food resources; however, the databases for these species are not as extensive (possibly excepting the crocodile). Spoonbills primarily feed on wetland fishes (Dumas 2000) and time their nesting with low water levels that result in the prey base fishes becoming highly concentrated into the remaining wetted areas (Loftus and Kushlan 1987, DeAngelis et al. 1997, Lorenz 2000). Studies suggest that tactile feeding wading birds, such as the Roseate Spoonbill, are particularly dependent on high prey density in order to successfully forage, probably more so than the visually oriented avian predators (Kahl 1964, Kushlan et al. 1985, Frederick and Spalding 1994, Gawlik 2002). Presumably, this is due to tactile feeders being more efficient when prey density is very high and visual predators being more efficient at lower prey densities (Kahl 1965). Gawlik (2002) experimentally demonstrated that two species of tactile feeders (wood storks and white ibis) abandoned foraging sites while prey was still abundant enough to attract visually oriented wading birds in high numbers. Although no spoonbills visited the study site, Gawlik’s (2002) experimental approach lends empirical evidence to the idea that tactile feeders are more sensitive to prey availability. Because tactile foraging birds in general and roseate spoonbill in particular are more dependant on high prey concentration than other wading bird species (Kahl 1964, Gawlik 2002), they are more sensitive to changes in environmental conditions that determine fish concentrations, specifically water levels (Gawlik 2002). The requirement for highly concentrated prey intensifies during nesting cycles when the high energetic demands of their offspring require a consistently available and high density of prey items (Kahl 1964, Lorenz 2000).

Spoonbill nesting success is dependant on suitable environmental conditions. Correlations between biological responses and environmental conditions contribute to an understanding of the species' status and trends over time (Lorenz 1999, Lorenz and Serafy 2006). The positive or negative trends of this indicator relative to hydrological changes (Lorenz 2000, Lorenz et al. 2002, Bartell et al. 2005) permit an assessment of positive or negative trends in restoration. Restoration success or failure would be evaluated by comparing recent and future trends and status of spoonbills with historical population data and model predictions; as stated in the CERP hypotheses related to the food web (CERP Monitoring and Assessment Plan section 3.1.2.4; U. S. Army Corps of Engineers 2004).

CERP MAP Hypotheses related to Roseate Spoonbill Indicator

- Restore nest numbers to pre-SDCS levels of 1250 nests with at least half in the northeastern sub-region (as defined by Lorenz et al 2002) of Florida Bay. Although specific numbers for the pre-plume hunting era are unknown for Florida Bay anecdotal evidence suggests that the long term target should be in excess of 2000 nests bay wide.
- Spoonbill's should experience successful nesting (defined as an average production of >1chick/nest) in 7 of 10 years and average 1.5 chicks/nest overall (initially using a ten year running average).
- A return of extensive nesting activity in the Ten Thousand Islands region south of Cape Romano with a short term target of 100 nests and a long term target of steadily increasing nesting activity in this region.
- Restore the density, seasonal concentration, size structure, and taxonomic composition of wetlands fishes and other aquatic fauna within the coastal wetlands of Florida Bay, southern Biscayne Bay and the Ten Thousand Islands to levels that support sustainable breeding populations of spoonbills and other higher vertebrates.

What Has Happened To Affect The Indicator?

In 1979, 1,250 Roseate Spoonbill nests were located in Florida Bay, with more than half the nests located in the northeastern bay (Powell et al 1989). The distribution of nesting by roseate spoonbills has shifted from northeastern Florida Bay to the western Bay since the advent of the South Dade Conveyance System. The shift is attributed to altered hydrology and salinity patterns, and subsequent reduced abundance and concentrations of prey organisms in the coastal wetlands adjacent to northeastern Florida Bay (Lorenz 2000). Those coastal wetlands represented the primary feeding grounds for the spoonbills that nested on islands in northeastern Florida Bay (Bjork and Powell 1994). In addition to a large nesting population in Florida Bay, spoonbills are historically reported as having, "nested in the thousands" in the Ten Thousand Islands region south of Cape Romano (Scott 1889). Restoration of more historic hydrological conditions should promote greater prey abundance and availability in both Florida Bay and the Ten Thousand Islands, leading to an increase in the number of years spoonbills can successfully nest, defined as the survival of offspring to fledging. Therefore, roseate spoonbills are good indicators for evaluating the CERP's effectiveness at restoring estuarine conditions (Lorenz et al. 2002).

What Areas of the Everglades Does This Indicator Cover?

Roseate Spoonbill nesting parameters are an indicator for the Florida Bay and Southern Estuaries regional modules of RECOVER & SCG (Figure 1).

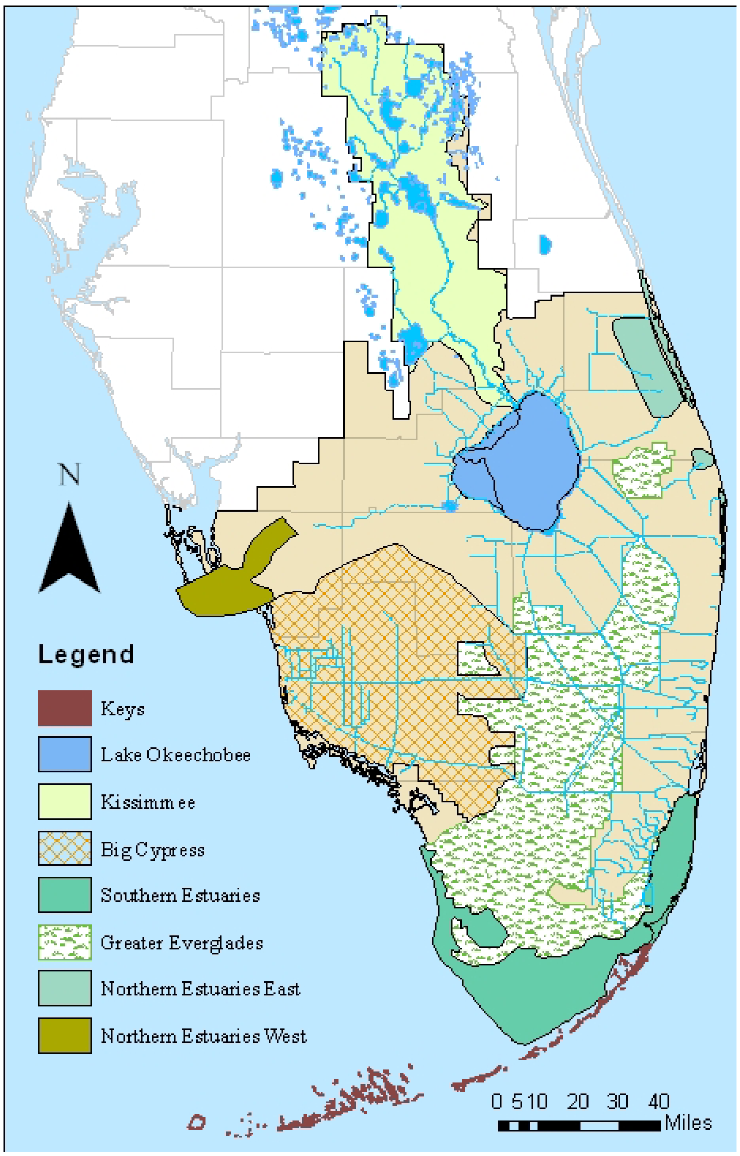

Figure 1. Map showing the RECOVER and SCG regional modules

What Does The Research Say?

Lorenz et al (2002) analyzed the extensive Roseate Spoonbill nesting data in conjunction with foraging information to determine the response of spoonbills to anthropogenic disturbances. The preponderance of scientific evidence indicated that the availability and quality of food resources have been altered by land and water management practices in and around the Florida Bay landscape. In each of five sub-regions of Florida Bay, environmental conditions initially favored nesting and effort increased over time to some sustainable level. At varying intervals, the foraging grounds in each sub-region were anthropogenically altered and spoonbill nesting effort and nest success waned at the colonies within the impacted sub-region, thereby explaining an observed boom-and-bust cycle in nesting effort through time within each sub region. The major anthropogenic perturbations to spoonbill foraging grounds have been the filling of wetlands for urban development in the upper Florida Keys and the alteration of wetland type and function along the northeast coast of Florida Bay by water management practices. A striking implication of these findings is that current water management practices in the southern Everglades have resulted in the ecological degradation of the coastal wetlands in northeastern Florida Bay. The severity of this degradation is such that the resulting impact on Roseate Spoonbills was similar in scale to the complete destruction of more than half of the suitable foraging wetlands on the Florida Keys. These data suggest that nesting Roseate Spoonbills exhibit a measurable response to water management practices in the southeastern Everglades and respond in a predictable manner, thereby making them good indicator species for the restoration of the Everglades/Florida Bay watershed.

A long term study of the roseate spoonbill prey base in northeastern Florida Bay indicated that prey fishes respond negatively to altered salinity patterns (Lorenz 1999, Lorenz and Serafy 2006) such as those that resulted from the construction and operation of the SDCS. Furthermore, the availability of prey fishes is dependent on the concentration effect that occurs when water levels within the wetland are below 12.5 cm (Lorenz 2000). Combining this prey information with the documentation of spoonbill foraging flight distance from the nest (Bjork and Powell 1994) allowed for the development of a habitat suitability index (HSI) model for spoonbills that nest on islands in Florida Bay (Bartell et al 2005). The HSI model evaluated the influence of hydrology on conditions for foraging by spoonbills in the mangrove swamps adjacent to the northeast portion of Florida Bay. The HSI model provides resource managers with a means to evaluate the benefits to spoonbills of changes to hydrologic conditions caused by changing the amount or timing of managed surface water flows through Taylor Slough and into Florida Bay. Validation of the model indicates that spoonbills respond in a predictable manor to hydrologic and hydrographic changes on their foraging grounds. Under the ATLSS modeling effort the HSI model is being adapted to develop a predictive tool that can be used to evaluate the ecological implications of hydrodynamic models (e.g. NSM) .

Why Is This Indicator Important?

1. <u>The Indicator is relevant to the Everglades Ecosystem and Responds To Variability At A Scale That Makes It Applicable To the Entire Ecosystem or Large Portions Of The Ecosystem:</u>

    - Spoonbills were abundant in Florida Bay and throughout the Southern Estuaries regional module prior to Everglades drainage

activities and have responded negatively to water management activities;
- They are top predators that share a common prey base (small demersal fishes) and foraging habitat with myriad other species;
- Spoonbills feed by tactolocation rather than visual hunting. This makes them more sensitive to perturbations than the other species dependant on the same resource (i.e., they are an early warning indicator);
- Nesting productivity is directly linked to hydrologic conditions within the Southern Estuaries;
- Nest production is linked to hydrology through the impact of water management on primary producers (e.g. periphyton, submerged aquatic vegetation) and lower trophic level consumers (i.e., prey base fishes).

3. The Indicator is Feasible to Implement and is Scientifically Defensible:

    - There are existing, funded cooperative research and monitoring programs with USFWS, ENP, USGS-BRD, USACoE, and SFWMD;
    - There is a long term data base covering over 70 years;
    - There are reliable models available to determine the impacts of water management on nesting patterns;
    - Pattern metrics (e.g. nest numbers and nesting success) are statistically correlated to Ecosystem Drivers;
    - A SESI model is being developed as part of the ATLSS modeling effort;
    - There are numerous peer reviewed journal articles;
    - This indicator is already part of the CERP RECOVER interim goals and Food-Web Monitoring Component of the CERP MAP.

3. The Indicator is Sensitive to System Drivers (Stressors)

    - Key environment Drivers (Water depth, hydroperiod and salinity) are statistically correlated to nesting success;
    - There is a causal link between hydropatterns, prey abundance and availability, and nesting success.

4. The Indicator is Integrative

    - Spoonbill nesting success is linked to fish production and in turn, fish production is linked to periphyton and SAV production;
    - Nesting responses are representative of hydrological improvement (i.e. Water Management);
    - Spoonbills are included in the CERP Food-Web Monitoring Component that includes an index of food-web function and landscape connectivity (“intactness”);
    -

5. <u>Goals and Performance Measures are established in the RECOVER MAP for the Indicator and the following metrics are being monitored:</u>

    - Number of nests
    - Distribution of nests
    - Nesting success

Discussion

The RECOVER Conceptual Ecological Models identify three major stressors to wetlands that are affecting the spoonbill nesting activities in Florida Bay. They are: 1) reduced freshwater flow volume and duration (affecting hydrology and hydrography, fish abundance and availability); 2) invasive exotic species (affecting primary producers and the prey base fish community); and 3) sea level rise (affecting habitat loss, wetland function and geomorphology, preliminary and secondary production in the prey base) (CERP Monitoring and Assessment Plan; U. S. Army Corps of Engineers 2004).

Changes in salinity patterns (primarily from changes in water volume and distribution but also exacerbated by sea level) can reduce primary production (through stresses caused by rapid and frequent fluctuations in salinity; Montague and Ley 1993, Ross et al. 2000, Frezza and Lorenz 2003). They also can alter the fish (prey base) community to a state of lower secondary production (Lorenz 1999, Lorenz and Serafy 2006). This results in an overall reduction in abundance of spoonbill prey items.

Changes in the timing and distribution of fresh water deliveries result in increased water levels on the primary foraging grounds of spoonbills nesting in northeastern Florida Bay (Lorenz 2000). Studies performed in the mangrove foraging grounds indicate that the prey base fishes begin concentrating into deeper creeks and pools when water level on the wetlands drops to 12.5 cm (Lorenz 2000). Spoonbills time nesting with falling water levels on these wetlands such that prey will be concentrated at the time of egg hatching (Bjork and Powell 1994). This provides a highly available and consistent prey resource at a time when the energetic demands of their rapidly growing young are highest. Out-of-season pulse releases resulting from upstream water management activities rapidly raise water levels above the 12.5 cm mark and fish disperse across the surface of the wetland. This eliminates the needed abundant and easily captured food resources for the spoonbills. Even brief reversal events (3-5 days) can result in total failure of the spoonbill colonies. CERP and related projects will alleviate this situation leading to higher nesting success and a return to higher nest numbers in northeastern Florida Bay.

Exotic species, both plants and animals, may impact the populations of fish and macroinvertebrates thereby affecting spoonbills. Exotic fish predators, such as the Mayan Cichlid can affect the fish community dynamics (Trexler et al 2004). This could be particularly dramatic during the dry season when populations are congregated in drying refuges (e.g. mangrove creeks and ponds) thus reducing the available prey base for spoonbills. Exotic plants may affect these prey fish populations by altering the native vegetation and hydrological characteristics of wetland areas. For example, melaleuca can replace open grassy wetlands with forest; and it is documented to raise soil levels thus reducing the area of inundation and water flow.

Longer-Term Science Needs

The techniques used to survey spoonbills are relatively well worked out. Migratory patterns are not well understood for spoonbills and need to be assessed to determine dispersal after nesting is complete. A banding program is underway to determine movements within the state but a satellite-tagging program would provide a great deal of information on international movements (e.g. Cuba, Yucatan). This would also allow definitive data on local foraging flights. Currently, we use inferences (such as flight line counts) to track where birds are feeding.

Response to Review Panel

The review panel's remarks were very helpful and will assist in strengthening the case for using Roseate Spoonbills as a system-wide indicator. The review panel listed five specific comments regarding this indicator species. The most significant comment from the Review Panel was to "define a species specific restoration goal." This glaring oversight apparently occurred in the editing phase of developing this document. The author inadvertently used targets from the "Fish and Macroinvertebrate" indicator (Trexler) and the "Wading Bird" indicator (Ogden) sections. Initially, the author used these as a template for developing spoonbill specific restoration goals. These were changed to include spoonbill specific restoration targets, however, an earlier version that still had the "borrowed" targets was accidentally submitted to the SCG, i.e., the document did not include any targets for spoonbills. This version contains the correct targets for spoonbills.
The review panels first comment (combine the roseate spoonbill indicator with the wading bird indicator) and last comment (why isn't there consistency in the metrics used for spoonbills and wading birds?) are related. Although I have no philosophical objection to combining these into a "Wading Bird" category, the differences in what is monitored for spoonbills verses wood storks and white ibis was the original reason for keeping the two separate. Spoonbills nest cryptically within the canopy of mangrove islands in Florida Bay whereas wood storks and Ibis nest conspicuously in the tops of trees throughout the Everglades landscape. Because of this difference spoonbills are not conspicuous from the air and, therefore, nesting surveys must be performed on the ground rather than the aerial surveys performed for other wading birds.

Because of these different methodologies, we use different parameters to monitor spoonbills than those used for other wading bird species. The nesting colonies are entered in order to monitor nesting effort, and we are thus able to get more accurate counts of total nests by region of Florida Bay, precise nest locations, and individual nest success through mark and re-visitation of individual nests. Because these data have been collected since 1935, these were (and are) the parameters used to demonstrate how spoonbills respond to water and land management practices.

Lorenz et al (2002) demonstrated that spoonbills had very high nest success with the majority of nests located in northeastern Florida Bay prior to the establishment of the South Dade Conveyance System (SDCS) in 1982-1984. The SDCS had a major effect on the hydrology and hydrography of the spoonbills primary foraging grounds in northeastern Florida Bay, i.e., the mainland coastal wetlands of Everglades National Park. The SDCS caused a degradation of spoonbill food resources of this region (Lorenz 1999, Lorenz and Serafy 2006), resulting in a 7 fold decline in the number of nests in northeastern Florida Bay and a 10 fold reduction in nesting success. In contrast, the aerial methodologies for other wading birds have resulted in the well documented shifts in nest timing, nesting location and the decrease in super-colonies. In short, spoonbills are monitored differently than other wading bird species resulting in differences in the metrics and restoration targets for the species.

Another reason for keeping spoonbills as a separate element of a “Wading Bird Indicator” is that they measure the health of two distinct biomes within the greater Everglades. In southern Florida, spoonbills show a distinct fidelity to estuarine habitats with approximately 90% of all nests found within Florida Bay, Tampa Bay and Indian River Lagoon (although in recent years, spoonbills have begun nesting at such inland freshwater habitats such as the Corkscrew Swamp, Water Conservations Areas and mainland Everglades National Park). In contrast, other wading birds are much more adaptable in their selection of breeding sites with a well documented switch from coastal mangrove habitats to the Water Conservation Areas in response to water management practices. Given these differences, spoonbills are an indicator for Florida Bay, the Ten thousand Islands region and, perhaps Biscayne Bay while other wading birds are indicators for central Everglades’ habitats. For these reasons, spoonbills need to remain a distinct element within the “Wading Bird” Indicator.

The two other comments from the review panel were 1) a citation was missing on page 34, and 2) justification of the concept that tactile feeders are more sensitive than visual foraging wading birds. These simple oversights by the author have been corrected in this revision of the indicator species description.

Other refinements are that the Lorenz and Serafy (in press) citation has been changed to Lorenz and Serafy 2006. More importantly, the author found a reference from 1889 (Scott 1889) which indicates that spoonbills nested “by the thousands” in extensive colonies south of Cape Romano in the Ten Thousand Islands region. This has been added as a target for restoration of this region.

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Florida Bay Submerged Aquatic Vegetation

Authors: David Rudnick and Peter Ortner

What Is This Indicator?

Florida Bay and adjacent areas of the Florida Keys and southwest Florida coastal zone contain one of the largest contiguous seagrass beds in world (Fourqurean et al. 2002). Within Florida Bay, seagrasses are the dominant biological community, covering 90% of the 180,000 ha of the bay's subtidal mudbanks and basins (Zieman et al. 1989). Submerged aquatic vegetation (SAV) is well documented as a community that serves many critical functions within estuarine and coastal ecosystems, including habitat for higher trophic level species, a base of primary production for the food web, and a beneficial influence on water quality through sediment stabilization and nutrient retention (Zieman 1982, Beck et al. 2001). A conceptual ecological model of Florida Bay (Rudnick et al. 2005), developed for RECOVER, identifies the SAV community and its structure and dynamics as being central to the health of the entire Florida Bay ecosystem – the condition of this community is an essential indicator for South Florida Ecosystem Restoration.

This SAV indicator has three components, focusing on species composition, coverage, and density of the Florida Bay SAV community. The restoration target for community composition is an increase in two species, *Halodule wrightii* and *Ruppia maritima*, that are far less common than the dominant species, *Thalassia testudinum*. With restoration, we expect greater species richness through a greater proportion of the bay. An indicator of this SAV property is the frequency of sites with at least two species (seagrass species richness, as in Fourqurean et al. 2002). Another restoration target is widespread SAV coverage with moderate density. For community coverage, the frequency of barren areas (as during seagrass die-off events) is expected to decrease as restoration actions are implemented. We expect *T. testudinum* coverage to remain largely unchanged, except for increased coverage in previous areas of "die-off" and decreased coverage in nearshore areas that are most influenced by freshwater flow. We expect other species to expand coverage into nearshore areas and other areas within the bay currently dominated by *T. testudinum*. Indicators of these SAV properties are the frequency of community cover levels (density indicated by intervals of the Braun-Blanquet cover index), individual species' cover levels, and the frequency of barren areas (Durako et al. 2002).

The basis of these indicators is described in the Florida Bay Conceptual Ecological Model (Rudnick et al. 2005), RECOVER MAP (2004), performance measures of the Florida Bay and Florida Keys Feasibility Study (www.evergladesplan.org), and the CERP Interim Goals Interim Targets Report (2005).

CERP MAP hypotheses (in the 2005 draft update) related to this indicator include:

- Changes in both salinity and water quality resulting from CERP implementation are expected to result in changes in seagrass cover, biomass, distribution, species composition and diversity through the combined and interrelated effects of light pentetration, epiphyte load, nutrient availability, asalinity, hypoxia/anoxia, sulfide toxicity, and disease

- Changes related to CERP implementation will include an expansion of areas with *Halodule* and *Ruppia* cover and a reduction in areas of *Thalassia* monoculture along the northern third of Florida Bay. Based on forecasted changes in hydrology, seagrass density and species composition in the southern two thirds of Florida Bay are not expected to change.

What Has Happened to Affect the Indicator?

Changes in the seagrass community of Florida Bay have been one of the primary drivers behind a public call for Everglades Restoration. Starting in 1987, a mass-mortality event or "die-off" propagated through much of central and western Florida Bay, denuding lush *Thalassia* beds (Robblee et al. 1991, Fourqurean and Robblee 1999). This die-off initiated a cycle of changes in the Florida Bay ecosystem, likely due to increased sediment suspension, turbidity, nutrient mobilization, phytoplankton blooms resulting in decreased light that caused additional seagrass mortality (Zieman et al. 1999, Rudnick et al. 2005). The cause of seagrass mass-mortality in the bay has been the subject of extensive research (Durako et al. 2003). Hypotheses have distinguished between proximate causes that triggered mortality during the summer of 1987 (e.g. high temperature, salinity, sulfide, low dissolved oxygen) and long-term causes that decreased the stability and resilience of the community, setting up the community for a catastrophic die-off (Rudnick et al. 2005). Long-term changes in freshwater flow was probably involved, in that decreased flow through Taylor Slough and Shark River Slough likely resulted in increased mean salinity and decreased frequency and magnitude of low salinity periods – Florida Bay became more marine than estuarine (Swart et al. 1999, Brewster-Wingard et al. 2001, Dwyer and Cronin 2001). As a result, *Thalassia*, a species that thrives under marine conditions, appears to have increased the spatial extent of its coverage and grown to an unsustainable density and biomass through much of Florida Bay (Brewster-Wingard et al. 2003; Rudnick et al. 2005), while estuarine species, such as *Halodule* and *Ruppia* decreased. It is notable that increased freshwater flow to the bay and decreased salinity in the bay in the mid-1990s, associated with operational changes and relatively high rainfall, coincided with a rebound in *Halodule* coverage and density (Durako et al. 2002).

What Areas of the Greater Everglades Does This Indicator Cover?

This indicator is specific to the southern estuaries module including Florida Bay, Florida's largest estuary, Biscayne Bay, Whitewater Bay, and other South Florida estuaries (see Figure 1). Sustaining diverse and productive seagrass beds, which constitute essential habitat for many animal species, is a common CERP goal for all estuaries.

What Does the Research Say?

Extensive monitoring, research, and modeling of Florida Bay's seagrass community has documented long-term trends in community composition and function, the influence of salinity and other factors on this community, and the central role of this community on the bay ecosystem (see Durako et al. 2003). It is clear from the research that salinity is a primary factor affecting seagrass dynamics in the Bay, but not the only factor. Statistical modeling has indicated salinity and water quality as important factors that influence the bay's seagrasses (Fourqurean et al 2003). Multifactor experiments (Koch and Durako 2005) and dynamic modeling (Madden and McDonald 2005) have demonstrated interactive effects and indicate that the effect of hypersalinity on seagrass growth and distribution is influenced by interspecific competition for nutrients. Statistical modeling of higher trophic level species has also indicated that these species benefit from the existence of SAV habitat and that the quality of this habitat matters to fauna; diverse seagrass beds (with *Halodule* and *Thalassia*) were more beneficial than monospecific beds of *Thalassia* (Bennett et al. 2005, Johnson et al. 2005).

Why Is This Indicator Important?

1. The indicator is relevant to the Southern Estuaries component of the Greater Everglades Ecosystem and responds to variability at a scale that makes if applicable to large portions of the ecosystem

    - The SAV beds of Florida Bay are the dominant form of habitat within the bay, covering almost all portions of the Bay;
    - The SAV community is central to the structure and function of the entire Florida Bay ecosystem – SAV productivity is a foundation of the food web, SAV nutrient retention and sediment stabilization sustains good water quality, and SAV habitat supports higher level species;
    - The bay is an important regional nursery for upper trophic level species - the productivity and diversity of these species in the bay and in adjacent areas depend on the bay's SAV habitat;
    - The structure and function of the bay's SAV community is sensitive to large-scale environmental management actions, such as CERP implementation, especially as these actions change salinity levels and variability over large regions.
    - SAV metrics are important performance measures within RECOVER, the Florida Bay and Florida Keys Feasibility Study, and virtually all other environmental management projects and programs in the Florida Bay region.
    -

2. The indicator is feasible to implement and is scientifically defensible:

    - A SAV monitoring program in Florida Bay has been maintained since 1995, establishing a baseline against which restoration success can be gauged;
    - Research by many agencies and universities has been coordinated, such that we have understanding of many mechanisms that influence the dynamics of SAV within the bay;

- Data have been synthesized and analyzed using statistical and dynamic models that help us understand ecological relationships, the influence of past human activities, and predict the influence of future human activities;
- A commitment to the development and application of SAV models has already been established within the Florida Bay Minimum Flows and Levels project, the Florida Bay and Florida Keys Feasibility Study, and RECOVER.
- SAV indicators have been effectively used within many other estuarine management and restoration programs, worldwide;
- Florida Bay science is coordinated and supported by numerous agencies through the Florida Bay Program Management Committee that provides long-term guidance and funding for restoration science

3. The Indicator is Sensitive to System Drivers (Stressors)

- SAV species composition and cover is statistically related to salinity and water quality in Florida Bay;
- Experimental studies and modeling have quantified this salinity relationship and mechanisms that modify salinity responses;
- Based on empirical and experimental studies, it is likely that the species composition, distribution, density, biomass, and productivity of SAV communities will change as a function of restoration.

3. The Indicator is Integrative

- Seagrasses are good indicators of environmental conditions because they integrate many highly variable aspects of the system, such as rapidly fluctuating water quality;
- Seagrasses are good integrative indicators of ecosystem status because they are so functionally important – the status of SAV is a strong determinant of the status of other entire food web components and other system attributes;
- While sensitive to system drivers, seagrass community responses generally occur on a time scale of months to years – seasonal to annual sampling is sufficient to document change.

4. Goals and Performance Measures are established in the RECOVER MAP for the Indicator and the following metrics are being monitored:

- SAV cover distribution over the entire bay (from aerial photography on a five year interval);
- SAV cover, density, species composition, and epiphyte biomass in indicator regions, annually.
- SAV cover, density, species composition, biomass, and epiphyte biomass estimates at a subset of sites near the northeastern Florida Bay coast, biannually (dry and wet season);

Discussion

Extensive discussions of the relationship of the Florida Bay SAV community to salinity and other anthropogenically influenced stressors can be found in Rudnick et al. (2005) and many of the other citations given below.

Longer-Term Science Needs

In addition to continued monitoring, further research and model development is needed is needed in order to understand cause and effect relationships and build reliable predictive capabilities. In particular, the dynamics of *Halodule*, *Ruppia*, and other SAV speices that are likely to become more common with restoration are not as well studied and understood as those of *Thalassia*. Modeling studies have indicated the importance of nutrient-salinity interactions within the benthic community and these interactions need to be quantified in order to understand and predict SAV dynamics. These interactions likely involve microbial and abiotic reactions (e.g. phosphorus-carbonate chemistry) within sediments with and without seagrass roots and also involve competition among SAV species for nutrients and light. While statistical models indicate the importance of habitat quality on higher trophic levels, the habitat value of different types of SAV beds (density and species composition, especially for *Ruppia* and nearshore species) has yet to be experimentally quantified. Dynamic SAV models, now developed for *Thalassia* and *Halodule*, need to be expanded and combined with a water quality model.

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Florida Bay Algal Blooms

Author: David Rudnick and Peter Ortner

What Is This Indicator?

Algal blooms are a major concern regarding the current and future state of Florida Bay, as well as of waters near the Florida Keys and southwest Florida coastal zone (Rudnick et al. 2005). Algal blooms decrease light penetration through the water column and thus can lead to seagrass mortality, which in turn can release nutrients and stimulate more algal blooms. This potential to propagate a negative spiral within the ecosystem (Rudnick et al. 2005, Zieman et al. 1999) elevates the importance of monitoring, research, and modeling of algal blooms and factors that may influence these blooms (PMC 2004, RECOVER MAP 2005). The role of nutrient inputs from the Everglades as a cause of Florida Bay algal blooms is not clear, but it has been hypothesized that these inputs are an important factor and increased fresh water flow with restoration could increase such blooms (Brand 2002, CROGEE 2001). While evidence in support of this hypothesis is correlative and inconclusive, it is nevertheless important to include Florida Bay algal blooms as a restoration indicator because these blooms, at the terminus of the entire Kissimmee-Okeechobee-Everglades ecosystem, could harm the Bay's adjacent coastal systems, and thus constrain upstream activities through the entire system.

The algal bloom indicator reflects overall water quality and is based on the assessment (monitoring status and trends) and evaluation (model prediction) of chlorophyll-a concentrations in the water column as a proxy of algal biomass. Based on concentrations monitored since 1991 (by SFWMD, FIU, and NOAA) and consensus among scientists reported in the CERP Monitoring and Assessment Plan (MAP) and CERP Florida Bay and Florida Keys Feasibility Study (FBFKFS) performance measures (www.evergladesplan.org/pm/studies/fl_bay.cfm) thresholds of chlorophyll-a concentrations that defines blooms of concern are 2 ppb in the eastern and southern bay, 5 ppb in the central bay, and 3 ppb in the western bay [see Boyer et al. 1997 and FBFKFS Project Management Plan (www.evergladesplan.org/pm/studies/fl_bay.cfm) for spatial boundaries]. The indicator has three components: bloom magnitude, frequency, and spatial extent as follows.

1. Magnitude: median of chlorophyll-a concentrations (ppb) that exceed the threshold value, per region per month.
2. Frequency: number of weeks (for model output) or months (for field monitoring results) per year when median concentrations exceed the threshold value, per region.
3. Spatial extent: area within a region with monthly median concentrations exceeding the threshold concentration.

The restoration target for all three components is to minimize the indicator value. We expect that improved water quality treatment of storm treatment areas combined with the sustained growth of seagrass beds (as a restoration response), nutrient availability and algal blooms will not increase (and may decrease) with restoration.

CERP MAP hypotheses (in the 2005 draft update) related to this indicator are:

- The spatial extent, duration, density, and composition of phytoplankton blooms are controlled by several factors that will be influenced by CERP. These include:
  - external nutrient loading;
  - internal nutrient cycling (seagrass productivity / die-off, sediment resuspension);
  - light availability (e.g. modified by sediment resuspension and DOM);
  - water residence time; and
  - biomass of grazers (e.g. zooplankton, benthic filter feeders).

- Through modification of the quantity, quality, timing, and distribution of freshwater, CERP implementation will affect dissolved and particulate nutrients delivered to the estuaries and alter estuarine water quality. These modifications will affect primary production and food webs in estuaries. These modifications include:
  - changes in the distribution and timing of nutrient inputs through increased flow via Shark River Slough and diversion canal flows from a ‘point source’ to more ‘diffuse’ delivery through coastal wetlands and creeks;
  - changes in the quantity of nutrient inputs to the estuaries through alteration in the mobilization and release of nutrients from developed and agricultural areas, through nutrient uptake in treatment areas, and through changes in nutrient processing and retention in the Everglades;
  - changes in the bioavailability of nutrients that depend on the quality of nutrients (e.g. inorganic nutrients versus dissolved organic matter, DOM) from the watershed and internal estuarine mechanisms (e.g. P limitation of DOM decomposition).

- Internal nutrient cycling rates (e.g., nitrogen fixation and denitrification) and biogeochemical processes, such as phosphate adsorption, will change with CERP implementation because of salinity and benthic habitat changes.

- Nutrient accumulation and retention in estuaries is affected by episodic storm events, which can export nutrient-rich sediments. CERP implementation will modify benthic habitats and nutrient loading, which will affect this export.

What Has Happened to Affect the Indicator?

The initiation of algal blooms in Florida Bay in 1991, following the seagrass mass-mortality event of the late 1980s, has been a major element of ecological change (Fourqurean and Robblee 1999, Rudnick et al. 2005). Since 1991, prolonged blooms (at least seasonal in duration) have been common in the central and western bay, with chlorophyll values frequently exceeding 5 ppb and occasionally exceeding 10 ppb (Hitchcock et al. 2003, Boyer et al. 2003). The most pronounced blooms occurred in the mid-1990s (a period of high rainfall) and following a series of tropical storms (including Hurricane Irene) in late 1999 and into 2000. Potential causes of these blooms have been detailed in Hitchcock et al. (2003) and potential links to management have been discussed in several documents (RECOVER MAP, Rudnick et al. 2005, Brand 2002).

Nitrogen inputs from the Everglades, associated with freshwater flow (Rudnick et al. 1999) are a potential link between watershed management and algal blooms in Florida Bay. It has been demonstrated that algal (phytoplankton) growth in central and western Florida Bay is frequently limited by the availability of nitrogen (Tomas et al. 1999). Freshwater flow from the Everglades is known to be a major source of nitrogen for the bay (Rudnick et al. 1999). Furthermore, the amount of nitrogen flowing into the bay from this source appears to increase with increasing freshwater flow. It is not certain that quality of this nitrogen (its "bioavailability"), which is contained in dissolved organic compounds, is sufficient to fuel algal blooms, but a positive correlation of chlorophyll concentration in central Florida Bay and annual freshwater discharge has been documented (Brand 2002). Assessment of the bioavailability of Everglades' nitrogen is part of the RECOVER Monitoring and Assessment Plan and is underway.

What Areas of the Greater Everglades Does This Indicator Cover?

This indicator is specific to the southern estuaries and Florida Bay, Florida's largest estuary that is part of the Southern Estuaries & Florida Bay Module (see Figure 1). However, the indicator is highly relevant to the assessment of other estuaries and coastal systems of South Florida and upper watershed areas included in the Greater Everglades' Module and the influence of land use and upper watershed management on the water quality of these downstream systems is of widespread concern to restoration managers and policy makers.

What Does the Research Say?

Extensive monitoring or research of the Florida Bay ecosystem has documented long-term water quality trends, including the dynamics of phytoplankton blooms (Boyer et al. 1999, Boyer et al. 2003, Hitchcock et al. 2003). Research has demonstrated that these blooms are commonly limited in the eastern bay by the availability of phosphorus, but more influenced by the availability of nitrogen in the western bay (Fourqurean et al. 1993, Tomas et al. 1999). A budget of nutrient inputs to the bay has show that the Everglades is a minor source of phosphorus, but a major source of nitrogen for the bay (Rudnick et al. 1999). However, most of this nitrogen is bound in organic compounds and its influence on phytoplankton depends upon rates at which these compounds decompose to inorganic nutrients and on the importance of other nitrogen sources and internal cycling (Boyer et al. 2003, Rudnick et al. 2005). These are all subjects of ongoing research (see Boyer et al. 2003 and Hitchcock et al. 2003 for details), which has indicated the complexity of nutrient inputs, cycling and hydrologic effects (Childers et al. 2006). Perhaps most importantly, nutrient availability is influenced generally by internal nutrient cycling and specifically by nutrient exchange between sediment and water – a consequence of shallow water depth and seagrass dominance in the Florida Bay system. Evaluating cause and effect relationships, including the influence of Everglades inputs, requires research of both external sources and internal cycling, along with data synthesis in a dynamic water quality model, which is under development as part of the Florida Bay and Florida Keys Feasibility Study.

Why Is This Indicator Important?

1. The indicator is relevant to the Southern Estuaries component of the Greater Everglades Ecosystem and reflects the wide-scale state of the Florida Bay ecosystem and adjacent waters.

    - Algal blooms in Florida Bay have been a major feature of the ecosystem since the early 1990s, reflecting a shift in the state of the system from largely benthic (seagrass) production to a system where benthic production is less dominant and less stable.
    - Algal blooms are features that have been observed to cover large areas of the central and western bay for extended periods of time (especially during summer and fall).
    - Algal blooms may be detrimental to the ecosystem, decreasing light penetration to the sediments, decreasing seagrass productivity, and propagating a cycle of seagrass mortality that leads to decreased sediment stability, increased nutrient loss from the sediments, increased algal blooms, and more seagrass mortality. This cycle can decrease ecosystem integrity and the sustainability of many bay resources (e.g. fish and shrimp) that depend on seagrass habitat.
    - While current evidence is circumstantial, the incidence of algal blooms may be related to restoration activities and needs to be carefully monitored; this indicator can be a sentinel for Florida Bay and may spur future adaptive management of upstream water resources.
    - Algal bloom metrics are important performance measures within RECOVER and the Florida Bay and Florida Keys Feasibility Study.

2. The Indicator is Feasible to Implement and is Scientifically Defensible.

    - Algal blooms have been monitored as part of the South Florida coastal monitoring program since 1991, establishing a baseline against which restoration success can be gauged.
    - Research by many agencies and universities has been coordinated, such that we have a baseline understanding of many mechanisms that influence bloom dynamics within the bay.
    - Data are being synthesized and analyzed through development of a water quality model, as part of the Florida Bay and Florida Keys Feasibility Study – model analysis will provide quantitative insights of ecological relationships,

the influence of past human activities, and help predict the influence of future human activities.
- Algal blooms have been observed in estuaries throughout the world and these blooms most commonly have been found to be caused by anthopogenic nutrient (especially nitrogen) loading – the chlorophyll a indicators of water quality have been widely utilized to assess the state of aquatic ecosystems and possible human impacts.

3. The Indicator is Sensitive to System Drivers (Stressors).

    - Algal blooms are generally known to be sensitive to nutrient inputs and may be sensitive to nitrogen inputs from the Everglades.
    - Algal blooms are likely to be sensitive to large-scale changes in the Florida Bay ecosystem with restoration – restoration of freshwater flow is expected to decrease stressor (particularly salinity) impacts on seagrass communities and grazers (e.g. bivalves and sponges), which could then improve water quality (potentially with long-term decreases in algal blooms).

4. The Indicator is Integrative.

    - Chlorophyll a in the water column of Florida bay is an excellent, integrative indicator of the bay's water quality – chlorophyll a changes likely are a response to overall variability of nutrient loading and availability and is likely a more sensitive and relevant indicator of water quality than nutrient concentrations.
    - This indicator is also reflects the overall state of the ecosystem, particularly with regard to the dominance of benthic versus pelagic components of the food web and their relative productivity.

5. Goals and Performance Measures are established in the RECOVER MAP for the Indicator and the following metrics are being monitored.

    - Monthly water quality monitoring, including measurements of chlorophyll a, are part of the MAP.
    - Algal bloom performance measures, as described here, are also included in the MAP.

Discussion

Extensive discussions of the relationship of the Florida Bay algal blooms to Everglades Restoration and other anthropogenic stressors can be found in Rudnick et al. (2005) and many of the other citations given below.

Longer-Term Science Needs

In addition to continued monitoring, further research and model development is needed is needed in order to understand cause and effect relationships and build reliable predictive capabilities. In particular, the fate and effects of dissolved organic nitrogen inputs from the Everglades and the effects of changing salinity on internal nutrient cycling (especially in sediments) needs to be assessed. Quantitative evaluations of multiple factors that will change with restoration and that may influence bloom dynamics also need to be made via model analysis (particularly with a water quality model). Such evaluations include not only the effects of changing nutrient inputs, but also the effects of changing salinity, water residence time, seagrass community cover and productivity, sediment stability, and growth of grazers.

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Crocodilians (American Alligators and Crocodiles)

Author: Frank Mazzotti and Ken Rice

What Is This Indicator?

Alligators and crocodiles (crocodilians) are critical in the food web as top predators, influencing abundance and composition of prey items (Mazzotti and Brandt 1994). The American alligator is a keystone species and ecosystem engineer creating variation in hydrological conditions that otherwise would not exist in the Everglades landscape (Palmer and Mazzotti 2004, Campbell and Mazzotti 2004). The American crocodile is a "flagship" endangered species representing the importance of freshwater inflow to estuarine health and productivity. The alligator indicator uses relative density (reported as an encounter rate), body condition, nesting effort and success, and occupancy rates of alligator holes, while the crocodile indicator uses relative density, growth and survival and to describe trends in their populations related to hydrology. These parameters are correlated with hydrologic conditions including depth, duration, timing, spatial extent, and water quality. Salinity is a critical parameter in estuarine habitats.

Crocodilians integrate biological impacts of hydrological operations affecting them at all life stages (Mazzotti and Brandt 1994, Rice et al. 2005, Mazzotti 1999, Mazzotti and Cherkiss 2003). This is important because research has linked three key aspects of Everglades' ecology to this indicator: 1) Top predators such as crocodilians are directly dependent on prey density, especially aquatic and semi-aquatic organisms. 2) 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 (Kushlan and Kushlan 1980, Palmer and Mazzotti 2004, Campbell and Mazzotti 2004). 3) The distribution and abundance of crocodilians in estuaries is directly dependent on timing, amount, and location of freshwater flow (Dunson and Mazzotti 1989, Mazzotti and Dunson 1989).

Responses of crocodilians are directly related to suitability of environmental conditions. Correlations between biological responses and environmental conditions contribute to understanding of species' status and trends over time. Positive or negative trends of this indicator relative to hydrological changes permit assessment of positive or negative trends in restoration. Restoration success or failure would be evaluated by comparing recent and future trends and status of crocodilian populations with historical population data and model predictions; as stated in the CERP hypotheses related to the alligators and crocodiles (CERP Monitoring and Assessment Plan section 3.1.2.5 and 3.1.2.6, 2004).

CERP MAP Hypotheses related to crocodilians

Alligators

- Expand the distribution of reproducing alligators and alligator holes to southern marl prairies/rocky glades and restore the keystone role of alligator holes as refugia for aquatic fauna;
- Provide salinity regimes that are suitable for expansion of reproducing alligators into oligohaline portions of estuaries;
- Sustain current populations of reproducing alligators in ridge and slough landscape.

Crocodiles

- Restoration of freshwater flows to estuaries and salinity regimes will increase growth and survival of crocodiles.

What Has Happened To Affect The Indicator?

Concerns about these indicators relate primarily to the role as top predator, keystone species and ecosystem engineer for the alligator; and as top predator, “flagship” species, estuarine dwelling, and endangered species for the crocodile. Reproduction, growth, and survival of crocodilians are dependent on food availability—birds, mammals, fish and macroinvertebrates—that, in turn are entirely dependent on hydrologic conditions. Loss of flow and relatively dry hydrologic conditions resulting from water management over the past several decades, and a loss of habitat (due partly to reduced areas of inundation increased dry downs, and increased salinization) in the Everglades have adversely affected alligators and crocodiles (Mazzotti and Brandt 1994, Mazzotti and Cherkiss 2003, Rice et al. 2004). Loss of habitat in southern marl prairies and rocky glades and reduction in depth and period of inundation of remaining areas have reduced abundance of alligators and alligator holes in these habitats (Craighead 1968). Reduced prey availability throughout the system as a result of hydrologic alterations correspond with lower growth rates, survival and reproduction of alligators (Mazzotti and Brandt 1994).

Both alligators and crocodiles have been affected by loss of freshwater flow to estuaries. This loss of flow corresponds with a reduction in distribution and abundance of alligators (Craighead 1968). Although there are more crocodiles in more places today than when they were declared endangered, virtually all of that increase is from crocodiles occupying and nesting in man-made habitats such as the Turkey Point Power Plant site (Mazzotti and Cherkiss 2003). The mangrove back-country of northeastern Florida Bay has always been considered as core habitat of the American crocodile in Florida (Kushlan and Mazzotti 1989, Mazzotti 1999). Today this physically unaltered area suffers from diversion of freshwater (McIvor et al. 1994). This area also has the lowest rates for growth and survival of crocodiles anywhere in Florida (Mazzotti and Cherkiss 2003).

What Areas of the Everglades Does This Indicator Cover?

Crocodilians cover virtually all of the Everglades freshwater wetlands and estuarine areas. These areas include the following RECOVER & SCG regional modules; Greater Everglades, Florida Bay and Southern Estuaries, Lake Okeechobee, and the Kissimmee River Basin (see Figure 1).

What Does The Research Say?

Because of the unique geographic location and subtropical climate, the Greater Everglades is the only place in the world where both alligators and crocodiles occur. The most important factors affecting distribution and abundance of these crocodilians regionally are the loss of habitat (including extent of areas inundated for both species and nesting habitat for crocodiles), hydroperiod, water depth and salinity (Mazzotti and Brandt 1994, Mazzotti 1999, Mazzotti and Cherkiss 2003, Rice et al. 2004)). Water management has changed the pattern of water levels in the southern everglades causing unnatural flooding events and mortality of alligator nests (Kushlan and Jacobsen 1990). Increasing drought frequency and depth of drying have reduced the suitability of southern marl prairie and rocky glades habitats and occupancy of alligator holes by alligators. Increasing drought frequency and depth of drying also increases the time required for fish and macroinvertebrate populations to recover to levels considered representative of the historical Everglades (Trexler et al. 2003). When drying events occur repeatedly at less than a 3-8 year intervals, fish and macroinvertebrate populations are continually recovering from past droughts and may fail to reach densities sufficient to sustain large predators such as alligators (Loftus and Eklund 1994, Turner et al. 1999, Trexler et al. 2005). This is correlated with lower growth and reproductive rates for alligators in the Everglades when compared to other parts of their range (Mazzotti and Brandt 1994). Repeated drying events may also wipe out entire age classes as alligators are forced to congregate in remaining bodies of water and suffer predation and cannibalism.

Water salinity also affects populations of crocodilians (Dunson and Mazzotti 1989, Mazzotti and Dunson 1989). Although American crocodiles are more tolerant of saltwater than alligators, both species prefer fresh to brackish water (Mazzotti 1983). The distribution of alligators in estuaries has been affected by intrusion of saltwater (Craighead 1968, Mazzotti and Brandt 1994). In northeastern Florida Bay the occurrence of alligators corresponds with the presence of freshwater (Mazzotti 1983). Regionally, lack of freshwater has been correlated with lower growth and survival of crocodiles (Moler 1992, Mazzotti and Cherkiss 2003).

In a particularly encouraging finding, Mazzotti and Cherkiss (2003) reported that after Buttonwood and East Cape canals in Everglades National Park were plugged in the 1980's to reduce saltwater intrusion into interior areas of Whitewater Bay and Cape Sable, crocodiles responded positively by increasing nesting effort and success. This suggests that restoring salinity patterns in estuaries can have a positive effect on this indicator and that monitoring is effective at determining population responses. It also indicates that nesting effort and success need to be included with growth and survival as monitoring parameters.

Models of different levels of complexity have been and are being developed for evaluation and assessment of hydrological alternatives using crocodilians. The ATLSS SESI alligator model simulates the probability of alligator reproduction across the southern Everglades' landscape based on hydrological drivers (www.atlss.org).

A simple salinity suitability model was developed to evaluated water deliveries to Taylor Slough/C-111 (Mazzotti and Brandt 1995). More sophisticated models are being developed for both species. An alligator production model has been developed that combines the alligator SESI model with functions for growth, dispersal, and survival to produce forecasts for nesting and relative density suitable for assessment of hydrological alternatives (Slone et al. 2003). An estuarine super-model combining the SICS hydrologic model with ALLFISHES, and models for spoonbills and crocodiles also is planned.

Why Is This Indicator Important?

1. The Indicator is relevant to the Everglades Ecosystem and Responds To Variability At A Scale That Makes It Applicable To the Entire Ecosystem or Large Portions Of The Ecosystem:

- No single species is more typical of the Everglades ecosystem than the American alligator;
- Alligators and crocodiles are characteristic of all Everglades' freshwater and estuarine wetlands;
- They are top predators that affect prey populations of all sizes;
- Productivity of populations and body condition of individuals is directly linked to hydrology;
- Alligators are a keystone species and ecosystem engineer. By constructing nests, trails, and holes, they provide drier and wetter conditions for species of plants and animals that otherwise would not be able to survive;
- Crocodiles are a flagship species for southern estuaries, representing the importance of restoring freshwater flow;
- Population measures (relative density, nesting, occupancy of alligator holes, growth, and survival) are key outcomes (performance measures) in RECOVER Conceptual Ecological Models and in CERP Interim Goals.

2. The Indicator is Feasible to Implement and is Scientifically Defensible:

- There are existing, funded cooperative research and monitoring programs with UF, USGS, USFWS, USNPS, USACOE, and FFWCC;
- There are both long and short term data bases covering over 25 years for some parameters;
- There are reliable models available to determine impacts of water management on these populations;
- There are peer reviewed journal articles and book chapters;
- This indicator is already included in the CERP RECOVER interim goals and Food-Web Monitoring Component of the CERP MAP.

3. The Indicator is Sensitive to System Drivers (Stressors)

- Key hydrological drivers/stressors (Rainfall, Hydropattern, Salinity) are correlated to species distribution, abundance, body condition, growth and survival;

- Distribution and abundance of crocodilians in estuaries is limited by freshwater;
- Nesting of alligators and crocodiles has been statistically correlated with regional hydrological conditions (water levels and rainfall).

4. <u>The Indicator is Integrative</u>

- As top predators in the Everglades, crocodilians integrate productivity throughout the trophic web;
- Species responses are representative of hydrologic improvement (i.e. Water Management);
- Improvements in indicator populations will result in increased aquatic refugia (alligator holes and trails) for all aquatic species in the system.

5. <u>Goals and Performance Measures are established in the RECOVER MAP for the Indicator and the following metrics are being monitored:</u>

- Number of animals per kilometer
- Size and sex structure
- Number of nests
- Growth and survival

  Occupancy rates of alligator holes

Discussion

RECOVER Conceptual Ecological Models identify three major stressors to wetlands that are affecting populations of alligators and crocodiles: water management practices (affecting hydrology); agricultural and urban development (affecting habitat loss and hydrology); and decreased freshwater flow to estuaries (affecting salinity regimes) (CERP Monitoring and Assessment Plan 2004).

Conversions of large areas of short-hydroperiod wetlands (marl prairies) east of Everglades National Park and the Water Conservation Areas into agricultural and urban uses represents a large regional loss that populations of alligators and other aquatic fauna once inhabited. This loss due to irreversible land-use changes has had a major impact on both distribution and abundance of alligators.

Relative density (encounter rate), growth, survival, condition and nesting of alligators are affected by the duration, and frequency of droughts. The reduction of hydroperiod resulting from long-term water management changes has artificially limited prey densities and size structure in Everglades' wetlands for many decades. Unnatural seasonal releases of water into Shark Slough and impoundment of water in the WCA's have caused loss of nests due to drowning of eggs. Restoration of areas of the southern Everglades (eastern portions of Everglades National Park) that have been over-drained for many decades and restoration of natural patterns of water level fluctuations in remaining area is needed.

Additional hydrological restoration should aim at restoring natural patterns of freshwater flow to estuaries. Research and modeling indicates that this would improve habitat conditions for both species of crocodilians. For alligators, this means increased relative abundance and nesting. For crocodiles, this means increases in relative abundance, growth, survival and nesting.

Although not in conceptual models, exotic species, both plants and animals, may impact populations of crocodilians. Exotic plants may affect alligators by altering native vegetation and hydrological characteristics of wetland areas. For example, melaleuca can replace open grassy wetlands with forest; and is documented to raise soil levels thus reducing the area of inundation and water flow. Exotic plants may affect crocodiles by limiting access to nesting substrate. The non-native caiman. Although currently restricted to man-made bodies of water, has not yet posed any threat to alligators or crocodiles. However, Burmese python breeding is documented within Everglades National Park and adjacent areas and there have been five reported encounters between pythons and alligators. The results of these encounters have been mixed (Snow et al. in press), and the long term effect of interaction between these two top predators is unknown.

Longer-Term Science Needs

Basic biology of alligators and crocodiles in the Everglades and methods to monitor their responses to hydrologic management effectively, are relatively well understood. Continued work is needed to improve the reliability of monitoring techniques in all habitats, to calibrate existing models and develop new ones, and to better understand the impacts of canals and levees to improve assessments of the effects of de-compartmentalization (removal of canals and levies in the interior of the Everglades' wetlands) on these two species. Existing monitoring programs and projects need to continue to capitalize on developing time-series information on these animals so it can be used to assess impacts.

Current monitoring techniques for relative density of crocodilians use airboats in freshwater habitats and outboard motorboats in mangrove environments. While these techniques are excellent for much of the Everglades, there are limitations. In particular, neither technique can be used effectively in the Rocky Glades during the dry season, cypress swamps, or in any wilderness area. Helicopter and other survey techniques for sampling in these landscapes are not well established by studies and need to be developed, especially for occupancy rates of alligator holes. Techniques for surveys for alligator nests in marshes of Everglades National Park have been established buy may not be suitable for use in other parts of the Greater Everglades Ecosystem. This is unfortunate because access to these areas is critical for research and monitoring of alligators and crocodiles and is invaluable for assessment and evaluation.

Prior to the establishment of pythons, alligators were the only large, abundant, widespread aquatic predator in Greater Everglades ecosystems. The occurrence of interactions between these species has been well documented. Research is needed to determine what the long-term consequences may be.

Response to the Independent Scientific Review Panel's Comments

We were concerned that the peer review panel recommended that alligators and crocodiles should not be used as system-wide indicators for Everglades' restoration. We feel that crocodilians will make good system-wide indicators and we offer the following comments and thoughts in addition to providing the ecological basis for inclusion of these species in the suite of system-wide indicators for restoration.

The comments of the peer review panel regarding the use of crocodilians suggests a lack of an intimate awareness and understanding of how people perceive and relate to alligators and crocodiles in the Everglades and their value for communicating to managers and policy-makers. Alligators and crocodiles are the charismatic mega-fauna of the Everglades. No other species seem to capture the imagination of the public, or symbolize the Everglades, as do crocodilians, often called the "Lords of the Everglades."

It appears that more people go to the Everglades to see alligators than anything else. The first thing visitors to the Everglades often ask is, "where can I see an alligator?" As noted by the reviewers, public interest and awareness are very important especially for communicating system-wide indicators. These species have already captured the hearts and minds of managers as well as the public and are strongly associated with the Everglades. It seems wise to capitalize on these existing impressions.

If crocodilians were not good ecological indicators, or if the indicator were difficult to understand or communicate then we would agree that perhaps they could be removed. However, they are good indicators because there are well-established relationships with environmental parameters that are under management control. In addition, the metrics (health and condition, relative density, and nesting success) are remarkably easy to understand and communicate. The first MAP Annual Assessment Report for Alligators and Crocodiles nicely summarizes the most recent advancements for both alligators and crocodiles (CITATION?) and we have included the executive summary of this report with these comments (WHERE IS IT?). The concepts of alligators in poor condition, crocodiles that survive more or grow less, nests that fail to hatch, and numbers of animals are all real concepts, with meaning to managers. Tracking improving or declining conditions due to restoration activities with these metrics we believe is easily communicated.

Crocodilians have a proven record of accomplishment for galvanizing the actions of managers. Recently, failure of the plug in East Cape Canal led to salinization of oligohaline interior wetlands. These wetlands provide habitat for forage fish, sport fish, Roseate Spoonbills, and American crocodiles. Although the impacts of salinization would be negative for all of the above groups, the endangered, charismatic crocodile was the species that spurred managers to respond.

Finally, we are looking for defining characteristics of the Everglades. Just as surely as there is no other Everglades, no other single species defines the Everglades, as does the American alligator. The Everglades is the only place in the world where both alligators and crocodiles exist. These species clearly respond to changes in hydrologic parameters of management interest. These relationships are easy to communicate and mean something to managers, decision-makers, and the public. Removing crocodilians from the list of system-wide, general indicators would deprive us of a powerful tool to communicate progress of ecosystem restoration in the Greater Everglades Ecosystems.

The reviewers may not have been as familiar with the detailed information on past and present studies of alligators and crocodiles and may not have adequately considered the importance of including indicators that reflect ecosystem response over several different spatial and temporal scales. The SCG indicator committee felt is was critical that indicators that cover several spatial and temporal scales be included in the suite of indicators for Everglades' restoration (see Figure 1b).

Specific responses to the individual reviewer's comments.

Crocodilians

1. The crocodilian indicator could be eliminated.

2. SAV is an effective indicator of hydrology and water quality (including salinity).

> Response: We agree that SAV may be effective indicators of water quality but do not replace crocodilians as indicators of salinity regimes in Everglades' estuaries. They are not necessarily "better" indicators. The relationships between salinity and SAV metrics or performance are not better known than those for crocodilians, and we do not have any better capability to forecast responses to ecosystem changes using SAV. Also, since the term SAV is not well defined, is different for different regions and habitats, and is sometimes unclear to mangers, communication of the concept seems less simple and clear. While we as ecologists agree that SAV are valuable indicators, the value and importance of SAV as an indicator for restoration will need better development and more refined communication tools to build a clear understanding for managers and policy-makers. This understanding already exists for managers and policy-makers in regard to crocodilians.

3. Fish are an effective indicator of hydrology.

> Response: We agree, however just as with SAV, fish are not "better" indicators than crocodilians. Crocodilians integrate hydrological processes over different spatial and temporal scales than fish. One of the critical elements of developing this suite of indicators was integration of the many individual indicators to create a "top-of-the-mountain" view of restoration. The integration of information from fish, SAV, crocodilians and other indicators improves the power and better communicates the interconnectedness of the ecosystem components.

4. Wading birds are a top predator and a better integrator of ecosystem function than crocodilians.

> Response: We agree that wading birds are good indicators of ecosystem function. However, wading birds may spend half of the year outside of the Everglades' region, are extremely vagile, and feed over large urban and agricultural areas. While they are good ecological indicators overall, for these reasons they cannot be considered "better" indicators. In addition, crocodilians and wading birds integrate ecosystem function over different spatial and temporal scales and thus make complementary indicators.

5. Crocodiles are too narrow an indicator by which to judge CERP progress.

> Response: We agree. This is why it is a crocodilian indicator. By combining the 2 species, the entire spatial extent of the Everglades is covered, only a few of the other indicators have this ability.

6. Alligators are too ubiquitous and adaptable to judge CERP progress.

> Response: We think that species that are ubiquitous make good indicators. They are much more representative of the entire ecosystem, yet may show change regionally potentially pointing out significant regional effects of management. We also find no ecological basis for considering a ubiquitous species a poor indicator. Being ubiquitous means that since an indicator is found throughout a system it can be used to compare progress, or lack thereof among different parts of the system. Adaptability means that an indicator will change within a system in response to system changes. We feel that both of these aspects are good attributes of an indicator.

7. Longer-term identified science needs should be addressed, including development of improved survey techniques for alligator nests in other areas of the Greater Everglades System beyond the marshes of the Everglades National Park, and assessment of impacts on alligator populations from non-indigenous pythons.

> Response: Longer-term science needs, including improved survey techniques for alligators and their nests have or are being conducted as part of the CERP MAP. Studies of pythons and their impacts are also being initiated as a CESI project.

8. What data bases are available for what years?

> Response: This information is reviewed in the text and the references are provided in the literature cited for the indicator template. For crocodiles, we have a database extending from 1978 to the present that can be used to analyze relative density, growth, survival, and body condition. The data on crocodile nesting extends back to 1970. For alligators, there is a current database on spotlight and capture surveys that extends 6 years and data

from Everglades National Park collected between 1977-1980 and 1986-1991, 1995.

9. Why isn't reproductive success a metric?

Response: Reproductive success in crocodilians is not a measure of performance because there is no system-wide method to monitor it.

10. Although the creation of runs and holes is given as an important aspect of alligator ecology, there is no metric to examine this aspect.

Response: This is a good point as we have a metric for occupancy of alligator holes but not for number or density of holes. We do have the database to address the spatial density of holes as a metric in Everglades National Park and will consider developing these data for future use with this indicator.

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American Oysters

Authors: Aswani Volety, William Arnold, Tomma Barnes and Patricia Sime

What is this indicator?

The eastern oyster once supported a Native American subsistence fishery prior to and during early European colonization of North America. Throughout recent history it has provided an important economic and cultural resource to coastal inhabitants. While not commercially harvested in the northern estuaries, oysters provide essential habitat for many other estuarine species such as crustaceans and fish that have a significant recreational and commercial value. In addition, oysters improve water quality by filtering particles from the water and serve as prey and habitat for many other animals.

In the Caloosahatchee, Loxahatchee and St. Lucie Estuaries, oysters have been identified as a “valued ecosystem component” (Chamberlain and Doering 1998a, b). Oysters are natural components of estuaries along eastern sea board of the US as well as the Gulf of Mexico and were documented to be abundant in the system. The American oyster is the dominant species in these oyster reef communities. Oyster bars provide important habitat and food for numerous estuarine species including gastropod mollusks, polychaete worms, decapod crustaceans, various boring sponges, fish and birds. Over 300 macrofaunal species may live in oyster beds and over 40 species have been documented to inhabit a single oyster bed (Wells 1961). Oysters are also an important commercial and recreational resource.

Salinity is important in determining the distribution of coastal and estuarine bivalves. Adult oysters normally occur at salinities between 10 and 30 parts per thousand (ppt) but they tolerate a salinity range of 2 to 40 ppt (Gunter and Geyer 1955). Occasional, short pulses of freshwater inflow can greatly benefit oyster populations by reducing predator (e.g., oyster drill, whelk) and parasite (e.g. *Perkinsus marinus*) impacts (Owen 1953), while excessive freshwater inflows may kill entire populations of oysters (Gunter 1953, Schlesselman 1955, MacKenzie 1977; Volety et al. 2003, Volety and Tolley 2005).

The organism density, biomass, and richness of reef resident organisms such as crustaceans and fishes are greater in oyster reefs compared to the sand-bottom (Tolley and Volety (In press, 2005). Therefore freshwater or habitat alteration unfavorable to oysters will result in decreases in the extent of oyster reefs and filtration associated water quality, but also the species residing on the oyster reefs.

The implementation of the CERP Monitoring Assessment Plan (MAP) will help us understand and determine how well the Comprehensive Everglades Restoration Plan (CERP) is meeting its restoration goals and objectives. The premise of CERP is that restoring hydrology in the estuaries described above will improve the spatial and structural characteristics of oyster reefs and improve the recruitment and survivorship of the Eastern oyster (*Crassostrea virginica*), and associated reef-resident and transient organisms. The measurements and hypotheses being tested below are a result of a conceptual model of stressors that impact oysters and oyster reefs and secondary habitat. Predictions of oyster reef development following implementation of CERP are made by using a Habitat Suitability Index (HSI) model described in the subsequent paragraphs (Volety et al. 2005). While not all the factors that influence oysters and their responses are being measured in the proposed study, their role in the success of oyster reefs in these estuaries will be examined based on the need and predictability of the HSI model employed. Factors that are not currently examined but may have potential influences on oysters and those that may be examined at a later time are indicated by dashed boxes in the conceptual model (see Volety et al. 2005).

Restoration of more natural freshwater inflows (retention in reservoirs, wetland rehydration, and changing delivery patterns), removal of muck, and introduction of artificial substrate into south Florida estuaries, as a result of CERP implementation, should provide beneficial salinity and habitat conditions that promote the re-establishment of healthy oyster beds.

CERP MAP Hypotheses related to American oyster indicator

- Undesirable shifts in the estuarine salinity envelope result in decreased survival, reproduction, spat recruitment, growth and increased susceptibility to diseases by Perkinsus marinus and MSX.

  Rationale. Large rainfall events or large volume releases from Lake Okeechobee cause large volumes of freshwater over a short period of time to enter the estuaries causing a sudden drop in salinity. This sudden drop can lead to significant mortality in the oyster population, and decreased growth, reproduction, and spat recruitment . Extreme droughts can also negatively impact oysters by making them prone to disease and predation.

- Accumulation of muck (high organic content depositional matter) on available substrate or nearby areas will make substrate unsuitable for oyster larval settlement and thus recruitment and growth of larval oysters. In addition, accumulation of muck may also impact dissolved oxygen content making the area / substrate unsuitable for larval settlement and growth.

  Rationale. Oyster recruitment is negatively effected by the accumulation of mucky sediments in the estuary. Muck is unsuitable substrate for spat settlement. Areas that once contained sand and/or shell have been covered by these very soft, unconsolidated sediments. Freshwater releases from the Lake and inland canals carries sediments with silt, clay and high organic content soils. Freshwater inflow from canals can also result in an increase in the transport of floating aquatics, which then decompose and contribute to the rate of muck accumulation.

- Increased sediment loads in the water column impair respiration and feeding of oysters resulting in decreased growth and condition index of oysters. In addition, sediment accumulation negatively affects spat recruitment.

  Rationale. Oyster populations are affected by increased sediment loads resulting from alterations to the natural hydrology. Adult oysters have effective morphological adaptations for feeding in much higher levels of suspended solids than are usually encountered under normal conditions. Oysters from relatively turbid estuaries appear to be capable of feeding in waters with total suspended solid concentrations as high as 0.4 g/l. However, this significantly reduces their pumping rates to as low as 0.1 g/l. Suspended solids may clog gills and interfere with filtering and respiration of oysters.

- Increase in oyster reef coverage will enhance secondary habitat for other estuarine species resulting in increased diversity and abundance.

  Rationale. Oysters are natural components of south Florida estuaries and are documented as having been abundant in the historical system. Although currently less abundant, they continue to be important. Reduction in oyster coverage was largely due to altered freshwater inflow, shell mining, and changes in hydrodynamics. These perturbations have resulted in a loss of oyster reef community and the estuarine species that use oyster habitat.

What has happened to affect this indicator?

Water management and dredging practices have had a major impact on the historical presence, density and distribution of oysters within the mesohaline areas of northern and southern estuaries modules. Historically, rainfall was retained for long periods (a year or more) in the Everglades' wetland systems where it gradually percolated into the groundwater, evaporated or flowed out to tide through tributaries. As south Florida developed, the canal network, built as a result of the Central and Southern Florida Flood Control project, worked too efficiently and drastically altered the quantity, quality, timing and distribution of fresh water entering the estuaries. Freshwater flows (usually as flood releases) into the estuaries and their tributaries increased both in volume and frequency relative to the pre-drainage era. This caused rapid (often within a few hours) reversals in salinity resulting in degradation of biological integrity of the estuaries. Additionally, flood releases and inland runoff contain numerous different contaminants from urban and agricultural development including excess suspended solids, nutrients, pesticides, and other Emerging Pollutants of Concern (EPOCs) such as hormones and pharmaceuticals. This results in poor quality water entering the estuaries and significant alterations in timing, frequency and quantity of flows to the estuaries. Inflows also are too great in the wet season and too little in the dry season to support a healthy estuary. Detailed descriptions of the estuaries and specific alterations and environmental threats to oysters in these estuaries is presented in the appendix to this indicator.

What areas of the Everglades does this indicator cover?

Oysters cover the estuarine portions of the northern and southern estuaries. These areas include northern estuaries (Caloosahatchee , St. Lucie, Loxahatchee, and Lake Worth Lagoon), southern estuaries (White water estuary, Shark River, Coot Bay, oyster Bay, and areas of the Ten Thousand Islands) (see Figures 1 and 2).

What does the Research Say?

Although Caloosahatchee estuary (see Figure 2 and appendix figures) is used as a specific example below, similar water quality concerns are present in the Northern and Southern estuaries given the similarities in watershed alteration. The Caloosahatchee River is the major source of freshwater for the Caloosahatchee Estuary (CE) and southern Charlotte Harbor aquatic environment. The river, which has been turned into a canal (C-43) that conveys both runoff from the Caloosahatchee watershed and regulatory releases from Lake Okeechobee, bisects the estuaries watershed. The canal has undergone a number of alterations to facilitate this increased freshwater discharge and flood protection. These alterations include channel enlargement; bank stabilization; the development of an intricate network of ancillary canals within the watershed; and the addition of three locks and dams. The final downstream structure, Franklin Lock and Dam (S-79), demarcates the beginning of the estuary, and acts as a barrier to salinity and tidal action, which historically extended much farther inland.

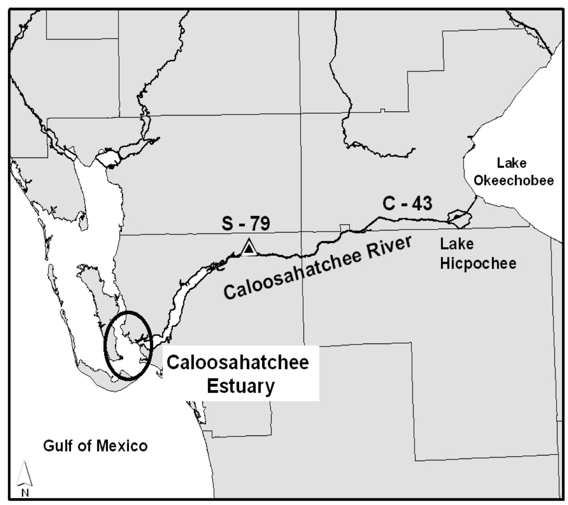

Figure 2. The Caloosahatchee estuary.

Alterations to the Caloosahatchee River and watershed have resulted in a drastic change in freshwater inflow to the downstream ecosystem. The resulting large fluctuation of salinity and water quality adversely impact estuarine biota (Chamberlain and Doering 1998a; Sklar and Browder 1998).

The dominant biological features in the San Carlos Bay area of the estuary are its numerous mangrove islands and many kilometers of mangrove shoreline, which are often closely associated with oysters. Because of its biotic richness and aesthetic appeal, San Carlos Bay supports a wide variety of recreational and fishery activities and generates significant economic value. The natural resources of this area are also impacted by large freshwater releases and are threatened by long-term shifts in water quantity and quality (Chamberlain and Doering 1998b; Doering et al. 2002; Volety et al. 2003). Under the current water management practices, the estuarine portion of the river is essentially fresh due to freshwater releases and runoff from summer wet season rains.

During the dry season freshwater releases are halted and the estuary become hypersaline because of the combination of shallowness of the estuary and evaporation. Freshwater releases during summer months result in flushing of oyster larvae to downstream locations that have unsuitable substrate or create salinity conditions that are unfavorable for larval survival in the estuarine portions of the river. Recruitment of oyster larvae to the estuarine portions is occurring only at the very end of the spawning season (Oct / Nov) when salinity conditions are in the tolerable range This is at least keeping the oyster populations at their current low levels (Volety et al. 2003)

Recent environmental investigations in the CE have resulted in an estimate of the optimum quantity of water needed by the CE to protect key biota. These species, or Valued Ecosystem Components (VECs), help sustain the ecological structure and function of the estuary by providing food, living space, and foraging sites for other naturally occurring estuarine species. Oysters and submerged aquatic vegetation (SAV) represent VECs in the CE. Proper management (frequency, timing, quantity and quality) of water releases to the estuary will protect these species and should lead to restoration of healthy and diverse estuarine ecosystems.

Research results reported by Volety et al. (2003) further demonstrated the importance of Crassostrea virginica (American oyster) as a VEC. They found that a greater abundance of decapods and fishes were associated with clusters of live oysters compared to dead-articulated clusters, while the structure provided by both living and dead oysters shells supported a greater abundance than no shells. Species richness and dominance were higher for samples with oyster clusters (dead or live) compared to controls with no oyster shell. This study suggests that the real significance of living oysters to habitat value lies not only in creating a three-dimensional structure, but also in maintaining this structure of clusters through time. Individual oysters within a cluster or bed may die, leaving empty compartments for reef residents, but mass mortality of a cluster results in the disarticulation and eventual loss of the oyster shells (Volety et al. 2003).

Volety et al. (2003) in field and lab research evaluated the survival of oyster adults and juveniles, as well as oyster health that include the prevalence and intensity of disease, and oyster recruitment success. The results were compared to environmental factors, including salinity and freshwater flow from S-79. Oysters grow best at a salinity of 14 to 28 parts per thousand (ppt). Infection by the oyster pathogen, Perkinsus marinus, increases during higher salinity and temperature. Field studies during this research determined that the prevalence of infection was high, but disease intensity was low, because temperature and salinity act antagonistically (i.e., high summer temperature occurs during the wet season and lower salinity). Therefore, freshwater releases to diminish Perkinsus marinus are generally not advised during warm summer months because of the potential threat to oyster populations from further lowering salinity.

The greatest oyster growth and recruitment occurs during the wet season, but slower growth, poor spat production, and excessive valve closure occurs at salinities below 14 ppt. During their study, salinity conditions were best suited for oyster growth just upstream of Shell Point. However, this upstream area is also the most vulnerable to high mortality when large releases cause salinity to fall below threshold tolerance, sometimes for prolonged periods. The Volety et al. (2003) report suggests that adult oysters are tolerant of variable salinity, salinities 5 ppt or lower will result in > 95% mortality of juvenile oysters. High juvenile mortality can occur when exposed to this salinity for just a week.

Experimental results indicate that adults are able to tolerate salinities as low as 5 ppt up to 8 weeks, but can not tolerate salinities lower than 3 ppt, which can occur upstream of Shell Point when S-79 discharges exceed 4,000 cubic feet per second (cfs). Therefore, high discharges can limit population survival and abundance in this region where oysters were historically present. Volety et al. (2003) indicated that because of high spat recruitment at intermediate salinities, along with good growth rates and low disease, it is feasible to reestablish oyster reefs upstream of Shell Point by strategically replacing oyster clutch in suitable areas, as long as freshwater releases are managed within oyster tolerances.

Oysters in southwest Florida spawn continuously, with peak recruitment (spat settlement) occurring during May to November. Recruitment near Shell Point and possibly upstream begins to peak in March, a full 3 months earlier than in San Carlos Bay, thus making these newly settled juveniles vulnerable to large releases from S-79, which have often occurred during this period to regulate Lake Okeechobee water level for flood protection. Large freshwater flows at this time and during the summer also expose oyster larvae to lethally low salinities, or flush the larvae to more downstream locations where there may not be suitable substrate for settlement.

The northern estuaries oyster indicator targets are based on optimization model outputs, natural variation that would occur during the period 1965-2000, and desirable salinity conditions for existing and potential aquatic resources. Targets for the CE are based on freshwater discharges from the C-43 canal at the S79 structure where the mean monthly inflow should be maintained between 450 and 2,800 cfs. Targets were developed to reduce minimum discharge and high flow events to the estuary to improve estuarine water quality, protect, and enhance estuarine habitat and biota.

Low Flow

The low flow target is no months during October to July when the mean monthly inflow from the Caloosahatchee watershed, as measured at S79, falls below a low-flow limit of 450 cfs (C-43 basin runoff and Lake Okeechobee regulatory releases).

High Flow

The high flow target is no months with mean monthly flows greater than 2,800 cfs, as measured at the S79, from Lake Okeechobee regulatory releases in combination with flows from the Caloosahatchee River (C-43) basin.

Frequency and Rates of Flows
The frequency distribution of monthly average freshwater inflows through S-79 for the entire period of record has been found to be important for protecting and restoring estuarine resources, while further promoting biotic diversity. Approximately 75% of the flows from S-79 should be in the 450-800 cfs range and most of the remaining inflow should be in the 800 to 2800 cfs range.

Lake Okeechobee Regulatory Releases
The alternative with the least daily discharge volume, the fewest number of total days of discharge, and the fewest number of consecutive days is preferred. Special considerations are provided for pulse releases that are for the benefit of the estuary.

Optimal flows in the Caloosahatchee estuary
Volety et al. (2003) recommended freshwater inflows for the protection and enhancement of oyster recruitment and survival around Shell Point and San Carlos Bay, which are consistent with the flows outlined above and for SAV. Flows between 500 and 2000 cfs would result in salinities of 16-28 ppt at all stations, conditions that are favorable to sustain and enhance oyster populations in the Caloosahatchee Estuary. Under current water management practices, oysters in the Caloosahatchee are not stressed by low flows of < 300 cfs from S-79. However, complete cessation of discharges during the winter will increase salinities in areas normally associated with lower salinity, and result in the migration of marine predators and pests. They further speculate that oyster spat recruit to downstream areas also will be exposed to higher salinity and heavy predation pressure resulting in very little survival. However, the greatest threat to oysters under current water management practices is due to high flows that exceed 3,000 cfs for extended periods (2-4 weeks). This is especially true for summer months during peak spawning, juvenile recruitment, and oyster growth. Volety et al. (2003) recommends that until the complete implementation of the CERP project while freshwater releases may still be necessary, repeated pulses of < 1 week duration during winter months be made instead of sustained releases of freshwater during summer or winter months. Interpretation of these results also indicates that such pulses would be least damaging during December through February, before increased spawning and recruitment begins at upstream locations. Salinity preferred by oysters will be maintained if the target flow frequency distribution is achieved, especially if 75% of the flows are between 450 and 800 cfs.

Why is this indicator important?

1. The indicator is relevant to the Everglades Ecosystem and responds to variability at a scale that makes it applicable to the entire estuarine portions of the ecosystem:

   - Oyster life cycle is typical of other estuarine species and hence water quality conditions that influence oysters similarly influence other estuarine species;
   - Oyster reefs provide habitat, shelter and food for over 300 species;
   - Oyster reefs are the primary components that link pelagic phytoplankton / detritus food source with the benthic fauna via deposition of mucus and uneaten food material on the floor – benthic-pelagic coupling;
   - Primary consumers that rely on phytoplankton that forms the base of food chain in the estuaries areas of the Everglades as well as other estuaries;
   - Productivity and community structure are directly linked to the hydrology and oyster reef survival and morphology;
   - Crustaceans and fishes that are residents and transients of oyster reef communities provide critical prey for secondary and tertiary carnivores such as fish and birds;
   - Oyster reef survival, distribution and abundance are key outcomes (performance measures) in most RECOVER Conceptual Ecological Models and in CERP Interim Goals;

2. The indicator is feasible to implement and is scientifically defensible:

   - There are existing funded cooperative research and monitoring programs with Florida Gulf Coast University and the Florida Fish and Wildlife Conservation Commission;
   - There is relatively long-term data base spanning over 6 years for some sites;
   - There are reliable models and scientific studies to determine the impacts of water management on these populations;
   - Pattern metrices (e.g. abundance, density, survival, spat recruitment, disease prevalence, condition index etc.) are statistically correlated to ecosystem drivers;
   - Oysters are included as part of the CERP Habitat Suitability Index Model (Volety et al. 2005).
   - There are numerous peer-reviewed journal articles about oysters and their responses to stressors;
   - This indicator is already a part of the CERP RECOVER interim goals and a component of the CERP MAP.

3. The indicator is sensitive to System Drivers (Stressors)

   - Key environment drivers (rainfall, water quantity, water quality, sediment loads) are statistically correlated to species abundance and indicators of oyster health;
   - High and low salinity estuaries have distinct oyster abundance, distribution and health responses;

- Oyster abundance, density, survival and health indices are causally linked to hydrological factors (water salinity, frequency of killing floods, sedimentation and contaminants in the water).

4. The indicator is integrative:

- Oyster survival, abundance and distribution is linked to water quality, phytoplankton production, sedimentation, and in turn crustacean, fish and bird success is linked to oyster reef health and abundance;
- Oyster reef and reef resident organism responses are representative of hydrological improvement (i.e. Water Management);
- Oysters are included in the following CERP RECOVER products; Interim Goals, all estuarine Conceptual Ecological Models, all estuarine module team assessments, and as a major Performance Measure for both RECOVER and many estuarine linked CERP project plans.

5. Goals and Performance measures are established in the RECOVER MAP for the indicator and the following metrices are being monitored.:

- Number of live oysters per square meter
- Number of acres of oyster reefs
- Condition index of live oysters
- Disease prevalence and intensity of Perkinsus marinus in oysters
- Larval / spat recruitment and reproductive potential
- Temperature and salinity of water near the reefs.

Discussion

The RECOVER Conceptual Ecological Models identify three major stressors that affect the success of American oysters (and associated invertebrate and vertebrate species): altered habitat (affecting habitat loss, hydrology, water quality), altered water management resulting in altered hydrodynamics (affecting hydrology and water quality) and sedimentation (affecting habitat loss) (CERP Monitoring and Assessment Plan 2004).

Land development around the watersheds of the northern (and southern) estuaries represents a large loss of habitat given the watershed runoff and resulting low salinities as well as poor water quality (contaminants, bacteria, sedimentation). This loss has had a major negative impact on oyster reefs and thus indirectly and directly impacted macroinvertebrate and fish species.

Water management activities within the watersheds of these estuaries resulted in significant alterations in the timing (excess wet season and insufficient dry season water flows), distribution (water now flows through canals instead of overland), volume and quality of water flow into these estuaries. Channelization and water control structures have reduced the ability of these systems to filter nutrients and have further degraded water quality. These impacts reduce the ability of the watershed to provide water storage, dry season flows, water quality treatment, and fish and wildlife habitat.

Pre-drainage estuarine systems received freshwater inflow primarily from direct rainfall and slow basin runoff that resulted in low nutrient inputs. These natural patterns of freshwater inflow sustained an ecologically appropriate range of salinity conditions with fewer salinity extremes. Water management and dredging practices have major impacts on the presence of oysters within these estuaries. CERP projects that will restore more natural freshwater inflows into the estuaries will provide beneficial salinity conditions, a reduction in nutrient concentrations and loads, and improved water clarity that will promote the reestablishment of healthy oyster bars and associated communities. These stressors and attributes are described in the conceptual ecological models in the RECOVER MAP.

Adult oyster density, substrate availability and suitability for larval oyster spat recruitment, disease intensity and prevalence of Perkinsus marinus, condition of oysters, reproduction, and susceptibility to predation are all influenced by the timing, duration and frequency of freshwater flows into the estuaries.

The CERP goal for the northern estuaries is to enhance habitat conditions while providing for economic and recreational opportunities. CERP projects are expected to moderate the stressors (i.e., freshwater discharges, diminished water quality, and habitat loss) and enhance the natural attributes (i.e., oysters) of the northern estuaries. This will be accomplished through habitat enhancement, as well as water storage and treatment projects.

Longer-Term Science Needs

Basic information about salinity changes and their impacts on oysters and their associated communities is relatively well-understood. However, this data is mostly from areas outside the Northern estuaries, oysters are adapted to local conditions, and therefore their responses to ambient environmental conditions in the northern estuaries may be different. Continued work is needed to standardize the measurements between estuaries and continue to capitalize on developing time-series information on oysters in various estuaries. Some of the techniques (e.g. assessment of reproductive stage and reproductive potential using histological techniques) are expensive and very time consuming thus limiting the number of samples that can be assessed from each location and time series. Development of anti-body based techniques would quicken the process.

A habitat suitability index model is currently under development for oysters in the Caloosahatchee estuary. This GIS-linked HSI will enable resource managers to make comparisons between different scenarios enhancing the decision making process. This model has to be optimized and expanded to other estuaries. Metrics currently include: changes in oyster distribution and abundance at a variety of estuarine sites on both east and west coasts of Florida, including the St. Lucie Estuary, Caloosahatchee Estuary, Loxahatchee, and Lake Worth Lagoons. This long-term monitoring program for the eastern oyster will focus on four aspects of oyster ecology: spatial and size distribution patterns of adult oysters, distribution and frequency patterns of oyster diseases, reproduction and recruitment, and juvenile oyster growth and survival. Data will be analyzed to determine if the health and spatial extent of oysters is improving with time as CERP projects are implemented. Maps of oyster bed location, density and health need to be produced.

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Appendix to Oyster Indicator

The Northern Estuaries includes Caloosahatchee, St. Lucie, Loxahatchee, and Lake Worth Lagoon (Figures 2 and 3). The Caloosahatchee Estuary is located on the southwest coast of Florida. Most of the freshwater flowing into the estuary comes from the Caloosahatchee River. Historically the Caloosahatchee River was a meandering system with numerous oxbows, flowing from its headwaters at Lake Hicpochee to the Gulf of Mexico (Figure 2). Activities that led to its degradation, beginning in the 1890s, include channelization, connection to Lake Okeechobee, and construction of an extensive canal network associated with agricultural development in the watershed. The channelized portion of the Caloosahatchee River (C-43) as well as this canal network has changed the timing, quantity, and direction of runoff within the watershed and led to abnormal salinity fluctuations. The tidally influenced portion of the estuary has been reduced by the operation of the S-79 control structure (Figure 2) which allows periodic large regulatory releases from Lake Okeechobee. Prior to these impacts, the Caloosahatchee estuary was a highly productive system with an abundance of aquatic plants and animals. Today, the abundance, health, and functionality of these species have been greatly reduced. The eastern oyster, important component of the biological community, has been reduced from a widespread distribution to a sparse occurrence.

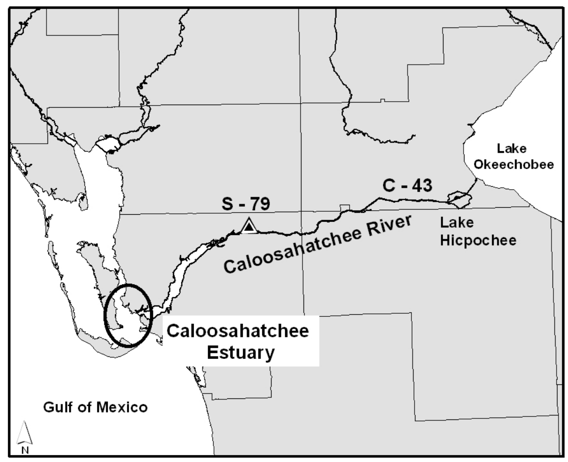

Figure 2. The Caloosahatchee estuary.

The St. Lucie Estuary (SLE), located on the southeast coast of Florida, flows into the Indian River Lagoon and the Atlantic Ocean. Historically, this estuary was a fresh water system influenced by ephemeral ocean inlets. When the St Lucie Inlet was permanently established in 1898, the system became an estuary, characterized by abundant mangroves, oyster bars, and SAV. Agricultural and urban drainage projects beginning in the 1910s expanded the area that now drains into the estuary. The historic watershed was approximately one-third of its present size of almost 775 square miles. Major drainage canals constructed in the watershed include the C-23 and C-24 canals (Figure 3). The SLE is connected to Lake Okeechobee by the C-44 canal that is used for navigation and regulatory releases from Lake Okeechobee. As a result, freshwater flow into the estuary tends to be excessive in the wet season and occasionally insufficient in the dry season. Thick deposits of mucky silt that cover large portions of the bottom and make it unsuitable for oysters have also degraded the estuary.

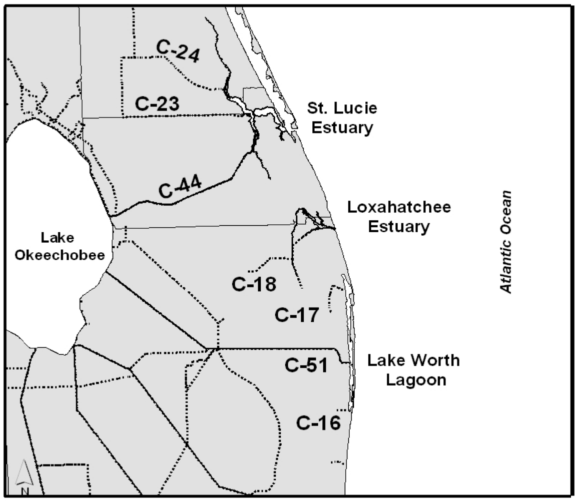

Figure 3. The St. Lucie, Loxahatchee, and Lake Worth Lagoon estuaries.

The Loxahatchee River is located on the southeast coast of Florida. The Loxahatchee Basin has been extensively altered by construction of canals, channelization of natural waterways, drainage and/or impoundment of wetlands, and stabilization of the Jupiter Inlet. Construction of the C-18 canal resulted in the disconnection of the Northwest Fork from its headwaters, the Loxahatchee Slough (Figure 3). This has resulted in periodic shortages of water for the Northwest Fork and increased flows into the Southwest Fork during storm events. Saltwater intrusion upstream into the Northwest Fork has resulted in the loss of six river miles of cypress swamp and freshwater floodplain vegetation. Oyster beds currently exist in a limited area of the estuary.

Lake Worth Lagoon, located on the southeast coast of Florida, was historically a freshwater lake receiving water from wetlands along its western edge. Creation of permanent inlets to the lagoon changed it to an estuarine environment. Although regionally important natural resources remain, the cumulative impact of human activities over the past 100 years significantly altered the lagoon environment. Changes affecting the hydrology include construction of major drainage canals (C-51, C-17, and C-16), shoreline bulkheads, a causeway, channels, and port development (Figure 3). Discharges from the C-51 canal produce excessive periodic releases of fresh water that adversely impact estuarine biological communities. Limited numbers of oysters remaining in the lagoon are unhealthy and reduced in number.

Water management activities within the watersheds of these estuaries resulted in significant alterations in the timing (excess wet season and insufficient dry season water flows), distribution (water now flows through canals instead of overland), volume and quality of water flow into these estuaries. Channelization and water control structures have reduced the ability of these systems to filter nutrients and have further degraded water quality. These impacts reduce the ability of the watershed to provide water storage, dry season flows, water quality treatment, and fish and wildlife habitat. The objectives of many CERP projects are focused on reducing these impacts.

Periphyton & Epiphyton

Author: Evelyn Gaiser

What Is This Indicator?

Periphyton communities, comprised of algae, floating plants, and associated animals, is a ubiquitous feature of Everglades' marshes. It is responsible for over half of the primary production in the greater Everglades (Ewe et al., 2006) and is the primary food source for small fish, crayfish, grass shrimp and other small consumers at the base of the food web. Because periphyton production is strongly linked to hydrologic conditions and water quality, understanding changes in this key Everglades feature is critical to determining causes for alterations in communities of charismatic megafauna (i.e., large fish, wading birds, alligators) linked to periphyton through the food web. In addition, through interactions with the physiochemical environment and other biota, periphyton influences many other features of the Everglades ecosystem including soil quality, concentration of nutrients, and dissolved gasses. Periphyton responds very quickly (days to weeks) and predictably to changes in environmental conditions at a large range of spatial scales (meters to tens of kilometers). It therefore serves as an excellent "early responder" and can be used as a warning of impending change. Detecting change quickly in this system is important, as the difficulty and cost of restoration increases with the duration of damage (i.e., it is much easier to stop an impending cattail invasion through P diversion than to replace a large cattail stand with sawgrass).

Studies of variation in Everglades periphyton along naturally existing and experimentally created gradients have found strong relationships of species composition, nutrient content and ratios, structure (growth form), calcite content, and physiology (i.e., nutrient uptake and, productivity) to water quality and quantity (Browder et al., 1982; Swift and Nicholas, 1987; Grimshaw et al., 1993; Raschke, 1993; Vymazal and Richardson, 1995; McCormick et al., 1996; McCormick and O'Dell, 1996; McCormick et al., 1997; Cooper et al., 1999; Pan et al., 2000; McCormick et al., 1998; Gaiser et al., 2006). The total phosphorus (TP) content of periphyton tissue is perhaps one of the most direct measures of P load history in the Everglades (McCormick & Steveson 1998; Gaiser et al., 2005, 2006). While increases in water as well as soil P are only detectable after years of enhanced P loading (because of rapid microbial and physical uptake), ecosystem effects are immediate and highly correlated with periphyton TP concentration (Gaiser et al., 2004). Large-scale losses of periphyton throughout the system have been detected in response to excessive P enrichment from canals (Gaiser et al., 2006) and these losses have been shown to have cascading effects throughout the Everglades ecosystem (Gaiser et al., 2005). For this reason, periphyton TP concentration and correlated variables (calcite content, species composition) are now regularly monitored in most Everglades programs. Additionally, strong visually apparent changes in periphyton biomass and composition have also been documented along spatial and temporal hydrologic gradients, so periphyton collections also offer an independent proxy of hydrologic change (Thomas et al., 2006; Gottlieb et al., 2006).

The positive or negative trends of this indicator relative to hydrological and water quality changes permit an assessment of positive or negative trends in restoration (Gaiser et al., 2006). Restoration success or failure would be evaluated by comparing recent and future trends and status of the periphyton communities with historical paleoecological data and model predictions; as stated in the CERP hypotheses related to the food web (CERP Monitoring and Assessment Plan section 3.1.2.4, 2004).

CERP MAP Hypotheses related to Periphyton

Enhance periphyton community characteristics and mangrove forest soil accretion rates as regional indicators of the functional bases of Everglades food webs.
Restore the density, seasonal concentration, size structure, and taxonomic composition of marsh fishes and other aquatic fauna to levels that support sustainable breeding populations of higher vertebrates
Shift the distribution of high density populations of marsh fishes and other aquatic fauna from artificially-pooled areas (the Water Conservation Areas) to the restored pools in the southern Everglades
Shift the foraging distribution of wading birds in response to expected trends in the density, distribution, and concentration of prey organisms
Reestablish wading bird nesting colonies in the coastal regions of the southern Everglades and increase the numbers of nesting pairs and colony sizes in response to desired trends in populations of prey organisms
Increase the nesting success/survival rate of wading birds in response to desired trends in populations of prey organisms

What Has Happened To Affect The Indicator?

Periphyton has been studied extensively in the Everglades because of its utility as an early warning indicator of impending ecosystem change and the significant consequences of altered periphyton communities on the rest of the food web. Increased nutrient delivery to natural Everglades marshes causes periphyton mats to disintegrate and collapse (Gaiser et al., 2006), resulting in a major alteration in food availability at the base of the food web. Research shows periphyton losses are initiated upon exposure to even very low nutrient enhancements (>10 ppb; Gaiser et. al., 2005). Models have been developed to determine the extent of periphyton losses throughout the Everglades ecosystem because of nutrient enrichment. Further, hydrologic changes have strong functional and structural consequences to the periphyton community. Studies have shown that sites that are dry for a majority of the year have minimal production values, while sites that are flooded for >6 months are most productive (Thomas et al., 2006; Gottlieb et al., 2005; Iwaniec et al., 2006). The timing of reflooding of previously dried periphyton mats is also important, as dried periphyton releases large quantities of nutrients into the water column upon reflooding that subsequently may negatively affect downstream systems (Thomas et al., 2005).

What Areas of the Everglades Does This Indicator Cover?

Periphyton covers virtually all of the Everglades freshwater wetlands and the southern estuarine areas. These areas include the following RECOVER & SCG regional modules; Greater Everglades, Florida Bay and Southern Estuaries, Lake Okeechobee, and the Kissimmee River Basin (see Figure 1).

What Does The Research Say?

Periphyton biomass in the Everglades is significantly higher compared to other wetlands, with dry mass values often exceeding plant biomass in many areas of freshwater marsh as well as offshore marine seagrass beds (Ewe et al., 2006). This primary biomass supports of the remainder of the food web, including invertebrates, fish and wading birds (Williams et al., 2006). Periphyton grows on any substrate available in the marsh, and, as a result, substrate associations vary throughout the Everglades. In the marl prairie, periphyton grows attached to the sediment or bedrock and stems of emergent macrophytes whereas deeper sloughs contain periphyton communities that are primarily attached to floating macrophytes such as the purple bladderwort (Utricularia purpurea; Gaiser et al., 2006). Therefore, hydrology affects periphyton not only directly but also indirectly by affecting the substrate available for colonization.

Changes in the hydrologic regime (i.e., duration and timing of flooding, water depth) can greatly influence periphyton community structure and function. During the dry season in short-hydroperiod marshes, periphyton communities are dormant and maintain a very low productivity (Thomas et al., 2006). Following re-flooding, periphyton recovers within days of re-hydration, but not before large quantities of nutrients have been released back into the water column (Thomas et al., 2006). In stagnant situations, these nutrients may be re-sequestered by the community upon recovery but if water is flowing, the released nutrients can be carried downstream and affect neighboring communities. Gottlieb et al. (2005) showed that periphyton communities can quickly transition in composition and structure if exposed to alternating hydrologic regimes. These fast responses to environmental changes strongly advocates for using periphyton in environmental monitoring in the Everglades.

Across the hydrologic spectrum, periphyton has been shown to respond directly and quickly to above-background concentrations of nutrients. The response is rapid, and easily detected, as low-level nutrient enhancements lead to a demise of the periphyton community altogether (Gaiser et al., in press). This has substantial consequences to the invertebrate and fish communities dependent on this biomass for food (Turner et al., 1999; Gaiser et al., 2005). Periphyton mats have also been shown to be extremely diverse, with more than 700 algae taxa having been documented from the Florida Everglades thus far (see www.serc.edu/~periphyton). Changes in nutrient availability to these taxa are what drive the nutrient-induced disintegration, and so taxonomic changes can be measured prior to the collapse of the community itself. The history of nutrient loading to a particular site can be interpreted from a single periphyton community sample with 98% accuracy (Gaiser et al., 2005). A variety of models exist that accurately predict the nutrient status of water from periphyton, and these can be applied to monitoring and paleoecological studies to determine trends in water quality over time.

Why Is This Indicator Important?

1. The indicator is relevant to the Everglades ecosystem and responds to variability at a scale that makes it applicable to the entire ecosystem or large portions of the ecosystem:

It contains an abundant community of species typical of the Everglades ecosystem;
It is characteristic of all Everglades' freshwater wetlands;
It is at the base of the Everglades' food chain
Productivity and community structure are directly linked to hydrology;
Productivity measures (abundance and standing stock) are key outcomes (performance measures) in most RECOVER Conceptual Ecological Models and in CERP Interim Goals.

2. The indicator is feasible to implement and is scientifically defensible:

There are existing, funded cooperative research and monitoring programs with FIU, Florida Coastal LTER Program, USGS, and the NPS;
There are reliable models available to determine the impacts of water management on these communities;
Pattern metrics (e.g. abundance, community structure) are statistically correlated to Ecosystem Drivers;
There are numerous peer reviewed journal articles;
This indicator is already part of the CERP RECOVER interim goals and Food-Web Monitoring Component of the CERP MAP.

3. The indicator is sensitive to system drivers (stressors)

Key environmental drivers (rainfall, water quantity, water quality) are statistically correlated to species abundance and community composition;
Short and long hydroperiod wetlands have distinct periphyton biomass and community composition;
Periphyton biomass and community composition are causally linked to hydrological factors (water depth, days since last dry-down, and length of drydown);

4. The indicator is integrative

Periphyton production is linked to fish and macroinvertebrate production and in turn wading bird nesting success;
Community responses are representative of hydrological improvement (i.e. Water Management);
Periphyton is included in the CERP Food-Web Monitoring Component that includes an index of food-web function and landscape connectivity ("intactness");

5. Goals and performance measures are established in the RECOVER MAP for the

Indicator and the following metrics are being monitored:

Biomass and cover
Frequency of dry-downs
Duration of dry-downs
Community composition in both short- and long-hydroperiod wetlands

Discussion

The RECOVER Conceptual Ecological Models identify three major stressors to wetlands that are affecting periphyton: water management practices (affecting hydrology and water quality); agricultural and urban development (affecting habitat loss, hydrology and water quality); and invasive exotic species (affecting habitat loss, abundance and community composition) (CERP Monitoring and Assessment Plan 2004).

Conversions of large areas of short-hydroperiod wetlands (marl prairies) east of Everglades National Park and the Water Conservation Areas into agricultural and urban uses represents a large regional loss that periphyton and associated populations of fish and macroinvertebrates once inhabited. This loss due to irreversible land-use changes has had a major impact on both the abundance and structure of these communities.

Periphyton cover, biomass, productivity and composition are affected by the duration, and frequency of droughts. The reduction of hydroperiod resulting from long-term water management changes has limited the period of production for periphyton in Everglades' wetlands for many decades (Davis et al., 2006). Increased water delivery to areas of the southern Everglades (eastern portions of Everglades National Park) that were over-drained for many decades have allowed for periphyton recovery and subsequent improvement in fish and macroinvertebrate populations with improvements (i.e. increases in duration of flooding and depth of water) in water management (Trexler et al. 2005). Further restoration is needed.

Additional hydrological restoration is expected to improve habitat for periphyton production in both long and short hydroperiod wetlands. In long hydroperiod wetlands, it is expected to reduce the incidence and severity of drying, further lengthening the production period and primary biomass available to the food chain. In short hydroperiod wetlands, improved water management should encourage more prolific periphyton growth, including more edible taxa (Gottlieb et al., 2006; Geddes et al., 2004), and facilitate recovery of dependent macroinvertebrates and fish.

Longer-Term Science Needs

The productivity and composition of periphyton mats throughout the Everglades is fairly well understood. Models of how periphyton responds to hydrology and water quality are also being developed, but few studies have examined the combination of these effects on periphyton and the rest of the food web. In addition, longer-term

effects of alterations in periphyton composition and function are necessary to determine consequences through the food web and in soil formation.
Paleoecological studies, where possible, would also be warranted to provide baseline information about past water quality and hydrology to provide a better guide to restoration.

Response to the Independent Scientific Review Panel's Comments

1. "The importance of tissue phosphorus concentration…is less clear" (Page 8, Line 16).

> Response: Periphyton tissue phosphorus concentration has been shown in several published experimental and descriptive studies to be one of the best metrics of P load (see McCormick & Stevenson 1998, Gaiser et al. 2006, Gaiser et al. 2004 in references). Models to calculate P load from periphyton TP are highly accurate and have been repeatedly tested such that this metric is now replaces water and soil TP as the leading measure of P load in this system (see CERP MAP documentation). More than half the variability in periphyton biomass and calcite content across the Everglades can be explained by TP load, which provides greater explanatory power than most ecological relationships in this system. In addition, at least a dozen papers have been published relating species composition directly to TP content and load (these are also in reference section).

2. "…Periphyton has difficult metrics around which to rally enthusiasm…Cattail might be a better indicator (Page 8, Line 21)…".

> Response: The public can be taught, there are many examples of this. It is algae, no different than in the ocean where there is wide public awareness of blooms and their impact. More important is the issue of scale in response. Periphyton is a "first responder". By the time cattail has invaded it is too late for easy reparations. "Eliminating cattail and restoring sawgrass" is a lot more difficult and costly than reversing a P loading problem detected at its outset.

3. "Links between periphyton and…[other] organisms..is unclear" (Page 11, Line 22 & Page 23, Line 44).

> Response: Measurements of primary productivity throughout the Everglades suggest that periphyton is the dominant producer in over half the system (Ewe et al. 2006). Besides being the only consumable producer for most of the microinvertebrate community, it has been shown to be the main direct and indirect support for the Everglades food web, including most of the other indicator taxa (inverts, fish and their dependents, birds and alligators; Turner et al. 1999).

4. Fish indicate hydrology at a broad spatial and temporal scale compared to periphyton (Page 24, Line 8, 19).

Response: Periphyton responds quickly (weeks to months) to hydrologic change at spatial scales from meters to tens of kilometers (Thomas et al., 2006; Gottlieb et al., 2006). These relationships to hydrology are now well understood and happen quickly in a way that can allow good adaptive management of restoration protocols.

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Pink Shrimp

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What Is This Indicator?

The southern estuaries—Biscayne Bay, Florida Bay, and the SW coastal mangrove estuaries—are nursery habitat for pink shrimp, which are a characteristic component of the estuarine epibenthic fauna. The pink shrimp, *Farfantepenaeus duorarum*, is an ecologically and economically important species of the southern estuaries. Pink shrimp spawn on the southwest Florida shelf, migrate shoreward as larvae/post-larvae, and spend their juvenile stage in the southern estuaries. They return to offshore waters to spawn and support a major fishery operating near the Dry Tortugas and near Sanibel/Captiva (Costello and Allen 1966). Statistical studies suggest a relationship between pink shrimp landings or catch per unit effort (cpue, an abundance index) in the Tortugas fishery and indices of freshwater flow from the Everglades to the lower southwest coast and Florida Bay (Browder 1985, Sheridan 1996). Laboratory experiments indicate that growth and survival of juvenile pink shrimp are influenced by salinity and temperature, suggesting they may influence pink shrimp distribution and abundance (Browder et al. 1999, 2002). In a meta-analysis of forage fish and macroinvertebrates in Florida Bay, Johnson et al. (2002a, 2005) found that pink shrimp were more closely correlated with salinity and seagrass than the other species (10 other species in the 2002 study and 19 other species in the 2005 study). A model of juvenile pink shrimp growth and survival in relation to salinity and temperature by Browder et al. (1999, 2002) has been applied to several water management issues (e.g., minimum flows and levels for Florida Bay (Browder and Johnson 2005), the Picayune Strand project implementation report (Wang and Browder 2004), and the Biscayne Bay Coastal Wetlands Restoration Project (Browder, unpublished).

The indicator is juvenile shrimp density in each of five areas, as sampled biannually in the CERP Monitoring and Assessment Plan (RECOVER 2004) or as simulated by the pink shrimp model. The Interim Goals component of CERP (CERP RECOVER 2004) proposes to compare, at 5-yr intervals, peak field-measured juvenile pink shrimp density within the period August-October to predictions from the model. These results will be evaluated in relation to goals and compared to (1) model predictions for interim goals and (2) model predictions under daily salinity during the ~3-month period immediately preceding sampling. Input data for modeling will be the output of models relating salinity to indices of freshwater flow from the Everglades (e.g., the FATHOM model of Colby et al. [1999]; the multiple linear regression models of Marshall [2003]; the basin model of Nuttle [2002]; or the EFDC hydrodynamic model of Hamrick [SFWMD 2006]).

The five areas to be sampled by the CERP MAP are Western Florida Bay, South Central Florida Bay, North Central Florida Bay, the Southwest Coast, and Biscayne Bay. The density of pink shrimp, measured with the same gear (1-m^2 throw-trap), is higher in Western Florida Bay than other parts of Florida Bay (Robblee et al. 1991, Johnson et al. 2005), South Biscayne Bay (Browder et al. 2005b), or the SW coast estuaries (Rice 1997). The biggest year-to-year differences in shrimp density are expected in the north-central bay because this area frequently experiences hypersaline conditions, which depress growth and survival of pink shrimp (Browder et al. 2002). This area has the greatest potential for improvement in pink shrimp density if water management changes in CERP provide sufficient freshwater inflow to reduce the frequency, intensity, and duration of hypersaline periods.

To take into account annual variation in spawning strength and immigration of post-larvae to the Bay from offshore grounds, predicted densities in each area will be evaluated in relation to densities in Western Florida Bay, which is viewed as the optimum area because shrimp densities are highest there (Robblee et al. 1991, Johnson et al. 2005) and also because the area least affected by water management. Results of coordinated sampling on both sides of Florida Bay (Keys side and Gulf side) suggest that postlarval movement into the western side of Florida Bay is generally much higher and more predictable than movement across the eastern boundary (Criales et al., 2006); thus recruitment of settlement-stage postlarvae to Western Florida Bay may be greater than that to other parts of the bay.

Using Western Florida Bay as the barometer of potential density in the other areas, the Interim Goals and Interim Targets report (CERP RECOVER 2004) set as goals 17, 7, 5, 7, and 2 shrimp per square meter for Western Florida Bay, south-central Florida Bay, north-central Florida Bay, the southwest coast, and Biscayne Bay, respectively, with the goals for the other areas expected only when shrimp density in Johnson Key Basin is at least 15. These goals may be revised as more perspective is gained from on-going pre-project-implementation monitoring as part of MAP.

CERP MAP Hypotheses related to Pink Shrimp Indicator

Pink shrimp is one element of the fish and macroinvertebrate complex of the southern estuaries module of the MAP and is included in the nearshore nursery function component of the 2005 draft update of the MAP. Key hypotheses include:

- CERP implementation will affect nursery habitat (e.g., seagrass, mangroves) quantity and quality with respect to refugia and feeding, resulting in an expansion of the area of optimal habitat and an increase in the overall abundance of dependent invertebrate and vertebrate species, including pink shrimp and spotted seatrout.

- CERP implementation will affect the life cycle and abundance of fishery species not only through habitat dependencies but also through the direct physiological effects of salinity conditions upon growth and survival.

What Has Happened To Affect The Indicator?

Historically, water management practices have changed the quantity, timing, and distribution of freshwater inflow to estuaries, which have affected both ambient salinities and the frequency and rate of salinity change. Both Florida Bay and parts of Biscayne Bay (i.e., especially Card Sound, Barnes Sound) have been subjected to prolonged hypersaline conditions. Eastern Florida Bay, Whitewater Bay, and Biscayne Bay experience large, rapid changes in salinity. Water management to date may have amplified tendencies toward both hypersalinity and large and rapid changes in salinity in all of these areas, but nearshore areas and areas most isolated from exchange with seawater are most affected.

Florida Bay also has experienced major changes in the coverage, species composition, and condition of its seagrass beds, possibly partly in response to changes in salinity patterns (Rudnick et al. 2005). A recent analysis of ~20 years of data from Johnson Key Basin (Robblee and Mumford, in prep.) found changes in the density and composition of the epifauna, including pink shrimp, that may be related to the seagrass die-off that occurred in the late 1980s and the subsequent shift in seagrass composition.

A decline in landings and cpue in the Tortugas pink shrimp fishery occurred in the middle 1980s (Sheridan 1996), roughly corresponding to the seagrass die-off discovered somewhat later (Fourqurean and Robblee 1999). The decline in landings was characterized particularly by a decline in the fall/early winter fishery, which had previously yielded the greater part of the annual catch (Ehrhardt and Legault 1999). The high monthly average cpue (e.g., >800 pounds per vessel-day) characteristic of the fall/early winter fishery prior to 1985 first reappeared in 1995, a year of exceptionally high rainfall, coinciding with modifications to water management operations that enhanced the movement of fresh water to Florida Bay and the lower southwest coast, and then not again until 2004 and 2005.

What Areas of the Greater Everglades Does This Indicator Cover?

Pink shrimp are found in virtually all South Florida estuaries. These areas include the following RECOVER & SCG regional modules: Southern Estuaries and Northern Estuaries. Pink shrimp are especially indicative of ecological conditions within the Southern Estuaries, including Biscayne Bay, Florida Bay, and the mangrove estuaries of the southwest coast. Pink shrimp are also found in the Northern Estuaries, including the Caloosahatchee River estuary and the Indian River Lagoon South. The southern estuaries module is displayed in Figure 1.

What Does The Research Say?

Proposed relationships of pink shrimp with salinity and seagrass density and composition are supported by the laboratory experiments of Browder et al. (2002) and the meta-analyses of Johnson et al. 2002a, 2005). Analyses by Browder (1985) and Sheridan (1996) found statistically significant relationships of indices of abundance in the Tortugas pink shrimp fishery and indices of freshwater flow from the Everglades to Florida Bay and the lower southwest coast. Application of the pink shrimp model of Browder et al. (1999, 2002) to water management issues suggested that changes in water management could substantially affect pink shrimp density in north-central Florida Bay, the western nearshore area of South Biscayne Bay, and the southwest coast estuaries (Browder et al. 2005). The meta-analyses of Johnson et al. (2002a, 2005) suggest that the pink shrimp relationships to salinity and seagrass are more effectively quantified than those of other abundant members of the small forage fish and macroinvertebrate community.

Why Is This Indicator Important?

1. The Indicator is relevant to the Southern Estuaries component of the Greater Everglades Ecosystem and Responds To Variability At A Scale That Makes It Applicable To Large Portions Of The Ecosystem:

- The pink shrimp is a characteristic estuarine species that is representative of other prey species and strongly linked to predator species;
- The pink shrimp is characteristic of all South Florida estuaries;
- The pink shrimp is a primary and secondary consumer that relies on the benthic detrital and microalgal-based food webs;
- Through influences on survival and growth, pink shrimp density is related to salinity;
- Pink shrimp density is related to type and density of seagrass cover;
- Fish and Macroinvertebrates provide the critical prey for secondary and tertiary carnivores such as wading birds;
- Density, a measure of abundance, is a key outcome (performance measure) in most RECOVER Conceptual Ecological Models and in CERP Interim Goals.
- The pink shrimp is economically important as a fishery species.

2. The Indicator is Feasible to Implement and is Scientifically Defensible:

- There are existing, funded research and monitoring programs with NOAA and USGS;
- There is a long term data base covering much of a 20-yr period in Johnson Key Basin;
- Reliable models are available to determine the impacts of water management on these populations;
- Reliable models exist for estimating historical shrimp densities in regions where historical databases do not exist;
- Pattern metrics (e.g. abundance) are statistically correlated with water management indices (e.g., indices of freshwater inflow and salinity);
- There is an existing model, based on experimental data from 2000 young pink shrimp from Florida Bay, relating pink shrimp growth and survival to temperature and salinity;
- A new project is funded to examine Biscayne Bay pink shrimp growth and survival in relation to temperature and salinity;
- There are numerous peer reviewed journal articles;
- This indicator is part of the CERP RECOVER interim goals and Southern Estuaries component of the CERP MAP and is currently being monitored.

3. The Indicator is Sensitive to System Drivers (Stressors)

- Key environment Drivers (Rainfall, Water Quantity, Water Quality) are statistically correlated to indices of abundance in the Tortugas fishery for pink shrimp;
- Pink shrimp densities in Florida Bay and/or Biscayne Bay have been statistically related to salinity, both directly and indirectly, through relationships with seagrass.

4. The Indicator is Integrative

- The pink shrimp is an important link in the food web between benthic detritus and microalgae and high consumers such as sport fish and wading birds;
- Pink shrimp is included in the Southern Estuaries component of CERP MAP.
- Catch and effort in the Tortugas fishery associated with this indicator species have been monitored since 1960 (best data since 1965), providing a long time series of data that may relate to region-wide abundance. Catch and effort in the Biscayne Bay fishery have been monitored since 1986.

5. Goals and Performance Measures are established in the RECOVER MAP for the Indicator and the following metrics are being monitored:

- Number of pink shrimp per square meter, frequency of occurrence
- Salinity
- Temperature

Discussion

The RECOVER Conceptual Ecological Models for Florida Bay (Rudnick et al. 2005) and Biscayne Bay (Browder et al. 2005a) identify three major stressors to estuaries that, through influences on salinity and water quality, affect pink shrimp in estuaries: water management practices (affecting salinity and water quality); agricultural and urban development (affecting salinity and water quality); and sea-level rise (affecting salinity).

Longer-Term Science Needs

Continued work is needed to further quantify the relationship of spatial and temporal patterns of juvenile pink shrimp to salinity and to determine the influence of transport processes on the recruitment of postlarval pink shrimp to the SW coast, Florida Bay, and Biscayne Bay nursery grounds. Processes that may affect postlarval transport from the spawning grounds to the nursery grounds include ontogenetic behavior, tide, wind, storm events, and oceanographic features of the area between the Tortugas spawning grounds and the coastal nursery grounds. These processes are under study and the topic of three recent manuscripts, two published (Criales et al. 2005, Criales et al. 2006, and another recently submitted (Criales et al, in review). Transport patterns within the bay may affect large-scale patterns of juvenile pink shrimp density. Tide, wind, and storm events may affect the movement of pink shrimp from bay boundaries to bay interior areas. Transport processes and other factors influencing spatial patterns of postlarval and early juvenile recruitment to

Florida Bay are a present focus of scientific investigations by NOAA Fisheries and the U.S. Geological Survey.

Spatial patterns of linked habitats may influence pink shrimp density. For example, recent research from other regions suggests that the proximity of seagrass beds to mangroves may affect penaeid shrimp densities in seagrass beds (Skilleter et al. 2005).

Response to the Independent Scientific Review Panel's Comments

Reviewers noted that pink shrimp indicate hydrology and salinity. Reviewers commented that the role of pink shrimp as an indicator might be covered by the wading bird and SAV ecological indicators, however they argued for inclusion of pink shrimp because of its economic importance. We agree that its economic importance gives pink shrimp special relevance, and we added "economic importance" to the list in the "Why is this indicator important?" section above. But the pink shrimp is an important ecological indicator for other reasons as well, and it specifically reflects the response of Florida Bay and Biscayne Bay in ways not covered by other ecological indicators. The wading bird and SAV ecological indicators described in this report do not serve the same function as the pink shrimp indicator. The Roseate Spoonbill wading bird indicator relates more to the healthy functioning of the oligohaline wetlands than to the shallow open-water areas of Florida Bay and Biscayne Bay that are the principal nursery habitat of juvenile pink shrimp. In six years of a monthly survey from a low-flying helicopter, Browder and Bass (pers. comm.) never saw Wood Storks in Florida Bay. The White Ibis wading bird indicator relates to the healthy functioning of the southern Everglades region as a whole, not specifically the estuaries. Note that Florida Bay and Biscayne Bay are not even included in the above wading bird section as areas being surveyed or important areas needing to be surveyed. While the distribution and abundance of pink shrimp is influenced by SAV, the functions of the pink shrimp ecological indicator cannot be fully captured by the SAV ecological indicator. The two indicators operate on different time scales. The response of pink shrimp—a relatively short-lived species—to environmental conditions is more rapid than that of SAV, which is moderated by storage of energy and nutrients in roots and rhizomes. The two indicators respond differently to salinity and temperature, and synergistic effects of salinity and temperature extremes may further separate pink shrimp from seagrasses in their responses. The distribution and abundance of pink shrimp is indicative of the presence and abundance of other epibenthic fauna and indicates the availability of food for predators such as game fish and wading birds. Because of the linkage, inclusion of the pink shrimp indicator helps to better understand the relevance of SAV as an indicator.

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Lake Okeechobee Littoral Zone

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What Is This Indicator?

Specific CERP MAP Performance Measures (Section 3.4.3.2; RECOVER 2004a) related to the Lake Okeechobee Littoral Zone (RECOVER 2004b) are:

- LO-A6 Lake Okeechobee Native Vegetation Mosaic - Littoral Plant Communities and Bulrush
- LO-E14 Lake Okeechobee Native Vegetation Mosaic (Submerged Aquatic Vegetation, SAV)

The littoral zone emergent vegetation community in Lake Okeechobee is a diverse mosaic of native and exotic plants covering an area larger than 400 square kilometers. It provides nesting habitat and food resources for economically important sport fish populations, wading birds, migratory waterfowl, alligator, and the federally-listed endangered Everglades snail kite. The structure of the littoral vegetation community is influenced by both hydroperiod and phosphorus loading from the lake's eutrophic pelagic region.

The lake's SAV community, occupying the zone lakeward of the emergent plant community out to a depth of approximately 2 m. NGVD provides habitat for fish and wildlife, stability for sediments, and a substrate for periphyton that can sequester nutrients from the water column. These effects of SAV are widely documented in both the freshwater and marine literature. In Lake Okeechobee, healthy SAV corresponds to good conditions in terms of resource availability, habitat structure, and water quality. The SAV community is influenced by hydroperiod, nutrients, and water clarity. When conditions are favorable, SAV can occupy 40,000 + acres of lake bottom, but coverage can be reduced to near zero when conditions are poor.

The littoral zone of Lake Okeechobee, in its current form, is a relatively recent system. Much of it was formed after construction of the Herbert Hoover Dike in the mid-1900s and control of the lake at a lower average surface elevation than under pre-settlement conditions. The lake's natural littoral zone probably was much larger and occurred to the west and south of its present location (Havens et al. 1996, Steinman et al. 2000). Despite its young age, the existing littoral zone supported a diverse array of native plants when it first was mapped in the early 1970s (Pesnell and Brown 1973). The community included large areas of spikerush (*Eleocharis cellulose)*, sawgrass (*Cladium jamaicensis*), willow (*Salix caroliniana*) and beakrush (*Rhynchospora tracyi*). At the south end of the lake there were remnant stands of pond apple (*Annona glabra*) and along the western shore there was a nearly continuous band of dense bulrush immediately lake-ward of a zone dominated by spike rush and submerged plants. Although there is no quantitative record, various anecdotal reports from the early 1970s indicate that the submerged plant beds were both widespread and dense, including species such as eelgrass and peppergrass, favorable habitats for fish (Furse and Fox 1993).

Today the vegetation mosaic of the littoral zone is dramatically different (Richardson and Harris 1995). Upland areas that were previously dominated by beakrush and mixed grass assemblages now have been infested by the invasive exotic torpedograss (*Panicum repens*). Certain areas have become dominated by the exotic tree melaleuca (*Melaleuca quinquenervia*), although much of that species has been killed by applications of herbicide (SFWMD 1997). The spatial extent of willow has declined and there has been a large expansion of cattail. Pristine spikerush sloughs in the interior littoral zone now are surrounded by cattail (a native but invasive nuisance species) and torpedograss and contain a higher density of water lily (*Nymphaea* spp.) than in the 1970s. The long-shore bulrush stands now are sparse (just 50% of the former coverage) relative to their historic amounts, and the shoreline spike rush community no longer exists. Submerged vegetation was largely eliminated from the near-shore pelagic region in the late 1990s, although a marked recovery has occurred during a period of low water levels in spring-autumn 2000. However, peppergrass has severely declined relative to its historic abundance and large acreages are now occupied by the invasive exotic *Hydrilla verticillata*.

Three main factors have interactively affected the native vegetation mosaic in Lake Okeechobee. These factors are *altered hydroperiod*, *excessive phosphorus loading*, and the *introduction and expansion of exotic plants*. The following general hypotheses describe how these factors are thought to affect the vegetation mosaic attribute, and are organized by geographic region (littoral zone, near-shore bulrush zone, and near-shore submerged vegetation zone).

CERP MAP Hypotheses related to Lake Okeechobee Littoral Zone Indicator

- In the littoral zone, the distribution of native and exotic plants primarily is determined by hydroperiod.
- Excessive inputs of phosphorus from the lake's pelagic zone have promoted the spread of cattail in certain littoral areas and may have contributed to the expansion of water lily.
- Prolonged periods of deep water, combined with increased turbidity and physical damage from wind-driven waves, have dramatically reduced the spatial extent and biomass of near-shore bulrush stands and submerged aquatic vegetation.

CERP Restoration Expectations:

<u>Littoral plant communities</u>

The performance targets for spikerush and beakrush will be met when these plants recolonize much of their historic coverage areas. Large reductions in the distribution of torpedograss and cattail also are targeted, encouraging the development of a more diverse landscape dominated by open water and desirable native plant assemblages. Willow (*Salix* spp.) and pond apple (*Anona glabra*) trees provide important nesting habitat for wading birds. The performance target for these plants will be a moderate increase (500 to 1,000 acres) in the distribution of continuous stands of trees in areas that are surrounded by open water (e.g., not adjacent to the Herbert Hoover dike or canal banks where protection from predators would be reduced).

Bulrush

The target is to have a nearly continuous and thick band of bulrush located along the lakeward edge of the littoral zone from Clewiston north to the area near the mouth of the Kissimmee River (>30 miles), and around Kings Bar and Eagle Bay Islands (see Table 8).

Table 8. Performance Measure for LO Bulrush using Lake Stage

Lake Stage (feet NGVD)	Effect	Condition
17 or >	Serious damage any exposure period	Poor
16	Serious damage for >1 month	
15	Serious damage for > 3 months	
14	Damage if exposed for > 6 months	
13	Survives and grows slowly	Acceptable
12	Grows well	Optimal
11	Grows well	
10	Grows well and recruits via seed germination after 6-10 weeks	
<10	Serious Damage through desiccation after 1 month	Poor

Submerged Aquatic Vegetation

The target is to have an average annual coverage at the end of each growing season of at least 40,000 acres; half of which is composed of desirable vascular species.

What Has Happened To Affect The Indicator?

In recent decades, Lake Okeechobee has experienced a rapid expansion of exotic and nuisance plants and the introduction and expansion of certain exotic animals (approximately 120 species at last count). The plants have been the greatest concern to date. There are now 15 species of exotic plants in the lake's littoral zone. Species that have caused the most substantial harm are *Melaleuca* and torpedo grass (*Panicum repens)*, which were purposely introduced to the region, for dike stabilization and cattle forage, respectively. Other exotic plants that have stressed the lake's values include *Hydrilla* sp., water hyacinth (*Eichornia crassipes*), and water lettuce (*Pistia stratiotes*). Exotic animals in the lake now include fish, amphibians, reptiles, mollusks and macroinvertebrates, as well as avifauna and mammals. Each of these species exerts different impacts on the ecosystem, as discussed below. Many of these species have been accidentally introduced to the lake, and this situation is likely to continue, as new species are introduced to the United States and subsequently spread by boats and other mechanisms into Florida waters. In addition, years of excessively high lake stages and storm events occurring during the 2004 and 2005 hurricane seasons have destroyed much of the native SAV community, have seriously impacted bulrush, and have shifted the emergent marsh community away from spikerush and beakrush and toward the development of large expanses of water lilly *(Nymphae*) flats.

What Areas of the Everglades Does This Indicator Cover?

The littoral zone of Lake Okeechobee encompasses the western 25 percent (106,255 acres or 43,000 ha) of the lake (Figure 4) and the Lake Okeechobee Module (see Figure 4).

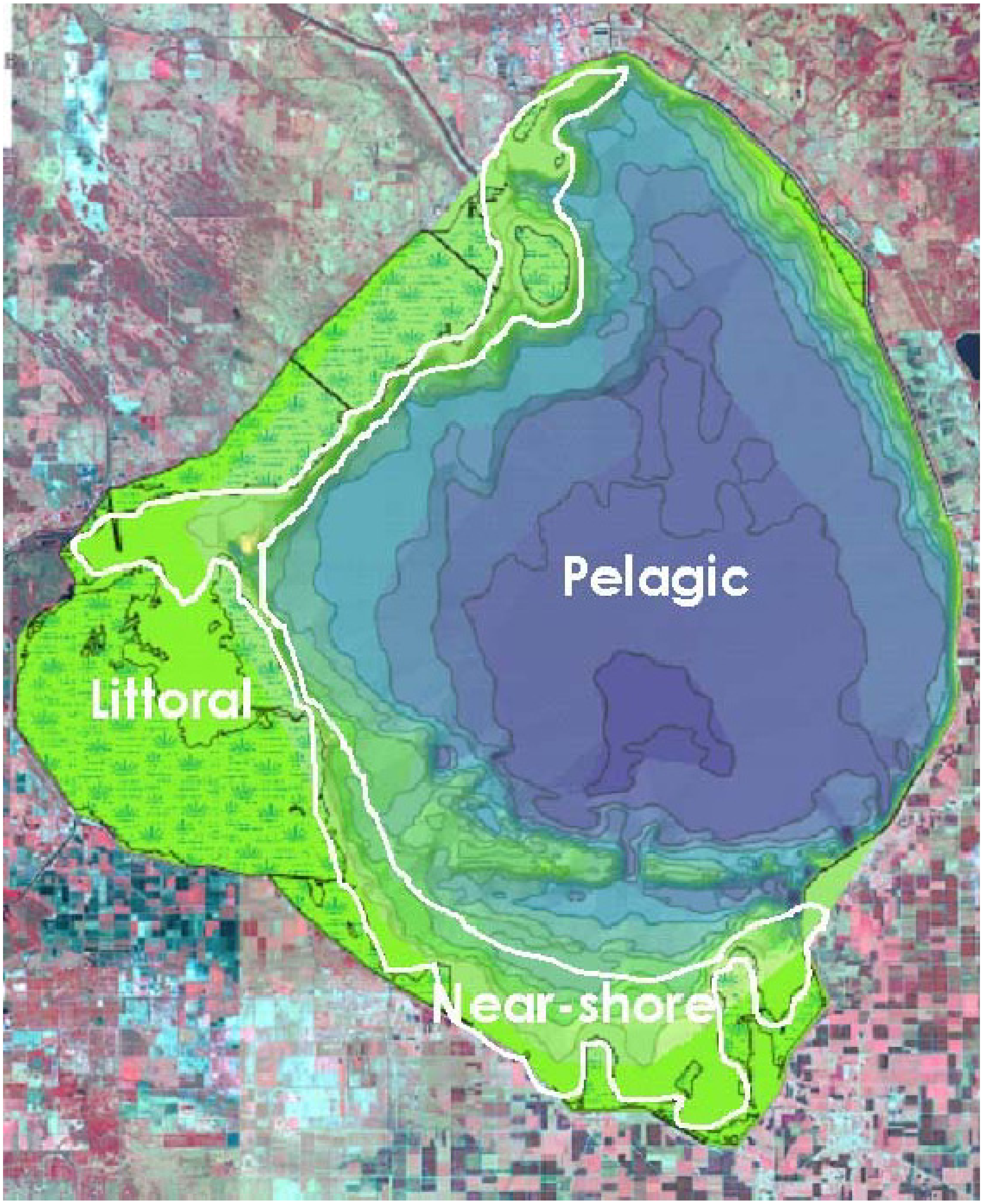

Figure 4. Map showing the Lake Okeechobee littoral zone.

What Does The Research Say?

The littoral zone of Lake Okeechobee is a diverse littoral community that provides spawning and foraging habitat for fish, wading birds, migratory water fowl, and the federally endangered Everglades snail kite (*Rosthrhamus sociabilis plumbeus*) (Aumen, 1995; Bennetts and Kitchens, 1997). The littoral zone has been extensively studied, with a primary focus on effects of hydroperiod and sediment type on emergent plants (Richardson et al., 1995), responses of periphyton and invertebrates to increased nutrient inputs (Havens et al., 1999; 2001b; 2004a), and temporal variations in vegetation structure (Richardson and Harris, 1995). In recent years, there has been more intensive focus on the interface between the littoral and nearshore zones because this area appears to be most dynamic in terms of changes in vegetation structure.

The SFWMD develops maps every other year to assess the spatial extent and distribution of torpedograss because this exotic plant is the focus of an ongoing eradication program. Mapping is also performed every other year to quantify the spatial extent of the “bulrush zone,” a band of emergent plants dominated by bulrush (*Scirpus californicus*) that generally defines the interface between the emergent marsh and the open pelagic zone. The dynamic emergent plant communities that occur immediately landward (west) of the bulrush zone also are mapped in this project while the entire emergent marsh is mapped at least once every 10 years. Recently, the southern islands and the marsh around Henry Creek have been added to the every other year mapping effort. The islands are being mapped to document ongoing restoration efforts; Henry Creek is being mapped because it will be the location of a major discharge from CERP mandated critical water storage and treatment projects. SAV is mapped at a resolution of $1km^2$ once each year, near the end of the growing season.

The most recent littoral zone vegetation map (Hanlon and Brady, in review) indicates that there are 77,838 acres (31,500 ha) of emergent plants. Cattail and mixed cattail with other emergent plants were the most abundant classes, covering more than 24,710 acres (10,000 ha). Torpedograss is the second most abundant class (13,343, acres or 5,400 ha), followed by spikerush (9,637 acres or 3,900 ha), fragrant water lily (8,154 acres or 3,300 ha), and willow (4,942 or 2,000 ha). These results are quite different from what was reported in a vegetation map developed in the early 1970s (Pesnell and Brown, 1977), when the littoral zone had less than 19,768 acres (8,000 ha) of cattail located only along the western edge of that region, with dominant taxa in the interior regions of beakrush, spikerush, mixed native grasses, and cord grass. Beakrush and cord grass are short hydroperiod plants that occurred in the higher elevation areas of the littoral zone where monocultures of torpedograss now occur. Much of the habitat formerly occupied by spikerush in the longer hydroperiod areas has now been taken over by cattail and water lily. These later changes are linked to higher water levels and/or transport of phosphorus into the interior littoral zone along boat trails (Havens, 1997; Hanlon and Brady, in review). Mapping of bulrush and other shoreline emergent plants indicates that in the late 1990s, when water levels were high for several years and substantial wave energy reached the littoral edge, there were losses of emergent vegetation 984 ft (300 m) to 1,640 ft (500 m) wide and up to several km long along the western shore. Those areas became open water by 1999. The spatial extent of bulrush was also reduced, but not to the extent observed for other plants. During 2000–2002, the emergent plant community recovered in the area between the bulrush and littoral zones, when over 1,977 acres (800 ha) of spikerush and mixed grasses developed in that area. This response may be partially responsible for the changes in population dynamics of largemouth bass.

In 2004 submerged aquatic vegetation coverage was greater than 54,000 acres; the highest level encountered since routine mapping was begun. However, after the 2004 hurricane season, coverage was reduced to less than 11,000 acres.

Why Is This Indicator Important?

1. The Indicator is relevant to the Lake Okeechobee Ecosystem and Responds To Variability At A Scale That Makes It Applicable To the Entire Ecosystem or Large Portions Of The Ecosystem:

    - Clear links have been established between hydroperiod (the primary lake characteristic to be modified by CERP activities) and the state of the emergent and submerged plant communities in the lake.
    - Clear links have been established between the quality and extent of the emergent and submerged plant communities and the ecological health of key faunal indicators such as wading birds, and Black Crappy and Large Mouth Bass.

2. The Indicator is Feasible to Implement and is Scientifically Defensible:

    - Remote mapping of emergent plant communities by infrared aerial photography has been conducted in the Lake Okeechobee littoral zone on a regular basis for more than a decade.
    - Annual mapping of SAV in Lake Okeechobee has been conducted on an annual basis since 1999.
    - Both techniques are standard methods and results obtained using them have been accepted in the peer reviewed literature.

3. The Indicator is Sensitive to System Drivers (Stressors)

    - There is statistical evidence that both indicators are responsive to inter-annual changes in hydroperiod; SAV appears to be a relatively short period indicator whereas the emergent marsh community may respond in over a somewhat longer time frame...

4. The Indicator is Integrative

    - Changes in key faunal system components such as wading birds, sport fish, and macroinvertebrate abundance and species composition respond to changes in the indicators

5. Goals and Performance Measures are established in the RECOVER MAP for the Indicator and the following metrics are being monitored:

    - Reduction in invasive and exotic plant coverage; particularly torpedograss, Melaleuca, and cattail.
    - Modest increases in pond apple and willow.

- A nearly continuous and thick band of bulrush located along the lakeward edge of the littoral zone from Clewiston north to the area near the mouth of the Kissimmee River (>30 miles), and around Kings Bar and Eagle Bay Islands.
- Forty thousand acres of SAV at the end of each growing season with at least 20,000 acres being comprised of desirable vascular plant species.
- THE SFWMD is monitoring SAV on an annual basis; torpedograss, bulrush and the most lakeward portions of the emergent marsh, plus the southern islands and the Henry Creek marsh every two years, and the entire emergent marsh at least once each decade.

Discussion

A key issue regarding restoration of hydroperiod, reduction of external nutrient loads, and removal of exotic plants is the potential benefit these management activities provide for the lakes, fish, and wildlife populations. The expectation is that all will benefit; however, certain actions such as reducing nutrients could actually lead to reduced fish productivity. It is assumed that this will be compensated for by the large-scale improvements in habitat quality. Prior to March 2004, there has not been any comprehensive evaluation of how the lake's fauna responds to major changes in plant habitat structure. Since then, the SFWMD's Lake Okeechobee Division has been evaluating two emergent plant communities, spikerush (a native) and torpedograss (an exotic and invasive plant) to assess the type of fish, macroinvertebrate, and periphyton (algae which grows on plants and benthic substrates) communities found in each plant habitat. This research will continue with bimonthly habitat comparisons through July, 2006. Future research is needed to describe floral and faunal communities in all of the lake's major plant assemblages and this has been identified as a priority research area both in the LOPP and by RECOVER. Beginning in autumn 2005, the first steps in this direction will be taken with the inception of a 5 year study designed to look at faunal community structure in several key submerged and emergent plant communities. Development of food web models for the major plant communities in Lake Okeechobee also could provide important information for future refinements to the lake's Minimum Flows and Levels criteria.

Longer-Term Science Needs

Littoral zone and hydroperiod - The uncertainty associated with this general relationship is quite low, because the linkage has been established experimentally in Lake Okeechobee (Steinman et al. 1997, 2000b) and on other systems as well as by multivariate models and GIS in Lake Okeechobee. In addition, the link between water lily expansion and long hydroperiod is circumstantial, since this species is known to respond both to hydroperiod and increased phosphorus inputs (McCormick et al. 1999). Because dense water lily degrades spikerush habitat, this is an area of uncertainty that merits further consideration.

Littoral zone and phosphorus - The uncertainty associated with this relationship also is low again because we can draw inferences from research conducted in the nearby

Florida Everglades. However, while nutrient effects on primary producers (plants and periphyton) are well established, little is known about how nutrients affect higher trophic levels in the littoral food web. It may be particularly important to quantify experimentally how increased or decreased nutrient-induced changes in plants and periphyton affect the productivity of certain key animal species such as apple snails (prey for snail kites) or small forage fish (prey for sport fish taxa and wading birds).

Bulrush & submerged vegetation and high water - It is clear that prolonged or extreme high water has damaging effects on these components of the lake's plant community. However, the causal mechanisms are only generally understood. Given the critical role that these plants play in terms of water quality and fish/wildlife habitat, research is needed to identify the "lake stage window" (yearly range of water levels) that is required to support a healthy community. Research is currently underway to elucidate the relationship between bulrush growth, survival, and vegetative and sexual propagation and hydroperiod. The gross impacts of high lake stage on SAV as mediated through light penetration are clearly understood, however it is unclear what the drivers are for observed interannual changes in species composition. There also is a need to determine conditions necessary to allow recovery of the community when unfavorable conditions do occur (e.g., two successive years of high rainfall and high stage).

District staff also intends to modify the existing lake water quality model so that it can predict, with a fine spatial scale, the extent of submerged vegetation that might occur under different lake stage management scenarios. That tool will be useful to the RECOVER process, because it will allow plan evaluations by the RET to include not only hydrologic and water chemistry predictions, but also predictions regarding responses of one of the lake's key biological communities.

Response to the Independent Scientific Review Panel's Comments

The peer review panel's comments on the Lake Okeechobee system-wide indicator were valuable. In recognizing the importance of the littoral zone, the panel encouraged identification of goals for littoral plant communities and SAV. The goals for the littoral plant communities and SAV are captured in the indicator document. There is one goal identified in the indicator document for bulrush. It is based on a qualitative measure of bulrush growth using lake stage as the metric (see Table 8). Historically, there were about 2,000 acres of bulrush on Lake Okeechobee (Pesnell and Brown 1973). At present, there are about 600 acres. Presumably, the restoration target is somewhere between these two values. It is important to recognize, however, that it will likely take a long time to reach 2,000 acres of bulrush. The panel's suggestion on presenting emergent and SAV information was appreciated and it being considered for future reporting efforts.

Additionally, the panel provided suggestions for several longer-term science needs that were valuable to our research efforts. First, relating to the suggestion to develop food web models the panel will be pleased to know that first steps are underway in the development of a trophic inventory for emergent and submergent plant communities. The panel's second suggestion – to examine whether hydroperiod influences water lily expansion – isn't amenable to direct experimental assessment, but, the SFWMD's efforts on periodic vegetation mapping of the marsh (as described in the indicator document) certainly suggests that this is a likely scenario. Further, this highlights a related, but possibly more pertinent question of whether an improved operating schedule for Lake Okeechobee, when coupled with selective Nymphaea control, might reverse this change. Work is also underway to examine the panel's third suggestion of trying to identify the yearly range of water levels ("lake stage window") required to support healthy bulrush populations and SAV. Finally, the panel's suggestion on efforts to modify the existing lake model for fine-spatial-scale prediction of SAV cover under different lake stage management strategies is valuable. However, it will likely be at least another year before the necessary experimental data will be available to facilitate a major model revision.

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Invasive Exotic Plants

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What is This Indicator?

An "indicator" for invasive exotic plants is not similar in nature or context to the other ecological indicators because exotic species do not make good indicators of ecological function, process or structure, especially for restoration. In addition, measurements of their biological "performance" do not provide any insight into how they may or may not impact other biological functions or restoration, especially since positive "performance" of exotics is considered detrimental to the environment. While invasive exotic plants may result in changes in ecological function and structure they do not necessarily indicate anything regarding ecological condition, or restoration except as pertains to their level of invasion and adverse impacts on the ecosystem and biota. Science cannot say with any level of certainty that the condition of the environment is directly linked to its invasion by exotic species. This instead, is an indicator of the status of the spread and spatial distribution and dominance of invasive exotic species and an indicator of progress (or lack thereof) in the control and management of invasive exotic species. The "indications" provided by monitoring and assessments of invasive exotic species are viewed more as an evaluation of the integrity of the natural system and native vegetation.

Invasive species are considered as drivers (stressors) in the RECOVER Conceptual Ecological Modules. Since exotic species often drive ecological changes that in some cases may well be irreversible, prevention and early detection and removal are key to control and management. Monitoring and regular assessment of the spread of existing exotic species and the detection of new potentially invasive species is critical to effective control and management. Trends in the spread and density of invasive exotic plants, and the impacts that control and management activities have on their spread and density will be important to any assessment of the success of management of invasive species in support of Everglades' restoration and CERP. That is the purpose of this indicator.

There are no CERP MAP II hypotheses specifically related to invasive exotic species at this time. However, the CERP MAP II addresses the issue with invasive exotic species and several of the ecological hypotheses discuss exotic species. See Chapter 9 of the 2006 MAP II document.

What Has Happened to Affect The Indicator?

Concerns about exotic species, both plants and animals, relate to their negative impacts on the natural environment. Because each exotic species new to south Florida has a latent but usually unknown potential to become invasive restoration of the south Florida ecosystem, including the prevention, eradication, control and management of invasive exotic species must include a means to assess the status of invasive exotics in the natural system and their impacts on restoration success. There is a clear consensus among scientists and managers that an Everglades' flora and fauna replaced by exotic plants and animals, irrespective of how well CERP manages the hydrology, is not a restored Everglades.

Florida is noted, along with Hawaii, California, and Louisiana as one of the states with the greatest number of invasive non-indigenous species. Approximately 1/3 of the plant species in south Florida are exotic and south Florida has more introduced animals than any other region in the United States. An estimated 26 percent of all mammals, birds, reptiles, amphibians, and fish are exotic (see Table 9). South Florida has one of the largest non-native faunal communities in the world (Gore, 1976; Ewel, 1986; OTA, 1993; McCann et al., 1996; Shafland, 1996; Simberloff, 1996; Corn et al., 1999).

Why is Florida being invaded? South Florida's tropical climate and island like situation appear to make it as vulnerable as other tropical island habitats, considered the most invaded habitats in the world (Simberloff, 1996). Because of these characteristics, and as a focal point of international importation, Florida has been an epicenter for biological invasions with their beginnings dating back to early commerce between the City of St. Augustine and South America (Doren and Ferriter, 2001). During the past 400 years, Florida has been inundated with many predominantly tropical non-indigenous plants and animals. These waves of introductions accelerated during the twentieth century principally through importations by the ornamental plant and exotic pet industries.

With continued conversion of natural lands for development, importation of exotic species and changes in the environment due to restoration activities and other causes, exotic species will continue to pose a serious threat to restoration of the Greater Everglades.

What Areas of the Everglades Does This Indicator Cover?

Exotic plants (and animals) are found throughout south Florida and in all of the CERP modules and areas outside these CERP modules (see Table 9 and Figure 1).

What Does the Research Say?

There is significant scientific evidence and research documenting that invasive exotic plants are degrading and damaging natural ecosystems (species abundance and diversity, functions and structure) in South Florida (see Doren and Ferriter, 2001). These species are causing significant ecological harm through crowding out and displacing native vegetation upon which native wildlife is dependent for food and shelter. Exotic species can become "keystone" species in new environments causing serious ecological changes including (1) alteration of soil accretion rates and types (2) changes in soil and water chemistry, (3) alteration of ecosystem functions such as carbon sequestration and nutrient cycling, (4) attenuation of gene pools and reduction in genetic diversity, (5) reduction in native species diversity, (6) alteration of community composition and structure, and (7) loss of native biodiversity (Gordon, D.R., 1998). Exotic plants provide reduced habitat value for native wildlife (Cox, G.W. 1999). The distribution, magnitude, and impacts of exotic animals in South Florida are less well understood but recent studies have shown that invasive exotic animals may also have significant impacts on natural systems (see SFWMD 2006).

Significant research has been conducted related to understanding species invasiveness and habitat susceptibility but to date useful generalizations that can be applied have not been able to be developed (Cox, G.W. 1999, Zalba et al. 2000). Recent work on the development of Weed Risk Assessments in several countries including the US is providing some information for assessing an individual species' risk of becoming invasive. However, significant knowledge of a species is required and no generalizations regarding invasiveness or habitat susceptibility can be drawn from the assessment tools currently available.

While research indicates that there is a relationship to disturbance and invasion by exotics, that relationship is still poorly understood and little or no functional ecological links are yet quantitatively described to provide significant predictive capability (Hengeveld 1987, Levin and D'Antonio 1999). The vast number of possible disturbance sources, including superimposition of anthropogenic and natural perturbations, and even restoration activities, further complicates attempts to identify clear links between disturbance, habitat invasibility and exotic species invasiveness. Additionally, invasive species are documented to invade undisturbed habitats (Lonsdale 1999, Cronk and Fuller 1995). To date, the best predictor of invasiveness is still whether or not the species is invasive in other similar habitats and in similar climatological zones (Reichard 1997).

Invasive exotic plants (and animals) are present in all seven regional modules and throughout south Florida (Ferriter, Doren et al. 2006). Over 600 species of exotic plants are documented in southern Florida, however, only 67 of those are considered to be serious pests of natural areas (see FLEPPC 2005; http://www.fleppc.org/list/list.htm) and even fewer are considered as high priority for control (Ferriter, Doren et al. 2006) (see Table 9).

However, without control and management of exotic species there is the potential that restoration would fail since exotics have the capacity to drastically alter the natural environment (Mack et al. 1999, Mack et al. 2000). Therefore, this "indicator" is being developed with the need in mind to be able to report regularly on the status, progress and outlook of invasive species, their control, and restoration success (see Table 6).

MODULE	Plants	Amphi-bians	Rep-tiles	Birds	Mam-mals	Fish	Inverte-brates
FL. Keys	11	4	19	9	8	6	16
Fla. Bay & Southern Estuaries	13	4	36	4	12	95	26
Greater Everglades	5	4	42	8	13	65	43
Big Cypress	15	3	23	7	8	10	15
N. Estuaries - West	18	2	20	9	7	7	21
N. Estuaries - East	9	3	20	8	9	16	23
Lake Okeechobee	8	4	22	8	9	11	8
Kissimmee River	23	3	12	7	11	10	13

Table 9. Numbers of exotic species by class (except all invertebrates are lumped and not broken out by class) and module. Invasive plant numbers listed represent only those species considered as acute problems that have been identified as high priorities for control actions by land managers.

Why is This Indicator Important?

1. The Indicator Is Relevant To The Everglades' Ecosystem And Responds To Environmental Conditions At Multiple Scales That Makes It Applicable To The Entire Ecosystem:

    - Over 600 species of exotic plants and over 200 species of exotic animals have been introduced into south Florida
    - Approximately 10% of these species are Invasive and threatening natural areas of southern Florida

- Invasive exotic species can become “keystone” species once they invade a natural area and can alter ecosystem function, composition and structure
- Once established species may exhibit long lag-times prior to becoming serious invaders and are more susceptible to control or eradication during this period
- Unanticipated cross-scale interactions [natural or anthropogenic (i.e. CERP projects)] may lead to exponential invasion rates in a relatively short period of time
- Invasive exotic species threaten the restoration goals of CERP, RECOVER and the Task Force

2. <u>The Indicator is Feasible to Implement and is Scientifically Defensible:</u>

   - There are existing funded cooperative invasive exotic plant monitoring and assessment programs, and control and management programs with the EPA, NPS, USFWS, USDA, Corps of Engineers, Florida DEP and South Florida Water Management District
   - There are good spatial data for all of south Florida for several key species from 1990 and spatial data for several other species covering some sub-regions
   - There are reliable models for the spread of Lygodium microphyllum and Melaleuca and exotic species are being developed in the Everglades Landscape Model (ELM)
   - There are models and performance measures being developed for biological control agent spread and effectiveness
   - There are numerous peer reviewed journal articles, reports, and book chapters related to invasive species in south Florida
   - This indicator is being incorporated into the CERP RECOVER MAP program and the system wide indicators for the South Florida Ecosystem Restoration Task Force

3. <u>Exotic Plants are System Drivers (Stressors):</u>

   - Invasive exotic plants can alter and affect hydrological flow, depth, duration and quality
   - Invasive exotic plants can alter soil deposition rates, soil type, and biogeochemistry
   - Invasive exotic plants can reduce overall biodiversity, species abundance and composition, community and habitat structure

4. <u>This Indicator is Integrative:</u>

   - Key Invasive exotic plants are monitored and assessed collectively
   - Control and management programs utilize monitoring information to develop integrated strategies for management

- Ecological areas of critical concern may be prioritized for management actions collectively

5. Goals, Performance Measures and a Conceptual Ecological Model are Being Established for the RECOVER MAP and the following metrics are being monitored:

   - Number of high priority invasive exotic plant species per module
   - Number of new exotic plant species found per module per monitoring time period
   - Number of new locations of existing invasive exotic plants
   - Number of acres by species by module
   - Assessment of species spread
   - Assessment of maintenance control program performance
   - Assessment of chemical or biological control program performance

Discussion

Cross-scale interactions challenge the ability of ecologists to understand and predict system behavior at one scale based on information obtained at either finer or broader scales. Under some conditions, fine scale processes can propagate nonlinearly to influence broader scale dynamics while under a different set of conditions broad scale drivers can overwhelm fine scale processes (Levine, 2000).

Invasive exotic species illustrate this well. A newly introduced exotic species initially may distribute relatively small numbers of propagules to remote locations. The fine scale processes (soil type, soil moisture, ph, etc.) in that location must be conducive to germination and recruitment in order for the species to establish. Once established, over time as the species matures and reproduces, additional propagules are released and recruit into new sites. In the early stages of spread the establishment sites may be widespread. As more propagules are produced and distributed more propagules are released over larger regions and time-spans providing a greater opportunity for more propagules to encounter the right fine-scale conditions helping to create greater spatial connectivity. It is at this point where the multiple-scale interactions such as those between numbers of propagules, propagule distribution, and finer-scale site conditions interact with larger-scale patterns (e.g. landscape heterogeneity, weather patterns, hydrology, rainfall, etc.) that may lead to the exponential increase in spread rates such as we now see with *Lygodium microphyllum*.

Thus, understanding processes at a single scale or even multiple scales requires consideration of the interactions across-scales. Cross-scale interactions often result in “surprises” with severe consequences for the environment (e.g., wildfire, pest outbreaks) and human welfare (e.g., spread of infectious diseases). Alternatively, cross-scale interactions can be used to accelerate recovery of vegetation following fire or removal of exotic species. Spatial heterogeneity in the environment often structures the outcome of cross-scale interactions by governing the nature and scales of particular processes (e.g., fire spread as affected by fine-scale fuel connectivity, wind parameters as affected by topographic position, exotic species invasion establishment and spread as affected by initial site conditions or propagule pressure). Assessing the spatial distributions, density, species and habitats related to exotic plant invasions will be critical to understanding the interactions of these species and the natural environment and also in controlling these species.

There are obvious limitations to this proposed "indicator". The monitoring programs used to collectively assess invasive exotic plants collect data at different spatial and temporal scales, different levels of precision and accuracy, and different geographic coverages. Also, given that the geographic coverage for the monitoring programs intersects predominantly in the Greater Everglades Module, species occurring in other modules may be un- or underrepresented. In modules that are either not covered by these programs or only partially covered in geographic coverage or in program coverage, the limitations of those results will be discussed and represented in the assessment reports to the Task Force. A lack of information regarding invasive exotic species is considered to be a serious deficit in our ability to manage these species and an understanding of where we lack information (i.e. a monitoring and assessment program) will assist us in developing a more comprehensive and strategic program for invasive species that may be considered for implementation through CERP or other agency programs.

While exotic plants may not be considered a conventional indicator, the need to understand and assess the status, scale, spread and impacts of invasive exotic plants, and our performance in controlling them, requires that the restoration program utilize effective measures to assess the status of these harmful species. This indicator helps provide those means and will offers a valuable tool in helping RECOVER and the Task Force understand the status of invasive species and our effectiveness in their management and control.

Longer-Term Science Needs

In monitoring for invasive species it is critical to understand how the asymmetry in the presence versus absence of a species relates to methodology. A key concern in monitoring exotic species relates to the absence of a species. A species can be absent from a sampling program either because it is actually not there or because it was not detected—i.e. the sampling program may not be capable of detecting the plant, or the detection method itself may not be designed to detect a species in certain situations. For example, a particular life stage may be too small to detect (e.g. seedlings), or the location of a plant may prevent its detection (e.g. under tree canopies). What is critical when sampling for invasive exotic species is to ensure that the sampling methods being used are likely to determine that when a species is absent in the data, that species is actually absent in the area being surveyed and not just being missed because of the survey method or study design. Data from four relatively independent monitoring programs are being used to assess invasive exotic species for this indicator. The gaps inherent in using these programs need to be rigorously reviewed in order to provide a sound scientific basis for either improving the detection and assessment capabilities of the existing programs or developing a different invasive plant monitoring program that overcomes the existing limitations including: gaps in spatial coverage, differences in levels of precision (e.g. GPS locational data), detection capability (i.e. signatures) for different species, integration of native vegetation and exotic spatial data. Animal species need to be included in any consideration for invasive exotic species monitoring, and control programs in the future.

As new exotic species may be found there is a critical need to:

1. Understand their basic biology in order to better determine control methods
2. Conduct research in possible biological control agents
3. Assess the risk that a new species may become invasive

Building these aspects into any long term science capability for exotics will be essential to helping detect, assess, eradicate or control invasive exotic species. Development of a rigorous and powerful risk assessment tool for exotic plants and animals in south Florida is needed.

The following are areas identified for scientific inquiry by the RECOVER MAP II (2006) and provided as recommended issues that the Module Groups should consider when conducting their assessments.

1) A major concern of the assessments is the need to consider the potentially irreversible alterations in ecological community structure and function caused by the replacement of native plants and animals.

    a. Carbon sequestration
    b. Nutrient cycling and nutrient mineralization
    c. Alterations in geomorphology including soil erosion, soil deposition and sediment accumulation, soil composition (i.e. soil types), soil decomposition, and changes in soil elevation
    d. Alterations of natural fire regimes (e.g.,intensity, frequency, and seasonality
    e. Alterations in surface water flow, quantity and quality
    f. Alterations in salinity of soil and water
    g. Alteration in primary productivity, food web structure and energy flow patterns
    h. Alterations in channelization of wetlands, estuaries and coastal

marshes

i. Decreased recruitment of native plants and animals
j. Alterations in water and nutrient uptake
k. Alterations in population and stand structure in plants and animals
l. Alterations in competitive ability and selective pressures on native species
m. Increases in the natural background rate of species extinctions (natural rate is approximately 1 to 10 million years per species, current extinction rate due to habitat loss and invasive exotic species is approximately 500 years per species).

2) The irreversible reorganization of the Everglades' ecosystem resulting in a new altered stable state (structural and functional) that is entirely manifested by and dependent on invasive exotic species.

3) The loss of native habitat

4) The development and implications of anoxic bacteria and low level of dissolved oxygen in wetlands and waterways resulting from infestations of exotic vegetation.

5) The alteration or elimination of natural vegetation community structure or abundance.

6) The occurrence of faunal shifts.

7) The potential hydrologic impacts.

8) The potential loss of biodiversity within the Everglades ecosystem.

9) The impacts and physical damage and loss to water control and conveyance structures such as canal banks, pumps, etc.

10) The reduction of habitat available for native and migratory birds.

Given the current and potential impacts of non-indigenous organisms in South Florida, scientists are obliged to begin to factor these species into restoration models, and research must be carried out to understand the distribution, biology, and impacts of these non-indigenous organisms. The idea of dealing with non-indigenous organisms in an all-taxa approach is a nascent study, but it is sure to emerge as an important field of science given global trade and the virtual "open door" situation with regard to importation of exotic organisms. Organisms will continue to arrive and will continue to establish breeding populations in South Florida. The abundance of non-indigenous plants in South Florida may be accelerating this process, as animals are arriving not only without their natural enemies but also into a hospitable environment that includes plant species from their native range. It is probably no coincidence that the Burmese python prefers levees covered with Burma reed in the Everglades.

Response to the Independent Scientific Review Panel's Comments

The Independent Scientific Review Panel provided some very helpful comments and suggestions and felt strongly that the status and management of invasive species "should be monitored and communicated to decision-makers." The majority of the reviewers comments related to the 'stoplight' communication tool and are addressed on pages 21 and 22 in this report. The reviewers pointed out that the current metrics are general and thus harder to measure. I agree and we will be trying to develop more quantitative metric measures through the development of a Performance Measure that evaluates actual numbers of observations of exotic species. However, even this effort will be limited by the current monitoring programs and the species they monitor. I agree with the reviewers that an idealized goal for invasive species is zero, however, realistic goals are needed but are probably one to two years from being developed. They also recommended clarifying the targeted species, which we did, (see Tables 6 a – h). They also recommended better standardization and coordination among the monitoring programs. For several years we have been working on developing standard methods for sampling and will be continuing to implement a more coordinated approach where we can. The reviewers also recommended addressing the longer term science needs, and we agree.

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PART III

RESTORATION COMPATIBILITY INDICATORS

WATER VOLUME

SALINITY INTRUSION IN THE BISCAYNE AQUIFER

FLOOD PROTECTION SOUTH DADE AGRICULTURE

Water Volume

Authors: David M. Wegner and Robert F. Doren

What is this Indicator?

The Comprehensive Everglades Restoration Plan (CERP) includes 62 projects that will be constructed to retain and store water in the system instead of releasing it to tide (RECOVER, 2005, see Figure 5). Completed projects will include both above- and below-ground storage systems. The cumulative objective of these projects is to significantly reduce the release of millions of acre feet of water for flood control by increasing storage capacity and thus increase the amount of freshwater available to all water users—people as well as the environment—and to meet anticipated water supply needs for the 50 year CERP planning horizon. This retained and stored water is referred to as “new” water.

New water is defined under CERP as being *additional water made available through implementation of CERP projects that is greater than the water that was available in the 1995 Base level.*

The indicator for water volume includes meeting predicted target “new” water volume targets (in acre feet (af)) identified through the C&FS RESTUDY, specifically:

- By 2010 - 931,000 af of new water
- By 2015 - 1,060,000 af of new water
- Full Restoration – 1,620,000 af of new water

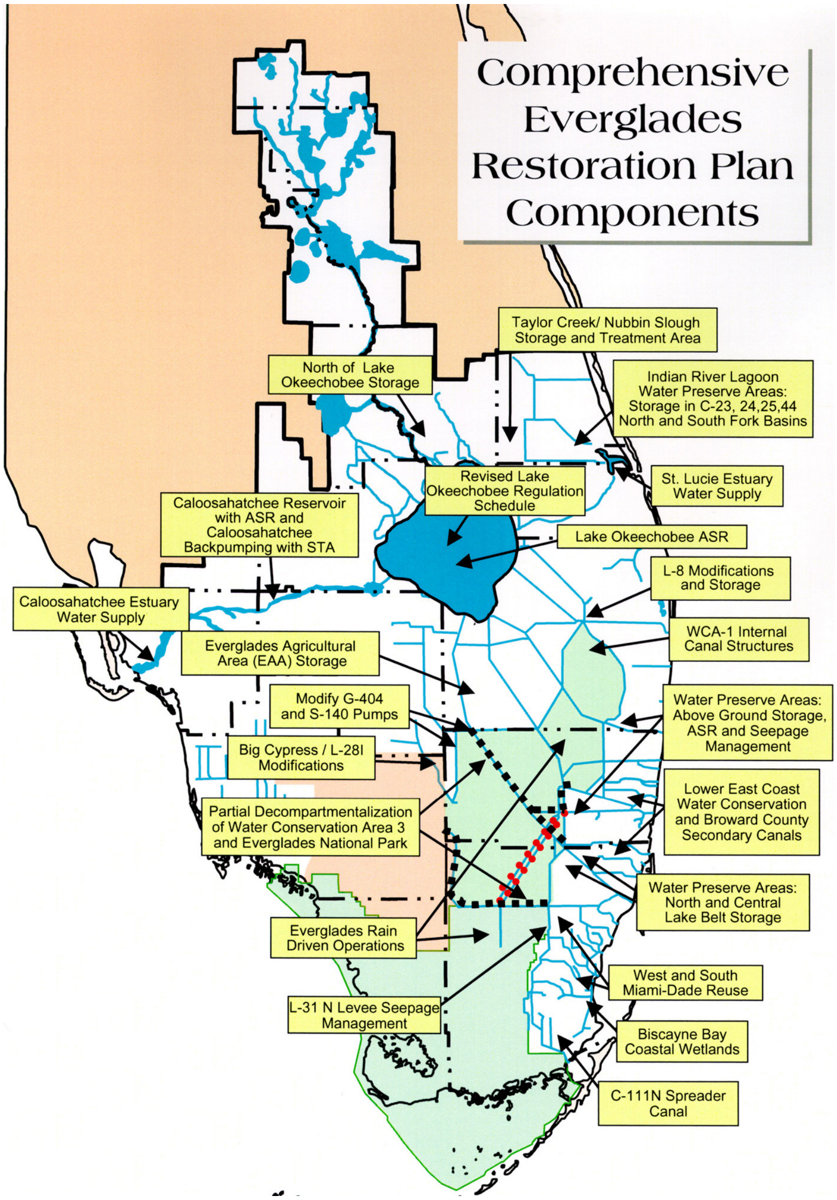

Figure 5. CERP proposed water projects (available at http://www.evergladesplan.org/images/cerpmap_200.jpg, interactive project search engine available at http://www.evergladesplan.org/pm/projects/cerp_gis.cfm**.**

CERP MAP Hypotheses related to Water Supply in South Florida:

- Restore hydrology in the natural system to conditions similar to the Natural System Model or other restoration targets by distributing the appropriate amount of water to the right place, at the right time, and of the right quality

- Reduce harmful releases of excess water to the natural system such as the Caloosahatchee Estuary, St. Lucie Estuary, Lake Worth Lagoon, and the Everglades Protection Area
- Meet a 1-in-10 year level of service for urban and agricultural water supply demands through regional water deliveries and control seepage from the Water Conservation Areas and Everglades' National Park (373.0361(2)(a)(1), Florida Statutes (FS))
- Achieve a minimum level for the Biscayne aquifer criterion by preventing saltwater intrusion into the Biscayne aquifer by maintaining the water levels in the primary coastal canals (Section 373.042, FS)

What Has Happened to Affect This Indicator?

In 1948 Congress authorized the Central & Southern Florida Project (C&SF). It was originally designed to provide flood control and deliver water for municipal, industrial, and agricultural uses. Later it was redesigned and managed to also prevent saltwater intrusion into groundwater resources and provide water for Everglades National Park. To accomplish these earlier mandates, numerous State and Federal agencies constructed this complex water-management system in an attempt to meet the estimated water needs for a projected population of approximately 2 million South Florida residents by 2000. In spite of those projections, the actual population in 2000 was over six million and it continues to grow rapidly.

As population increased, so did the demand for water and land, and the subsequent conversion of natural lands (e.g., uplands, wetlands, mangroves, estuaries, beaches, etc.) to urban and agricultural uses (RECOVER, 2005). When natural areas that are extremely permeable to rainfall are developed, and development occurs in previously wet or flooded areas, the water that once "flooded" these wetlands must now be removed which usually meant it was discharged to tide and thus no longer are available for recharging groundwater resources. The result is a reduction in the extent of the natural system, a reduction in water available for the natural system, a reduction in water resources and recharge capability for the aquifer, loss of water from the natural and human systems, increased needs for flood protection in urban and agricultural areas, less water available for the human population, and conflicts for water between the natural system and people.

The area encompassed by the C&SF Project (USACE and SFWMD, 1999) extends from Orlando to the Florida Keys. The watershed includes 16 Florida counties, and contains 11 major physiographic provinces, with the Kissimmee River, Lake Okeechobee and Everglades being the dominant sub-watersheds that historically connected a complex mosaic of wetlands, uplands, and coastal and marine areas.

The C&SF Project has over 1,000 miles of levees and canals, 150 water control structures, and 16 major pumping stations. Much of this infrastructure will be expanded, enhanced, or undergo major modification by current and proposed CERP projects (see Figure 5).

The South Florida Ecosystem Task Force (2002) identified three goals for restoration, one of which addresses the need to *Foster compatibility of the built and natural systems* (Goals 3) and specifically *Provide sufficient water resources for the built and natural systems* (Subgoal 3-C). The objectives of Subgoal 3-C is to increase regional water supply, increase volumes of reuse water, achieve annual targets for water and reduce overall water consumption for irrigation.

The water volume indicator measures the success of the CERP projects to: 1) retain and store "new" water (predominantly made up from water that usually was dumped to tide but in the future may include a small percentage from water reuse and conservation measures), and 2) actually proportion and deliver (between the natural system and the developed system) the "new" water as proposed under CERP guidelines. The indicator measures the ability of water managers to distribute "new" water across the ecosystem and built system in a manner that meets the needs of both the existing infrastructure of south Florida and the restoration of the Everglades ecosystem (RECOVER, 2005). Interim targets established using the South Florida Water Management Model (SFWMM) are characterizations of "new" water made available by implementation of CERP projects.

CERP projects that capture water categorize "New" Water and "New" Available Water.

- "New" water = additional water captured by CERP projects over three periods, 2010, 2015, and full implementation D13R.
- "New" Available Water = Additional water captured by CERP projects that is actually distributable to recipients over three periods, 2010, 2015, and full implementation of alternative D13R.

The "new" water comes from a variety of sources. For example, in the year 2010, almost all of the "new" water comes from capturing water previously sent to the estuaries and about 7 percent comes from the Everglades and Big Cypress. By the end of CERP implementation (D13R), wastewater reuse projects account for 18% of the "new" water with water previously released to tide still being the most significant source (RECOVER, 2005).

Based on RECOVER (2005) projections, the following volumes of "new" water will be made available by implementing the CERP program: (1) 930,000 acre-feet of "new" fresh water will be available for redistribution by 2010; (2) 1,060,000 acre-feet of ""new"" water will be available for distribution by 20105; and

1,462,000 acre-feet of *new* water will be made available for distribution a full D13R implementation (see Table 10).

Hydrological Basins	2010 931,000 af	2015 1,060,000 af	D13R 1,462,000 af
Urban Basins	41.9%	37.8%	28.9%
Everglades and Southern Estuaries	27.0%	26.9%	22.6%
Lake Okeechobee and Kissimmee River	15.9%	15.3%	15.0%
Agricultural Basins	15.2%	20.0%	7.4%
Northern Basins			23.5%
Big Cypress Basin			2.5%

Table 10. Proposed distribution of "new" water by date and basin.

Historically, water that supported the Everglades ecosystem collected in a wetland-based watershed that extended from Orlando to Florida Bay. This original Everglades' watershed had an area of approximately 10,890 square miles (Light and Dineen, 1994; Ogden *et al.,* 2003). Today anthropogenic impacts, including development and flood-control structures, has reduced the Everglades to approximately 50% of its original size (Davis et al. 1994) and greatly modified the hydrologic structure of South Florida. Figure 6 reflects the historical, current, and proposed hydrological patterns for South Florida.

In 1995, the National Research Council concluded that increased water storage and associated management of "new" water would be integral to successful restoration of the Everglades ecosystem (NRC 2005). The primary tool used to evaluate past, present, and future water supply scenarios in South Florida is the South Florida Water Management Model (SFWMM). The SFWMM simulates the hydrologic regime and the management of the South Florida water system from Lake Okeechobee to Florida Bay (NRC 2005).

Water supply in South Florida is directly correlated with flood-control activities. For example, rapid rainy season flood releases, coupled with the (1) lack of retention in Lake Okeechobee, (2) reduced areas of the northern historical saw grass plains, and (3) loss of the eastern peripheral wetlands and sloughs have reduced water storage within the hydrologic system. This has lead to excessive dry season demands on the regional water supply system.

What Areas of the Everglades does this Indicator Cover?

The water volume indicator covers the South Florida hydrologic system, with specific monitoring points at reference locations of the SFWMD model. Figure x depicts the general area of assessment for the Water Supply Indicator. Counties include all or parts of 16 counties, including Monroe, Miami-Dade, Broward, Collier, Palm Beach, Hendry, Martin, St. Lucie, Glades, Lee, Charlotte, Highlands, Okeechobee, Osceola, Orange, and Polk and incorporate all the regional modules as well as all areas outside the designated modules.

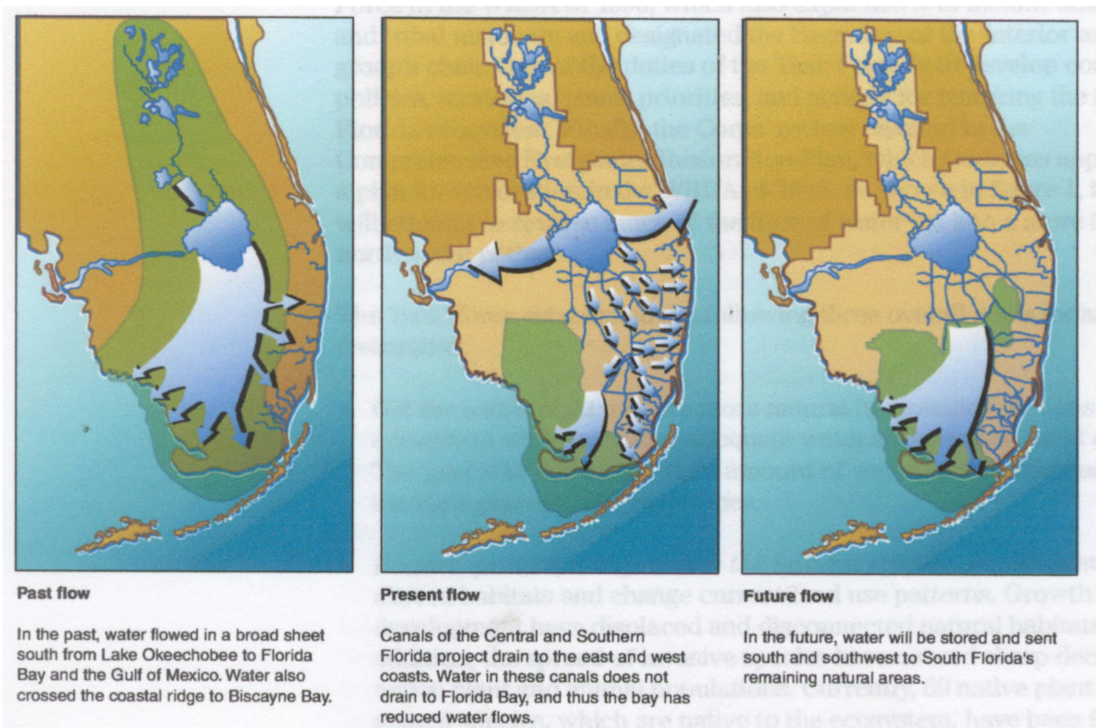

Figure 2. Flow movement in South Florida, historical, current and proposed (Source: South Florida Water Management District).

What does the Research Say?

SFWMM simulates the hydrologic regime and the management of the South Florida water system from Lake Okeechobee to Florida Bay (NRC 2005). The model can be used as a both a research and management tool to predict responses to changes in water inputs, outputs, and system processes related to changing operational anticipated water management control structures. Model parameters and results include:

- Rainfall
- Evapotranspiration
- Infiltration

- Overland flow
- Groundwater flow
- Canal flow
- Canal-Groundwater seepage
- Levee seepage, and
- Groundwater pumping

Why is This Indicator Important?

Resolution of the decline of the Everglades ecosystem requires that increased water needs to be supplied in both a spatial and temporally appropriate manner. Historical movement of water from the Orlando area southward was unimpeded by manmade structures. As water infrastructure was developed, an artificial pattern of water distribution and timing resulted, to which species and ecological processes adapted.

CERP is an aggressive approach to restoring ecosystem balance through implementation of water management projects. Some of these include the development of storm water treatment areas, underground and surface reservoirs; removal of selected levees and canals; and development of water management areas.

1. The Indicator is Relevant to the Everglades Ecosystem and Responds to Variability at a Scale that Makes it Applicable to the Built System

   - The indicator responds to spatial and temporal variability at a scale that makes it applicable and capable of being monitored throughout the South Florida area
   - The actual and predicted relationships between water management actions and available water are known and can be predicted through the SFWMM
   - Additional water availability for the natural system has been identified as decisive in Everglades' restoration

2. The Indicator is Feasible to Implement and is Scientifically Defensible

   - The South Florida Water Management District is collecting data on water management activities on a continuous basis throughout the entire system.
   - A definitive and agreed upon quality control and quality assurance program has been developed and implemented
   - Periodic review of the program occurs with appropriate changes made as necessary and appropriate

- Comprehensive hydrologic models have been develop and the relationships between rainfall, water supply, water management and hydrologic conditions in the natural areas is statistically correlated
- Numerous peer reviewed publications regarding the relationships of hydrologic resources, management, supply and the needs of the natural system have been produced

3. The Indicator is Sensitive to System Drivers (Stressors)

- Hydrologic conditions (water stage, depth, duration, timing and distribution) are directly linked to rainfall and water management and statistical correlations are well established for these relationships
- The South Florida hydrologic system is composed of surface and subsurface components. Rainfall is the primary driver for supply of water to the hydrologic system. The water supply is managed by Federal and State entities through a series of reservoirs, referred to as Water Conservation Areas (WCA's), groundwater reserves, canals, levees, pump stations, wetlands and lakes.
- Impacts from pumping, rising sea levels, and water management activities can be directly evaluated in the system components

4. The Indicator is Integrative

- Water supply volume is directly correlated with existing storage and distribution systems in South Florida
- Water volume is measured in all system components by specific metrics agreed to by Federal and State water managers
- Techniques and approaches are well established and have been peer reviewed
- Hydrologic conditions are affected by and affect all areas of the natural and built systems

5. Targets and Performance Measures are Established for the Indicator

- The South Florida Water Management District has developed a water management model that has been reviewed and agreed to by restoration hydrologists
- The water management model has been used to predict available new water under specific project options for specific years (2010, 2015 and full CERP implementation). Specific acre-feet of "new" water are forecast and will be used as targets and performance measures (see Table 10).

Discussion

Restoring the Everglades ecosystem and protecting the existing users of water in South Florida requires extensive and continual management efforts. Getting the water quality, quantity, timing, flow and distribution "right" for successful restoration requires an integrative approach that takes into account the complex and dynamic nature of water movement throughout the entire hydrologic system.

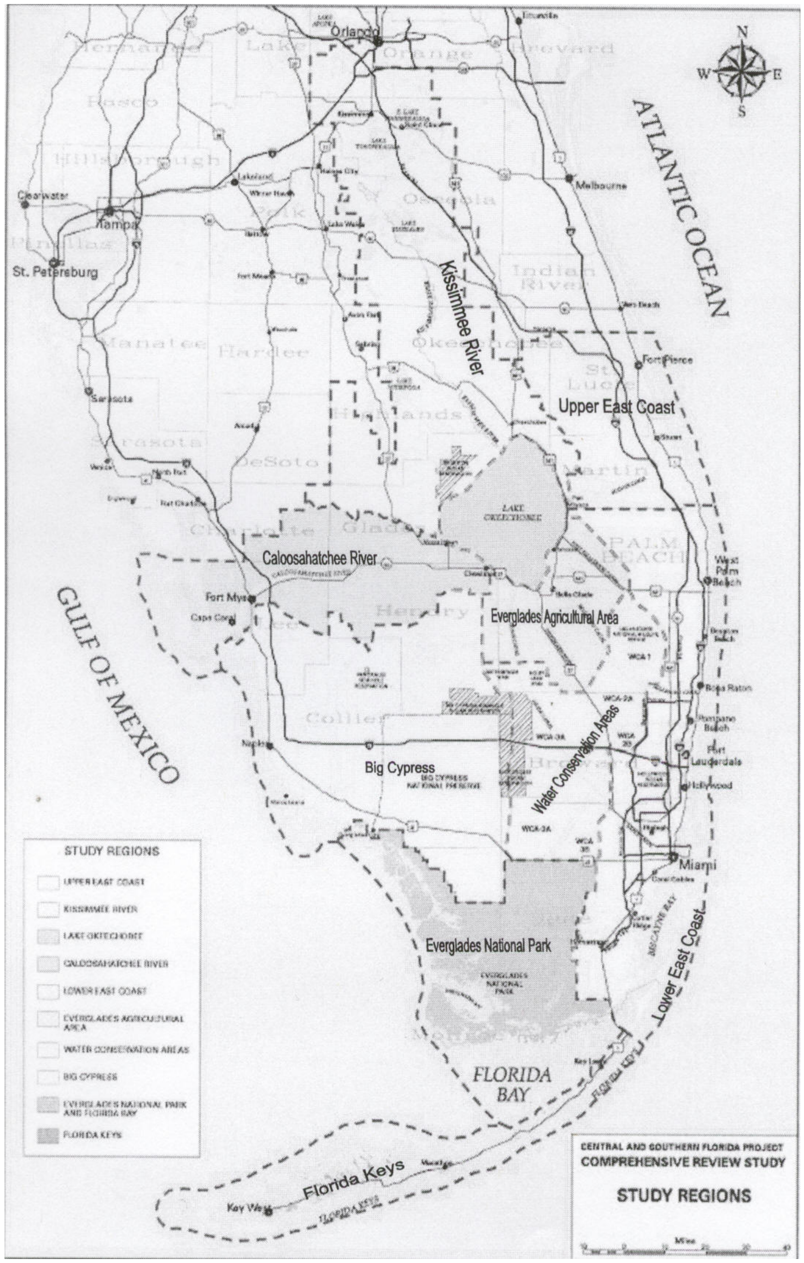

Figure 7. Regions to be evaluated during CERP implementation (USACE and SFWMD 1999).

The South Florida Water Management District, in cooperation with the U.S. Army Corp of Engineers and other participants, has developed an integrative hydrologic model. The South Florida Water Management Model has been used to define hydrologic conditions for the established base condition (1995) and three additional future years (2010, 2015, and hydrologic model D13R – full CERP implementation – 50 year planning horizon). Specific volumes of anticipated amounts of available "new" water have been predicted for the entire area and for individual system components.

It is clear that accurate assessments of water supply and distribution will be necessary to evaluate each of the major regions of the restoration area. Figure 7 depicts the locations of these major regions that will need to be evaluated as CERP projects come on line.

Longer Term Science Needs

Developing and implementing a viable and scientifically credible water volume compatibility indicator can be accomplished utilizing existing data and information. Refinement and development of flexibility in addressing in more detailed alternatives to water management in south Florida will require refinement of the primary measurement and evaluation tools. Listed below are specific areas where additional research and evaluation should be focused.

- Continued refinement and verification of the SFWMM to ensure that the results of simulation scenarios accurately reflect hydrologic system responses to restoration projects.
- Determine potential impacts from global climate change and its probable effects on hydraulic regime (increased or decreased rainfall, sea level rise, timing, and frequency of rain, intensity of rain).

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Biscayne Aquifer Saltwater Intrusion

Authors: David M. Wegner and Robert F. Doren

What is This Indicator?

A CERP goal is to enhance economic values and social well-being. One means to accomplish this is through ensuring adequate water supplies for current and future water users by protecting the primary water supply source, the Biscayne aquifer. Saltwater intrusion poses a continuing threat to the Biscayne aquifer. In order to restrict the inland migration of the saline interface, a sufficient freshwater head must be consistently maintained within the aquifer. Inadequate water levels occurred in 1939, when more than 10,000 water supply wells in South Florida were affected by high chloride concentrations, including the partial loss of five major wellfields (Parker et al.1955). Since that time, a number of different actions have been taken to protect public and private wellfields from the threat of saltwater intrusion. One of which was the completion of coastal water control structures in the 1950s. CERP implementation will increase the storage capacity of water in the regional system for delivery to the Lower East Coast Service Area. The increase in regional storage capacity provided by the CERP will supplement regional and local sources used to maintain sufficient water levels behind these coastal water control structures to prevent saltwater intrusion. In addition to public water supply, the Biscayne aquifer also provides base flow to importantestuaries such as the Lake Worth Lagoon, Biscayne Bay and Florida Bay during low rainfall years.

In order to prevent harmful movement of the saltwater interface in the Biscayne aquifer, the South Florida Water Management District (SFWMD) manages coastal groundwater levels by operating the primary canal network, regulating surface water control elevations for developments (through surface water management permitting), and by limiting coastal consumptive use withdrawals. Operational criteria for the coastal canals are maintained by the SFWMD to prevent harm. These management levels vary seasonally as the SFWMD works to balance the goals of flood protection (wet season control level) and water supply (drought management control level). The drought management control levels represent target management elevations during the dry season. Water supply releases are made from regional storage sources (currently the Water Conservation Areas and Lake Okeechobee) to achieve these targets whenever possible. These canal levels in turn influence the adjacent dry season groundwater elevations within the Biscayne aquifer.

Two metrics are applied to measure the likelihood of saltwater intrusion based on different climatic conditions:

1) Two feet National Geodetic Vertical Datum (NGVD) is used for comparison in keeping with the Ghyben-Herzberg relationship that estimates that one foot of freshwater head is required to protect forty feet of aquifer. The aquifer along the

southern Miami-Dade is approximately eighty feet thick and would require two feet of freshwater head. The stage where the frequency of exceedance is 90% was used since it reflects lower stage of the dry season when the risk of saltwater intrusion is increased.

2) The second metric uses the stage when the frequency is exceeded 50% of time since it represents approximately the midpoint between the wet and dry seasons and can be viewed as “average conditions” for the 2000 base condition. Saltwater encroachment has occurred during the period of record and, therefore, exceeding the 50th return frequency is considered an improvement but may not prevent further encroachment.

Currently, these canals are generally maintained at these stages. During drought or the dry season, there may not be enough water in the regional system to maintain these canal stages.

The surficial aquifer system, the principal source of ground water in southeastern Florida, is a wedge-shaped, eastward thickening sequence of limestone, quartz sand, shell, and terrigeneous mudstone of Pliocene to Holocene age. The prolific Biscayne aquifer, a sole-source aquifer, is the most transmissive of three separate aquifers that comprise the surficial aquifer system. Transmissivity of limestone-rich areas is greater than 1,600,000 ft2/d but decreases to 54,000 ft2/d where the surficial aquifer system mostly consists of sand; yields of 1,000 to 7,000 gal/min are reported from some wells completed in the cavernous part of the surficial aquifer system.

A broad zone of diffusion characterizes the saltwater interface in southeastern Florida in which the position of the interface is a consequence of three principal mechanisms: westward lateral movement of seawater within the surficial aquifer system, seepage from tidal canals, and upconing of relict seawater. Prior to 1945, uncontrolled drainage contributed considerably to lowering the water table of the surficial aquifer system along the Miami Canal. Water levels were lowered further by heavy municipal withdrawals, inducing tidal seepage into the aquifer system. Canal drainage contributed greatly to intrusion of the saltwater interface in Broward County, lowering ground-water levels with the subsequent landward movement of saltwater in the surficial aquifer system from the Atlantic Ocean. Well-field withdrawals and tidal seepage are an important, but less important, source of saltwater intrusion.

Predevelopment freshwater spring discharge in Biscayne Bay diminished considerably following the emplacement of canal drainage networks and the loss and compaction of inland peat deposits that formerly maintained higher water levels in the ecosystem, and stored excess surface water that helped to recharge the underlying aquifer.

The Biscayne aquifer underlying southeast Florida provides freshwater resources to both the ecosystem and most of South Florida's human population. Both the volume and water quality in the aquifer are readily affected by anthropogenic activities, including extractions for public and private water services, and pumping and diversion of the freshwater to restoration projects or to sea.

The goal of the indicator is to monitor the Biscayne aquifer for saltwater intrusion in order to:

1. Maintain water levels in the primary coastal canals of the Central and Southern Florida Project at levels to protect the Biscayne aquifer from saltwater intrusion.
2. Maintain groundwater levels so that there is no net inland movement of the saline interface from the coast.

Currently both the South Florida Water Management District and the U.S. Geological Survey measure water stages and water quality conditions in wells located throughout the Biscayne aquifer region. The South Florida Water Management District has correlated water levels in the wells with salinity conditions and developed isohaline maps of the Biscayne aquifer (USACE and SFWMD, 1999).

CERP MAP Hypotheses related to Salinity Intrusion in the Biscayne Aquifer:

- Restore hydrology in the natural system to conditions similar to the Natural System Model or other restoration targets by distributing the appropriate amount of water to the right place, at the right time, and of the right quality
- Reduce harmful releases of excess water to the natural system such as the Caloosahatchee Estuary, St. Lucie Estuary, Lake Worth Lagoon, and the Everglades Protection Area
- Meet a 1-in-10 year level of service for urban and agricultural water supply demands through regional water deliveries and control seepage from the Water Conservation Areas and Everglades' National Park (373.0361(2)(a)(1), Florida Statutes (FS))
- Achieve a minimum level for the Biscayne aquifer criterion by preventing saltwater intrusion into the Biscayne aquifer by maintaining the water levels in the primary coastal canals (Section 373.042, FS)

What has Happened to Affect this Indicator?

Seasonal water level fluctuations in the Biscayne aquifer influence the movement of the saltwater in terms of volume and rate. Increased saltwater intrusion indicates lowered water table level in interior wetlands and leads to increased halide levels in groundwater withdrawn from wells nearer the coast (USACE and SFWMD, 1999). This results in increased water treatment costs for municipal and industrial use, and negative impacts to ecosystem resources and processes. Actions that have been taken when salt levels increase in pumped water includes; cessation of pumping from wells near the coast, increasing pumping from inland well fields, and/or the release of more water from northern water conservation areas—which are usually already at low water levels. All of these actions, either directly or indirectly, affect the amount of water allowed to flow into the natural areas including Everglades National Park, Big Cypress National Preserve, Loxahatchee National Wildlife Refuge and the Water Conservation Areas.

In order to prevent inland movement of the saltwater interface in the Biscayne aquifer, the South Florida Water Management District (SFWMD) manages coastal groundwater levels through the following methods: (1) operation of the primary canal network, (2) regulation of surface water control elevations for urban and agricultural developments (for both high and low water events) through surface water management permitting, and (3) limitations of coastal consumptive-use groundwater withdrawals. The SFWMD must try to balance the often-conflicting goals of flood protection during the wet season with providing water supply for the dry season (USACE and SFWMD, 1999).

Groundwater levels within the Biscayne aquifer are directly linked to local rainfall amounts and the subsequent management of the canals and structures operated by SFWMD. Rainfall during the wet season, and seepage from canals during the dry season when water is moved into areas through the canals, support groundwater levels locally. Rainfall, and its subsequent management and movement throughout the system are the only source of water for aquifer recharge throughout the aquifer area (see Figure 8).

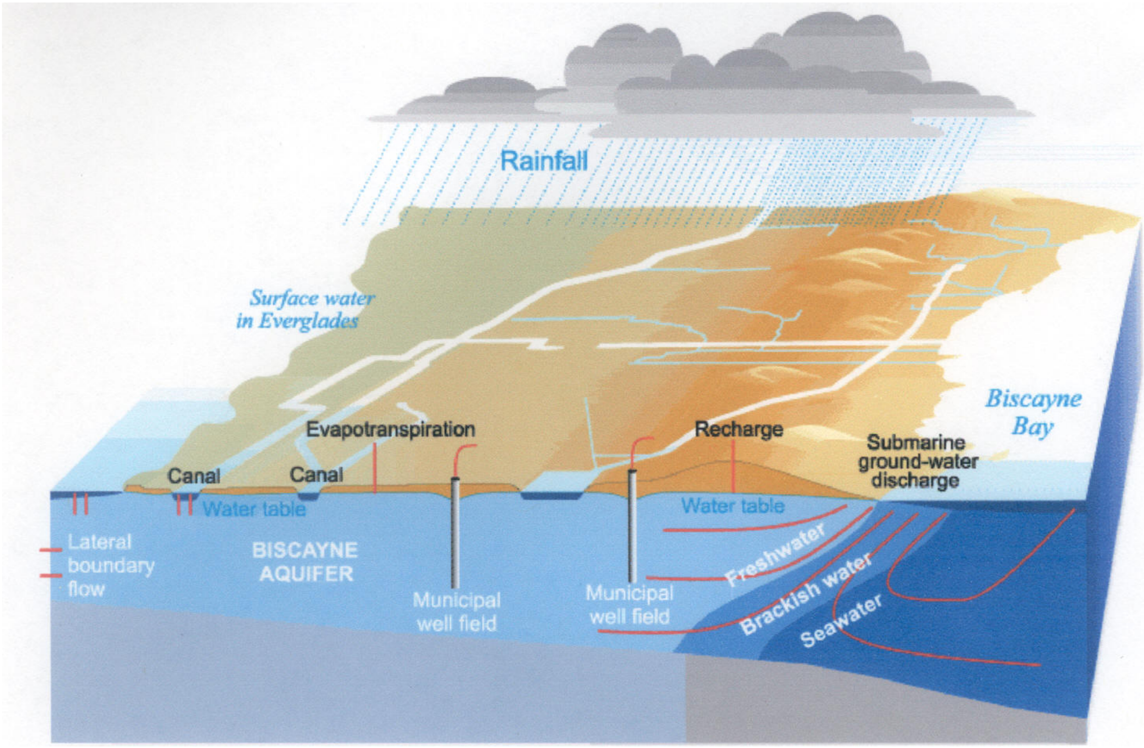

Figure 8. Conceptual diagram of hydrologic system of South Florida (from Langevin, 2000).

The Biscayne aquifer fluctuates in direct and rapid response to variations in recharge (precipitation), natural discharge, and pumping (depletion) from wells. Natural discharge of water is by seepage into streams, canals, ground water movement to the coast and into the bays and estuaries, and by evaporation or transpiration by plants (USACE and SFWMD, 1999).

The Biscayne aquifer is highly permeable and is at or near the land surface in many locations. Consequently, it is susceptible to ground-water contamination. Major sources of contamination include saltwater encroachment (intrusion) and infiltration of contaminants carried by wind and rainfall (e.g. mercury) and in canal waters (e.g. nutrients) (USACE and SFWMD1999).

The municipal consumptive use permit conditions for the protection of coastal fresh groundwater are coordinated with canal management and operation by requiring permitted coastal groundwater well users (this does not include individual homeowners or agricultural users) to maintain higher water stages between the withdrawal point and the coast (SFWMD, 1994). Specific relationships include:

- Cumulative withdrawals from a freshwater aquifer may only occur in such a manner that a hydraulic barrier between the withdrawal facility or facilities and the source of saline water is maintained.
- Expansion of existing withdrawal rates or approval of new withdrawal must meet the following criteria:
    - The hydraulic gradient between the well field and saline water is such that a hydraulic gradient (mound of freshwater) less than one foot National Geodetic Vertical Datum exists between the well field and saline water source during the months of November through April.
    - Monitoring wells within 800 feet of a production well reflect chloride concentration increases at the base of the aquifer, indicating long-term advancement of the saline front toward the well field or within the freshwater portions of the aquifer.
    - Saline water intrusion will be a serious threat to the well fields and natural resource if pumping is allowed or increased. Withdrawals of freshwater must not result in significant upcoming of saline water. Significant movement is defined as a movement of one-third of the original distance separating the bottom of the screened or open interval of a production well from the boundary of the saline water below it.

What Areas of the Everglades Does this Indicator Cover?

The aquifer underlies an area of approximately 4,000 square miles and is the principal source of water for all of Miami-Dade and Broward Counties and the southeastern portions of Palm Beach County in southern Florida (see Figure 9). The natural areas represented within this area include the Greater Everglades and Southern Estuaries modules.

Major population centers that depend on the Biscayne aquifer for water supply include Boca Raton, Pompano Beach, Fort Lauderdale, Hollywood, Hialeah, Miami, Miami Beach, and Homestead. The Florida Keys is supported primarily by water piped from the Biscayne aquifer from the Navy Wells pump station south of Florida City, Florida (USACE and SFWMD, 1999). There are approximately 512 permitted wells located within the Biscayne aquifer region. These wells are for agricultural, municipal and industrial purposes. Some are also used as observation wells.

What Does the Research Say?

Salinity is a measurement of the mass of total dissolved ions in water and used as a descriptor of estuarine and marine ecosystems. Correlations between stage levels and isohaline conditions are available for specific wells within the Biscayne aquifer.

Development in South Florida has resulted in the direct loss of recharge areas that historically maintained groundwater levels while forcing more water to move faster through canals to the coasts without the benefit of allowing for recharge of the aquifer. Parker et al. (1955) described how anthropogenic changes have affected the position of the saltwater intrusion line. Agricultural and population development has resulted in many additional wells developed for withdrawing water. These wells are not part of the 512 wells referenced above. These wells frequently withdraw volumes of water that are in excess of levels required to maintain local or regional aquifer levels. Research and monitoring have documented three aspects related to the impacts of wells.

1. Aquifer water levels are dropping as more water is withdrawn than can be re-supplied by rain
2. Salt water moves inland from the coastal marine areas and into the aquifer as the fresh water hydraulic head is reduced due to drought, over pumping, etc.
3. The cumulative effect of pumping water from the aquifer has resulted in a general decrease in aquifer water levels and often-increased levels of salt water in wells close to the coast.

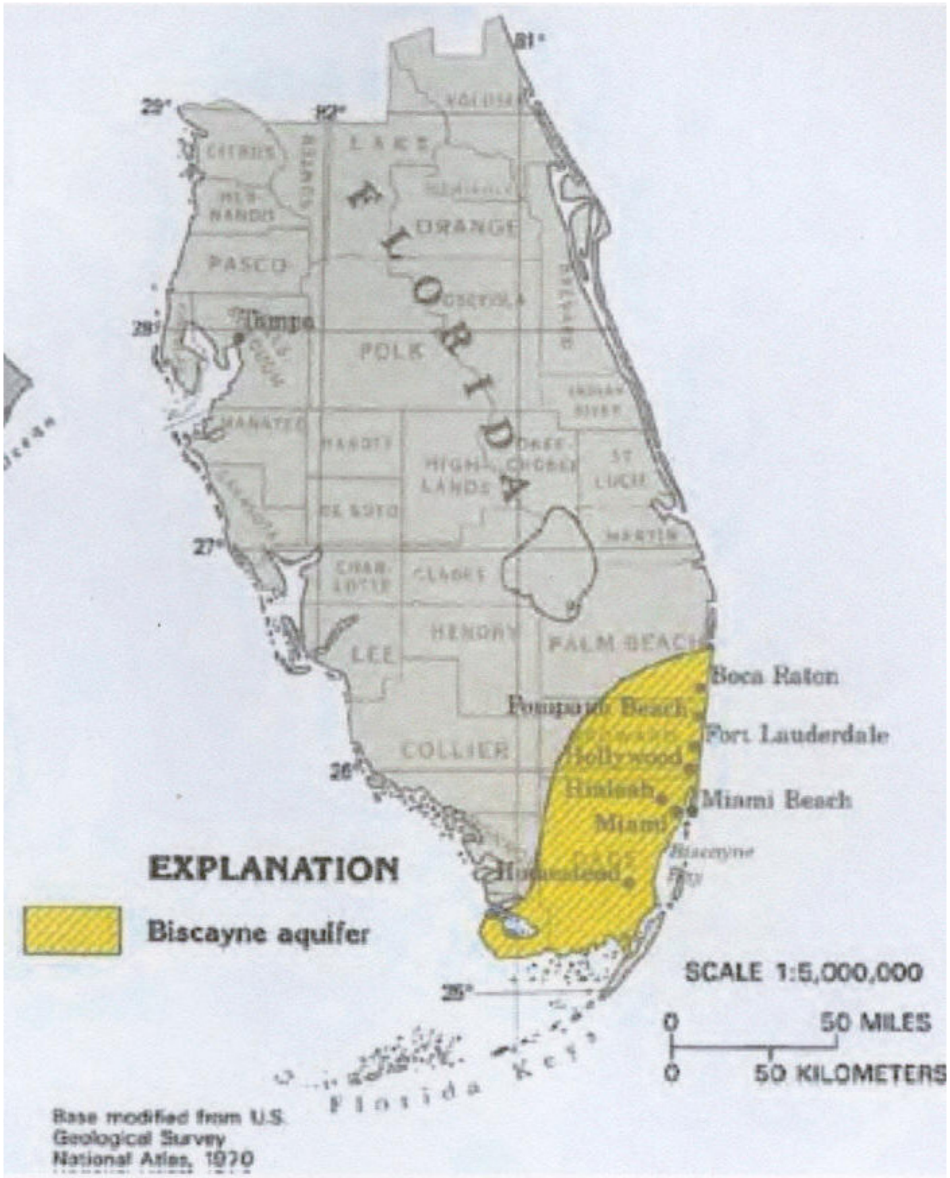

Figure 9. Biscayne aquifer (from Langevin, 2000).

Analyses presented in the RECOVER Team's Recommendations for Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan (RECOVER, 2004) and the CERP Monitoring and Assessment Plan (RECOVER 2004) conclude that the ability to protect the Biscayne aquifer from saltwater intrusion will be difficult under severe drought conditions without CERP projects. Projections of the CERP models indicate that protection of the Biscayne aquifer from salt intrusion will improve as CERP restoration projects are implemented.

CERP Water Projects that directly or indirectly may affect Biscayne Aquifer Dynamics

- Surface and Water Storage
- Aquifer Storage and Recovery (ASR)
- Modify Impediments to Sheet-flow (Decompartmentalization)
- Conveyance, Infrastructure, Feasibility and Restoration

The high transmissivity of the Biscayne aquifer provides for the rapid recharge of Lower East Coast well fields. The rapid recharge and increasing use of the aquifer has led to increased conflicts between water users and the needs of the environment. Due to subsurface geologic structures and surface water management, the distance inland that saline groundwater extends inconsistent and in many cases exhibits a broad transition zone (Langevin, 2000).

South Florida Aquifer System

South Florida contains three major aquifer systems: the surficial aquifer system (i.e. Biscayne Aquifer), the intermediate aquifer system/intermediate confining unit, and the Floridian aquifer system (USACE and SFWMD, 1999). The Biscayne aquifer constitutes the surficial aquifer system in south Florida and is currently the only source of freshwater being used.

The discontinuous and locally productive water bearing units include four major surficial aquifers, one of which is the Biscayne aquifer. Research has shown and documents that in southern Florida, the Floridian and intermediate aquifer systems are often either saline or do not provide adequate flow levels (yield), usually due to differences in aquifer density, to meet the needs of users (Langevin 2000). The Biscayne aquifer system is composed of porous limestone sedimentary rock extending from the land surface to a lower geological structure called the intermediate confining unit.

Research and monitoring have shown that the Biscayne aquifer is a highly productive and unconfined (Langevin, 2000).. It is wedge shaped, highly permeable, and is more than 200 feet thick in the Atlantic Coastal Ridge and thins out completely about 35 to 40 miles west into the Everglades.

There is significant research describing the movement of salt water inland and its affects on the Biscayne aquifer (Kohout, 1960a, 1960b, and 1964). These studies have shown that natural movement of saline water inland has historically been defined by sea level elevation, inland stage levels, and the subsurface hydro-geologic interactions.

Calcium bicarbonate water is dominant in shallow parts of the surficial aquifer system, whereas sodium bicarbonate and sodium chloride water are dominant in more deeply buried parts of the aquifer system or along the coast. Chloride concentrations generally are less than 100 mg/L at depths shallower than 50 ft, except in coastal areas and southeast of Lake Okeechobee. Chloride concentrations are less than 100 mg/L at the 150-ft depth in eastern Palm Beach County, eastern Broward County, and much of central and northwestern Dade County.

Sea Level Rise

The U.S. Environmental Protection Agency (EPA) completed a study of the probability of sea level rise in 1995 (USEPA, 1995). They conclude that as a result of global warming, sea levels will likely rise 15 cm (0.48 ft.) by 2050 and 34 cm (1.09 ft.) by the year 2100. Sea level rise changes the boundary conditions of the South Florida Water Management Model in the Lower East Coast. Analysis using the South Florida Water Management Model concluded that sea level rise would have the most impact on the coastal canals and communities with loss of flood protection and increased saltwater intrusion.

Number of Monitoring Wells

Currently there are approximately 512 permitted wells (USACE and SFWMD, 1999) that are located within the Biscayne aquifer. The South Florida Water Management District and the U.S. Geological Survey service these wells (see Figure 10).

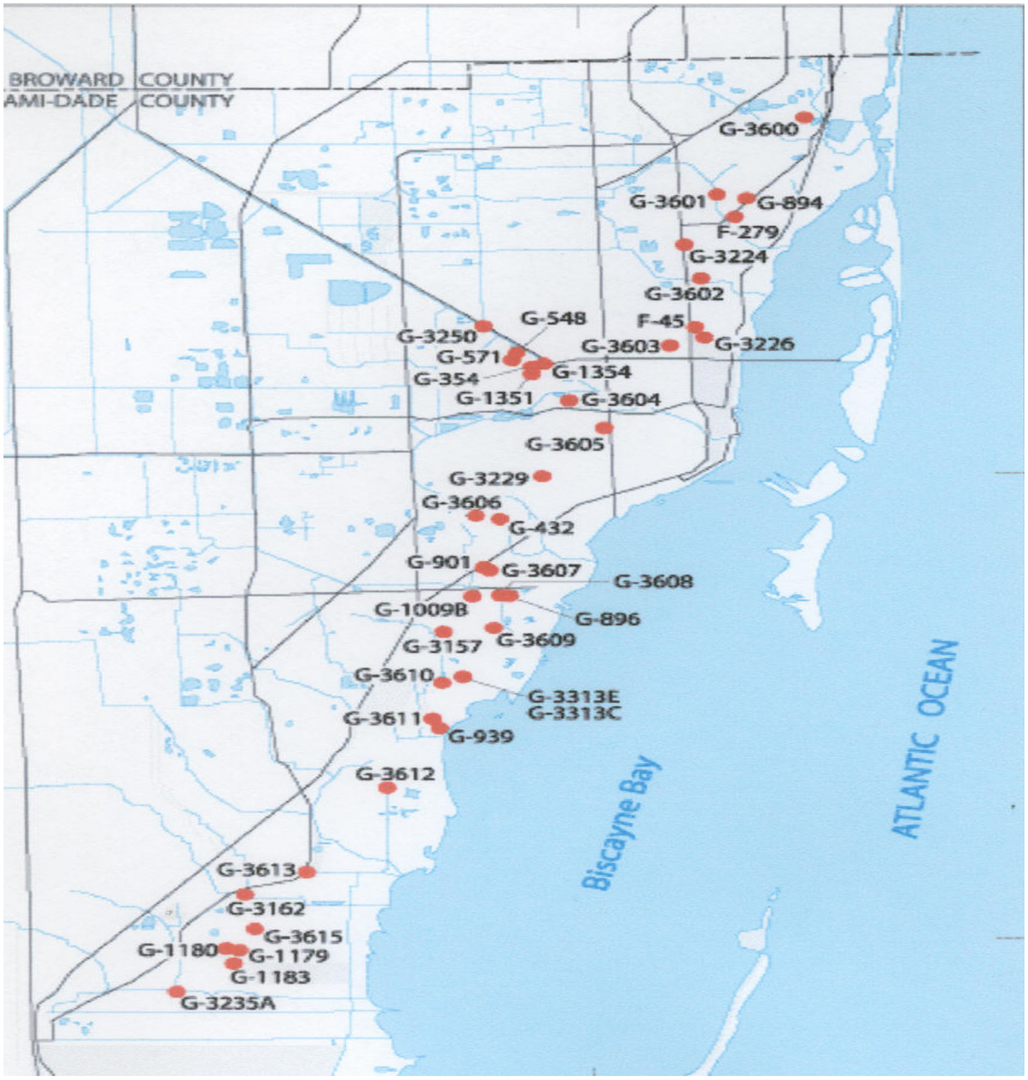

Figure 10. U.S. Geological Survey groundwater observation wells (from Langevin, 2000).

Why is this Indicator Important?

1. <u>The Indicator is Relevant to the Everglades Ecosystem and Responds to Variability at a Scale that Makes it Applicable to the Built System.</u>

   - The indicator is directly linked to water levels and water management in the entire Biscayne Aquifer
   - This indicator links the use and further development of water resources for human consumption with the water needs of the natural system (depth, duration, timing, frequency, flow and quality) and the relationships between increased salinity levels and effect on public water supplies and coastal environments

2. The Indicator is Feasible to Implement and is Scientifically Defensible

    - The South Florida Water Management District has an extensive and long-term (over 30 years in some areas) database for analyzing and reporting stage levels of observation wells throughout the Biscayne aquifer
    - The District uses permits to regulate pumping from the aquifer.
    - Water quality conditions, and salinity level metrics are unified throughout all agencies in the south Florida area
    - Statistical correlations of coastal canal stage and salinity levels have been developed and predictive models are available to evaluate different hydrological scenarios on isohaline positions in relation to the freshwater/saltwater interface
    - Groundwater levels (stage) are directly correlated with existing isohaline maps developed for the entire Biscayne aquifer

3. The Indicator is Sensitive to System Drivers (Stressors**)**

    - There is a direct statistical relationship between drivers (precipitation and seepage) and groundwater levels
    - Impacts from pumping, rising sea levels, and water management activities are directly measurable using the network of observation wells that are located throughout the Biscayne aquifer area.

4. The Indicator is Integrative

    - There is a direct relationship between ground water levels and input and withdrawal activities
    - The cumulative effect of pumping and flooding can be determined from direct measurements and model output for the entire water shed or sub-regions

5. Targets and Performance Measures are Established for the Indicator

    - “New” water volume targets are included as targets for this indicator
    - Target water level stage minimums (NGVD) at canal structures

Canal and Structure	**Canal Stage (feet NGVD*)**
C100A at S123	2.00
C-1 at S21	2.00
C-102 at S21A	2.00
C-103 at S20F	2.00

* NGVD = National Geodetic Vertical Datum

Discussion

Few data are available to accurately document the predevelopment conditions within the surficial aquifer system; the water table probably subtly reflected the Atlantic Coastal Ridge topography. Peat and muck deposits, an important predevelopment component of Everglades surface- and ground-water hydrology, functioned as a storage reservoir to a water column that extended upward from the underlying aquifer and maintained a higher water table that prolonged the hydroperiod and restricted movement of a coastal saltwater interface. Surface-water stage within the adjoining Everglades was sufficient to allow water to discharge through traverse glades areas, and shoreline and submarine springs discharged freshwater.

Uncontrolled canal drainage and a lengthy drought in 1945-46 caused water levels to reach their lowest recorded levels, exacerbating municipal well-field saltwater intrusion problems. The modern-day water table largely reflects the hydrologic influence of numerous engineering features, including primary and secondary canal systems, gated control structures, levees, impoundments, pump systems, and the drawdown effects of the larger well fields. Ground-water movement is largely coastward and water levels are highest near the water-conservation areas, except locally in southeastern Palm Beach County and northeastern Broward County, where surface water is pumped from the Hillsboro Canal into secondary canals to artificially maintain water levels. Regional water-level comparison maps of the difference in “average conditions” show that improved drainage systems built during the 1950s lowered inland ground-water levels and increased land areas for urban and agricultural development.

Gated coastal canal structures retard landward movement of saline water during the dry season through maintenance of stage higher than local water levels, inducing seepage into the aquifer. Management of canal stage has helped to increase ground-water levels in some coastal areas. Long-term canal coastal discharge appears to have declined, but coastal canal stage has been maintained gradually at higher levels, presumably to impede saltwater intrusion. Diminished coastal discharge is attributed to the rerouting of surface water to secondary canals, and induced recharge to the aquifer caused by increased municipal withdrawals.

The South Florida Water Management District is responsible for managing the canal, gate and pump system and protecting the water supply of south Florida. They have developed an extensive array of observation wells and evaluation techniques to assess the level of salt-water intrusion in south Florida. The Biscayne aquifer is classified as a Sole Source Aquifer under the Federal Safe Drinking Water Act and as such must be protected from contamination. Major sources of contamination are saltwater encroachment and infiltration of contaminants carried in the air and in canal waters. Specific water quality targets for water supply have been developed by the State of Florida and the U.S.

Environmental Protection Area and have been implemented by the South Florida Water Management District.

Increases in the saline water conditions reflect inadequate freshwater being available for dilution. As salt levels rise, physiological and biological processes are modified and may lead to ecosystem stress depending on the level and time of exposure to increased salt levels. Monitoring the level of saline water in observation well throughout the Biscayne aquifer will provide managers and researchers with an understanding of groundwater dynamics. Development of ground water models will provide and opportunity to investigate the relationship between planned restoration activities and expected groundwater conditions and quality.

Longer Term Science Needs

System-wide performance measures representative of the natural and human systems found in South Florida need to be evaluated to help determine the success of CERP. These system-wide performance measures address the responses of the South Florida ecosystem that the CERP is explicitly designed to improve, correct, or otherwise directly affect.

Generally, the South Florida Hydrology Monitoring Network is intended to support four broad objectives of the MAP:

a. Establish pre-CERP reference state including variability for each of the performance measures
b. Determine the status and trends in the performance measures
c. Detect unexpected responses of the ecosystem to changes in stressors resulting from CERP activities
d. Support scientific investigations designed to increase ecosystem-understanding, cause-and-effect, and interpret unanticipated results

The goal of the CERP MAP is to develop a single integrated, system-wide monitoring and assessment plan that will be used and supported by all participating agencies and tribal governments to track and measure system-wide responses to the implementation of CERP. To date, there is no one network that provides real-time stage data across the greater Everglades landscape to guide large-scale field operations, to integrate hydrologic and biologic responses, and to support the MAP assessments by scientists and principal investigators (PIs) across disciplines all of which are founded on the hydrology.

To address the needs of the CERP MAP assessments, a real-time surface-water stage data network requires adequate spatial coverage that provides data in every landscape unit in the greater Everglades including the Water Conservations Areas (WCA1, WCA2, and WCA3), eastern Big Cypress National

Preserve, and Everglades National Park. The stage network outlined in CERP MAP II complements the existing network of stage gages operated and funded by others including SFWMD, NPS, USFWS, USACE, and USGS. Gages installed and operated under CERP MAP II will complement the existing network and will provide water-level data at least one location in every landscape unit.

Currently, water level gages have different vertical datum's and are served on multiple websites or not available real-time without special FTP transfers and pre-arrangements. Scientists and investigators in the greater Everglades have used a wide variety of methods with varying consistency and success to transfer hydrologic data from gages to their study areas. This improved network will provide consistent, document-able, and easily accessible real-time hydrologic data throughout the greater Everglades.

Real-time hydrologic data, such as water depth, recession rates, day since last dry period, and water-surface slope, present investigators and managers with an opportunity for decision making and adaptive management not previously possible. Sufficient characterization of surface water hydrologic conditions aids in interpreting the water quality and ecological data in the wetlands and along the coast. A hydrologic network must provide the necessary information to link changes in the physical components to changes in chemical and ecological components of the system. Therefore, the first step is the adequate baseline monitoring of hydrologic data before a fully integrated multidisciplinary assessment of the ecosystem can be accomplished.

The website of real-time data will be a significant improvement over the current multiple agency websites of only selected sites and dissimilar format and data offerings. Historical and ongoing hydrologic data collected by scientists will be used to calibrate and improve water depth algorithms. In a future phase of the project (as yet unfunded), these site-specific data may be used to further define the topography finer than the existing ground elevation data.

The ARC-IMS tool provides restoration managers with a mechanism to evaluate how the Everglades respond to hydrologic change with timely feedback and perhaps, provide scenario-driven modeling in the future. Developing a reliable mechanism to facilitate comparison among metrics of hydrology, species monitoring data, and model outputs is the key to making adaptive management a reality.

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Flood Control

Authors: Robert F. Doren and David Wegner

What is this Indicator?

Flood protection and water supply provided by the Central and South Florida Project (C&SF) have facilitated the development of urban and agricultural areas in south Florida. The intent of the RECOVER program (2005) is to allow for the recovery of the Everglades ecosystem while continuing to provide the public with water supplies while also maintain existing levels of flood control. This Flood Protection Indicator is specifically for the C-111 Basin (see Figures 11 & 12).

Structural modifications and additions to the existing C&SF Project are required to enable water deliveries for the restoration of more natural hydrologic conditions in C-111 Basin areas of Everglades National Park (ENP) (see Figures 11 & 12). These improvements include: 1) structures S-349A, B&C in the L-67A borrow canal to prevent overdrainage of northern Water Conservation Area (WCA) 3A, 2) structures S-345A, B&C for the discharge of water from WCA 3A to WCA 3B, 3) structures S-355A and S-355B in L-29 to enable the release of water from WCA 3B to ENP, 4) modifications to existing S-344, and 5) raising Highway US 41 (Tamiami Trail). Together these improvements will enable the reestablishment of the historic Shark River Slough flow-way from WCA 3A through WCA 3B to ENP.

In preparing land to plant groves, farmers plow the top four-to-eight inches and dig trenches down to an average of 24 inches. The tree roots are found in the plow and trench layers. An occurrence of the water table within two feet of the ground surface for a duration of greater than 24 hours is considered a flood event with the potential for causing agricultural crop loss (Jonathan Crane, Institute of Food and Agricultural Sciences (IFAS), pers. comm.). The property east of the L-31N and C-111 Canals, south of Richmond Drive, was provided a beneficial level of flood protection during the 1983 to 1993 period due to how the canals were operated. During that period, waterlevels were raised during the dry months without causing increased water levels during the wet periods.

Under alternative canal management rules, farmers in the area have experienced a decreased ability to prevent water levels from rising into the root zones of their crops. In 2002, the South Florida Water Management District's Governing Board directed staff, during negotiations with the United States Army Corps of Engineers (USACE) and Department of Interior regarding the Cape Sable Seaside Sparrow nesting season, to not accept anything less than "the current" flood protection/risk, which is defined in the Interim Structural Operation Plan (ISOP) 2001*. Under ISOP 2001, canal management is expected to be higher ("worse") than during the 1983-1993 period (target for WS-E3) and lower ("better") than during more recent historical periods.

In order to prevent this redistribution of water from adversely impacting existing agricultural areas, several mitigation features in the C-111 Basin are included in the plan.

- The East Everglades residential area, also known as the 8.5 square mile area (8.5 SMA), will be provided with perimeter levees and a seepage collector canal to prevent increased water levels inside the 8.5 SMA after project implementation (i.e. flood mitigation)
- A new pump station, S-356 has been constructed adjacent to existing S-334, and will remove additional seepage from ENP into the L-31N borrow canal and thereby prevent increased flood damages east of the L-31N or in the downstream C-111 basin
- Existing roads and borrow canals within the ENP expansion area that would act as hydrologic barriers will be degraded to natural ground

C-111 Project

The C-111 Basin is located in the southernmost portion of Miami-Dade County adjacent to the Everglades National Park (ENP). The predominant land use in this basin is agricultural, although portions of Florida City and Homestead lie within the basin (see Figure x). The C-111 basin is under the jurisdiction of Miami-Dade County Department of Environmental Resources Management. In the 1960's, the area was channelized as part of the Central & Southern Florida Project for Flood Control and Other Purposes. Major restoration efforts have been ongoing in this area in recent years with goals intended to promote improvement of hydroperiods and timing of water deliveries to ENP while maintaining water table elevations to prevent salt water intrusion into the local groundwater.

The C-111 Basin covers an area of approximately 100 square miles. There are five main operational canals in the C-111 Basin: C-111, C-111E, C-113, the L-31N borrow canal and the L-31 W borrow canal. These canals have three functions: (1) to provide drainage and flood protection for the C-111 Basin; (2) to supply water to the C-111, C-102 and C-103 Basins, and to the ENP, specifically to Taylor Slough and the Panhandle of the Park; and (3) to maintain a groundwater table elevation near the lower reach of C-111 adequate to prevent intrusion of saltwater into local groundwater. Water is supplied to the C-111 Basin by the South Dade Conveyance System by way of the L-31N borrow canal.

There are three structures, S-18C, S-175 and S-332, within the C-111 Basin discharging into the ENP that are included in the Non-ECP permit. The L-31W borrow canal is used to make water deliveries to Taylor Slough in ENP by way of S-332D, S-332 and S-175. Water is discharged to the Panhandle of the park by way of overbank flow along the south side of the C-111 Canal between S-18C and S-197. The S-18C structure is located on the C-111 Canal approximately 2 miles south of the confluence of the C-111 Canal and the C-111E Canal in the Southern Glades region. Structures S-175 and S-332 are in close proximity along the L-31W borrow canal along the south side of the Frog Pond (an agricultural test site within the C-111 Basin), approximately 1.5 miles north of the entrance to the ENP. Water quality data have been collected at these structures since 1978 by the District and the USACE. Currently, the levels of TP in the C-111 Basin are below the 10 ppb level of concern. Monitoring at the “into” structures will continue, however, since these concentrations may change as future projects are constructed and seepage water entering the basin from the ENP is reduced. Upstream monitoring is performed by the District at the S-176, S-178 and S-332D structures. Results of the monitoring at the “into” and upstream structures are summarized in Appendix B from the *Everglades Stormwater Program Basin Source Control Schedules and Strategies Annual Report 2004*.

The C-111 project is a part of the southern Miami-Dade County portion of the C&SF project authorized in 1962 to provide flood control to agricultural lands in south Miami-Dade County and to discharge flood waters to Taylor Slough in the ENP. In 1968, modifications were authorized to provide water supply to ENP and Miami-Dade County. Environmental concerns caused construction to be discontinued before all authorized project features were completed. C-111 separates ENP from highly productive subtropical agricultural lands to the east. Because of the extreme permeability of the Biscayne Aquifer in the Miami- Dade County area, the project canals have a direct impact on water levels in adjacent areas. The C-111 General Reevaluation Report (GRR) with integrated Environmental Impact Statement (EIS) was completed and approved in 1994. It recommended project modifications designed to maintain existing flood protection and other C&SF project purposes in developed areas east of C-111 while restoring natural hydrologic conditions in the Taylor Slough and eastern panhandle areas of the ENP. Increased freshwater flows in these areas will also help conditions in Florida Bay, a part of the ENP. The C-111 GRR, approved in July 1994, recommends the development of an operational plan for Shark River Slough and Taylor Slough. The USACE and SFWMD are currently in the process of preparing a document that addresses the 50/50 land crediting issues, both authorized by WRDA 1996 and ENP land swap.

The South Floirda Water Management Model (SFWMM) is being used to simulate conditions for each of the five-year interim model runs subsequent to 2000 (Loucks et al. 1998, Tarbotton et al. 1999). The output of discharge from the C-111 Basin in response to selected rain events will be compared with the same discharge from the 2000 existing condition defined in CERP.

Using parameters specific to models and measurement will assess flood targets. Common metrics will include:

- Water stage duration
- Water stage frequency
- Canal operating levels
- Flow volumes

- Timing

CERP MAP Hypotheses related to Flood Mitigation in the C-111 Basin Agricultural Areas:

- CERP implementation will result in a reduction in seepage losses and harmful releases of excess water to the natural system while meeting a 1 in 10 year level of service for urban and agricultural water supply demands through regional water deliveries and seepage control from the WCAs and ENP (373.0361(2)(a)(1), Florida Statutes (FS)).
- CERP implementation will Achieve Minimum Flows and Levels (MFL) criteria by preventing salt-water intrusion into the Biscayne Aquifer by maintaining the water levels in the primary coastal canals (Section 373.042, FS).
- CERP implementation will provide for maintenance of flood protection at the levels in existence on December 11, 2000 and in accordance with applicable law as CERP is implemented (Section 601(h)(5)(B) Savings Clause, WRDA 2000 and 373.1501(5)(d), FS).

Combined Structural and Operational Plan (CSOP)

The C-111 Basin is part of the Combined Structural and Operational Plan (CSOP). CSOP is currently being developed by the USACE in partnership with the South Florida Water Management District. This Plan will include a complete analysis and redesign of drainage patterns from the Tamiami Trail south to the ENP. Drainage patterns in this basin have historically been in the form of surface water movement from west to east with very few canals or structures. In addition, surface water infiltrated directly into the ground water with high seepage influence from the ENP. Flow patterns are changing to pumped systems directing water to the west with goals to improve conditions in the Taylor Slough portion of ENP. In the lower C-111 Basin, water will sheetflow to the south and east to improve freshwater flows to Florida Bay and the panhandle of ENP.

Many of the water control features of the Modified Water Deliveries (MWD) and C-111 projects are interdependent in their respective operations and objectives to restore the natural distribution and flow of water in the Southern Everglades. The Combined Structural and Operational Plan (CSOP) will integrate operations of the MWD and C-111 projects and develop a unified water control plan to restore the hydrology of ENP while also maintaining existing levels of flood control for the C-111 basin. Portions of the MWD and C-111 project features are expected to become operational following interim operating guidelines established under the CSOP.

This indicator covers only the C-111 Basin. The description that follows is developed to provide the reader with the context within which the C-111 flood control measures will be set. Future flood control indicators may be developed to follow the same logic identified here for C-111.

Each interim target will be assessed by using parameters that include:

- Water stage duration with Stage Hydrographs
  - Compare pre-drainage hydrograph characteristics with those of different alternatives and actions at specific locations
- Frequency of flooding
  - Stage Hydrographs – compare pre and post drainage hydrographs in relation to the occurrence and frequency of cell dry out.
- Hydroperiod Distributions, Matches and Improvement
  - Cell by cell maps and areal histogram measures of hydroperiod distributions and differences.
- Mean Monthly Stages
  - At specific cells to permit comparison of inter-seasonal variability in stage between various alternatives and actions.
  - Temporal measurements can be made on long-term (period of record) or for selected periods (specific rainfall events)
- Timing of events and actions
  - Evaluate the sequencing of events and resulting actions.
- Water Budget
  - Quantify and compare the volume of water that enters a cell or region with that which is dispersed from the area.
- Ponding
  - Quantification of the acreage that allows comparison between ponding depth targets within each ponding class and each event or alternative
- Stage Duration Curves
  - Measure of the cumulative probability that a particular stage is exceeded or not exceeded.
- Normalized Stage Hydrographs and Duration Curves
  - Reference stage with respect to land elevation for comparison of ponding depths.

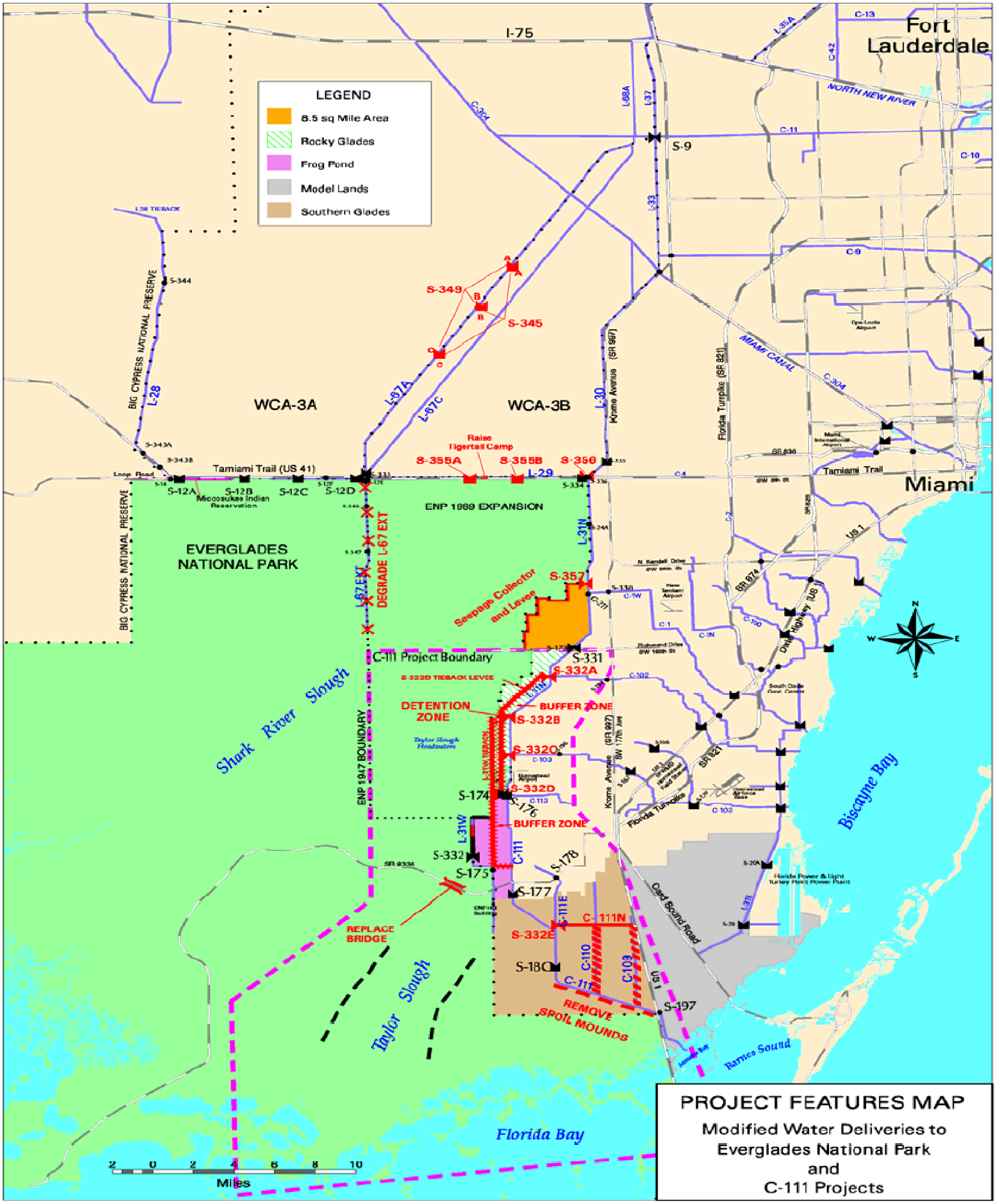

Figure 11. CSOP Project Modifications for C&SF Project

The South Florida Water Management Model (SFWWM) has been used to predict relative trends in flood stage levels in selected areas of the C-lll Basin (see Table 11). Of specific interest are the model predictions for sample cells to (1) predict stage levels and (2) how long the stages remain at certain levels. The following table has been developed to characterize the stages (levels) at the high end for specific reference cells (areas of interest) in the C-111 basin using the South Florida Water Management Model (SFWMM) (RECOVER 2005). These cells relate to 2 X 2 mile squares in the SFWMM and can be identified spatially using the SFWMM grid maps using row (R) and column (C) designations where Cell 1 = R10C25, Cell 2 = R13C25, Cell 3 = R15C26, Cell 4 = R17C27 and Cell 5 = R19C27.
(see:http://www.sfwmd.gov/org/pld/hsm/models/sfwmm/training/Miami-Dade_handouts_2002-10-24.pdf)

TABLE 11. Simulated Groundwater Stages (feet in NCVD)
(At the 10 percent line, high stage, of the stage duration curve)

	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
1995 Base	3.8	4.9	5.6	5.05	5.9
2010	3.65	5.1	5.8	4.8	5.8
2015	3.65	5.1	5.8	4.8	5.8
D13R	3.65	5.1	5.8	4.8	5.8
Target	3.65	4.75	5.4	5.1	5.85

What has Happened to Affect this Indicator?

In 1948 Congress authorized the Central and Southern Florida Project to help protect the public living in south Florida from flooding and provide adequate water supply to meet demands (DOD 2003). A large and complex water management system was designed and constructed, by State and Federal entities, to address flood protection and provide water to people and agriculture. The original project design assumption was that by the year 2000 approximately 2 million people would live in south Florida. Today the population figure is over six million and continues to grow.

As population increased, former and more easterly located agricultural areas were developed for housing, and natural wetlands were further west were developed for agriculture and agricultural areas continued to move westward toward the Everglades as housing continued to develop from the east. As agricultural areas finally abutted the Everglades a direct conflict for water occurred. During the wet season the Everglades wetlands re-flooded, but because of the high percolation rate and transmisivity of the aquifer ground water moved eastward out of the Everglades causing flooding in the agricultural areas. As flooding in these areas occurred they would be drained and thus would drain the Everglades and Everglades National Park of water that was essential for sustenance of the natural wetlands. During dry season the C&SF project moved water into south Miami-Dade for agriculture and the Everglades, but constant pumping drained even more water from the Everglades exacerbating the dry conditions. The CSOP projects are designed to reduce this conflict in the C-111 Basin where agricultural lands abut Everglades National Park.

The purpose of the project is to develop buffer areas to be used as reservoirs, and prevent seepage from the Everglades to the east. This will allow for the retention of water for the wetlands that would normally have seeped from the park, and maintain the water levels in the park high while providing flood protection for the adjacent agricultural lands.

Management of flood levels in south Florida has been the responsibility of the Corps of Engineers and the South Florida Water Management District. In general the flood management system has been developed in respect to average rainfall conditions (1 in 100 year events) and does not handle more frequent 100 year events or extreme events (greater than 1 in 100 year) well. The CSOP projects are intended to improve this level of flood protection for the adjacent agricultural areas.

What Areas of the Everglades does this Indicator Cover?

This indicator covers only the C-111 Basin (see Figure 12) which is part of the Greater Everglades and Southern Estuaries Modules.

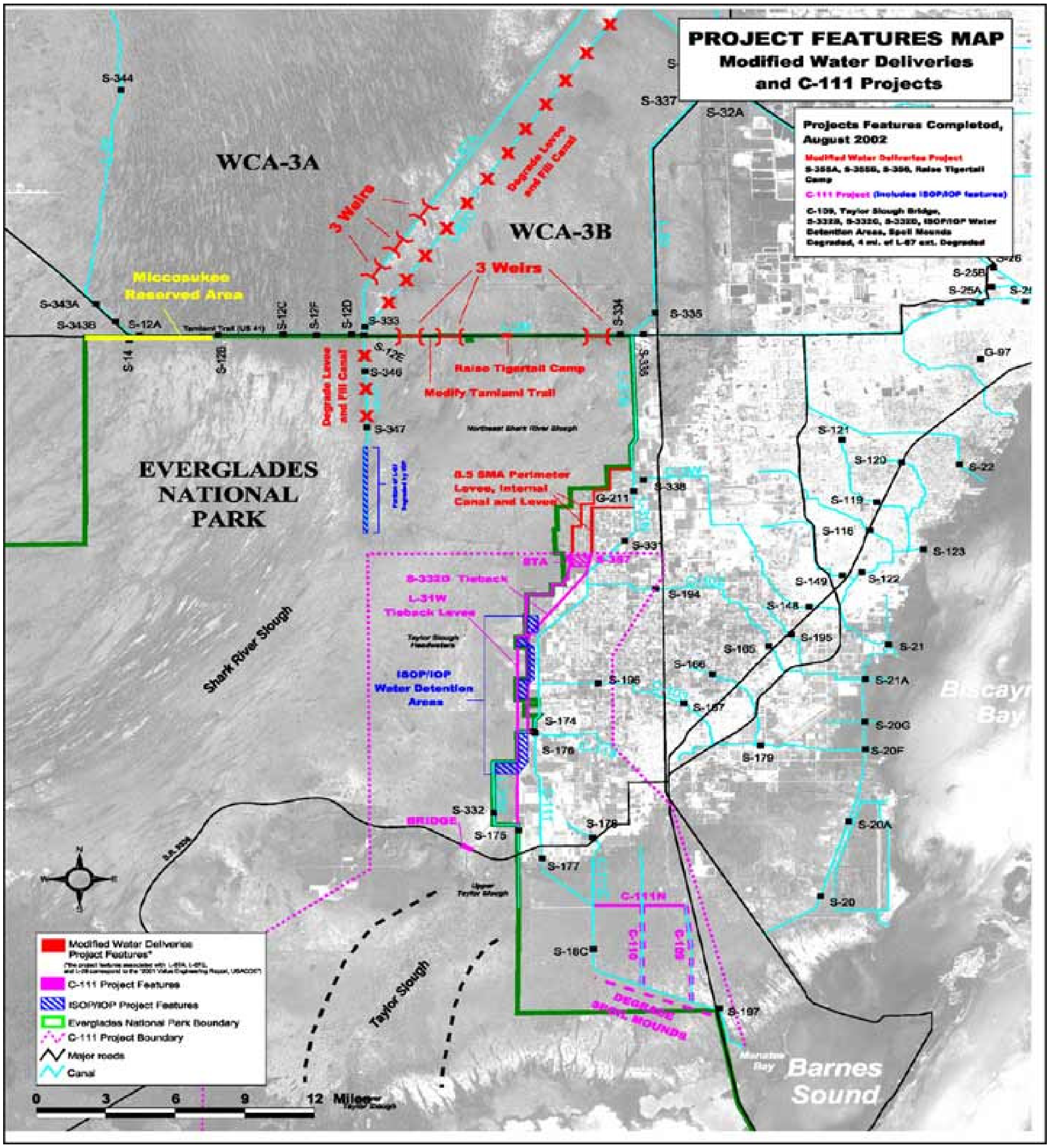

Figure 12. CSOP Project Area with C-111 Projects and Boundary (Purple)

What does the Research Say?

Experimental results show that in a managed hydrological area like the Frog Pond (an agricultural area in the C-111 Basin), the regional water management system (canals) is the main factor explaining the mean seasonal groundwater profiles, rather than precipitation. However, precipitation is important to explain instantaneous or extreme and localized groundwater responses that in some cases can be directly associated with the risk of flooding. Although the mean annual water table profile in the area shows a smooth down gradient towards the east in most of the area (north and mid sections), the local groundwater depth from the soil surface varies dramatically due to the local changes in surface elevation (around 30 cm or 1 ft).

This illustrates the importance of microtopography in the extremely flat lands of South Florida where currently there is no topographical data generally available to this resolution. Local estimations of the aquifer's specific yield showed that when the water table is already close to the surface (<2ft.), 1 in. of rain can raise the groundwater 9 in., so the risk of flooding can be actually up to 3 times greater than if calculated based on the general value accepted for the area (in rain=3 in raise). Successful calibration of the computer model MODFLOW (USGS) with experimental results show the profound effect that the permanently closed gate in L-31W (west boundary with the ENP) has on the general groundwater flow in the southern portion of the Frog Pond. There is a shift in the general west to east groundwater flow to turn around the structure (as far as 1-2 mi) with increasing speeds, and west towards the ENP once south of the structure. In addition, simulation of the effects of filling the new detention pond show that up to 30% of water pumped into the detention pond is lost back through seepage to the groundwater system west towards the C-111 canal.

Concentrations of total P in surface waters exceeded 10 ppb in 90% of the samples collected between 03/28/2002-03/28/2003. L- 31W canal samples were consistently higher than those obtained from C-111. Concentrations of total P and Ortho-P in groundwater samples were high during summer rainy season, and early fall growing season of vegetable crops. Concentrations of nitrate-nitrogen in all surface and groundwater samples were below 10 ppm (U.S. drinking water standard). There is evidence of a significant nitrate leaching from the enriched topsoil during the rainy season as well as at the beginning of the fall crop season when the fertilizer is applied to the soil (in beds or pre-planting). Ammonia in groundwater follows an inverse pattern to nitrate that might be largely the result of the chemical reduction to ammonia of the nitrate that was leached previously. High concentrations of copper were found in water samples from canals, ditch and wells in September 2002, possibly from applications in the agricultural areas to the east of the Frog Pond and mobilization form past residues. Although concentrations of trace metals in most of water samples were very low, some samples showed relatively high concentrations of arsenic (69 ppb in Torcise ditch), cadmium (23 ppb in Torcise ditch), cobalt (31 ppb in Well 1), chromium (31 ppb in Well 1), nickel (34 ppb in Torcise ditch), lead (128 ppb in Well 2), and selenium (98 ppb in Torcise ditch).

The South Florida Water Management Model (SFWMM) has been used to simulate conditions for each of the five-year interim model runs subsequent to 2000. For this exercise, the output of structural discharge from the Everglades Agricultural Area in response to rain events will be compared with the same discharge from the 2000 existing conditions.

Effective removal rate of water in response to significant rainfall events will be expressed in inches per day. This is computed by determining the pumping rate of the primary pumps. Of primary concern is the amount of water in the agricultural fields and the affect that this water has on the root zones of plants. Too much water on the roots will lead to losses in crops.

Understanding the existing south Florida storage components and the fluxes that exist between them requires development of an understanding of the hydrologic system. The South Florida Water Management District has developed the South Florida Water Management Model (SFWMM) to assist planners and managers gain a better understanding of the hydrologic regime and system dynamics. SFWMM simulates the hydrologic regime and the management of the south Florida water system from Lake Okeechobee to Florida Bay (NRC 2005). The SFWMM has been used as a research and management tool to predict water system responses to changes in water inputs, outputs and system processes related to changing operational rules and anticipated water management control structures. The SFWMM simulates:

- Rainfall
- Evapotranspiration
- Infiltration
- Overland flow
- Groundwater flow
- Canal flow
- Canal-Groundwater seepage
- Levee seepage, and
- Groundwater pumping

Why is This Indicator Important?

Providing infrastructure via the CSOP in order to relieve water conflicts such as exist in the C-111 Basin between Everglades National Park and the adjacent agricultural lands is critical to improving and sustaining the water supply to Everglades' wetlands. While non-structural elements for Everglades' water supply might be preferred these structural "solutions" in may cases are the only "solutions" available.

The CSOP projects will provide for sustained higher levels of water within Everglades National Park through a series of pumps, reservoirs, canals and seepage control barriers, while still providing flood protection to agriculture.

This indicator will provide the best opportunity to assess the success of those structures and their management on this hydrological interface. If this project is successful it will be an example of the compatibility of structural solutions for both natural and built system components to still meet restoration needs.

6. The Indicator is Relevant to the Everglades Ecosystem and Responds to Variability at a Scale that Makes it Applicable to the Entire System or Important Components.

   - The flood protection indicator will respond to spatial and temporal variability at a scale that makes it applicable and capable of being monitored throughout the C-111 Basin
   - The flood control indicator is relevant to the Everglades ecosystem because actual and predicted relationship between water management actions and impacts to specific areas in south Florida are predicable using existing models and technology
   - Preventing conflicts with agricultural areas and restoring hydrology (temporally and spatially) to the south Florida ecosystem is essential to restoring the eastern portions of Everglades National Park

7. The Indicator is Feasible to Implement and is Scientifically Defensible?

   - The South Florida Water Management District is the primary responsible entity for managing water distributed throughout south Florida
   - The Corp of Engineers has also developed flow routing models that integrate with the SFWMM approaches to provide and integrated assemblage of water management tools
   - Existing monitoring of water transfer and storage levels allows for real-time information to be available to managers
   - The South Florida Water Management Model has been developed and been peer reviewed and has been used to articulate current and future predicted conditions
   - Specific targets have been identified for project components.
   - Specific management actions and water management project are being developed as part of the CSOP for the C-111 Basin

8. The Indicator is Sensitive to System Drivers (Stressors).

   - Canal deliveries directly affect the seasonal water levels in the C-111 Basin
   - Rainfall directly affects immediate water level conditions and is usually responsible for agricultural flood events
   - Impacts from pumping, rising sea levels, and water management activities can be directly measured and evaluated in the system components

9. The Indicator is Integrative.

- Levels of flood protection in the south Dade area are directly correlated with levels of storage, pumping, and distribution systems in south Florida
- This indicator provides a good level of integration of the ability of structural components of the restoration program to adequately resolve the conflicts of water use and flood control

10. Targets and Performance Measures are Established for the Indicator

- Water levels (measured in inches NGVD) below ground related to specific crop and established root zones
- Ground groundwater levels in the South Miami-Dade Agricultural Area East of L-31N and water stages in Everglades National Park
- Flood control removal rates for the C-111 Basin
- Seepage rates from Everglades National Park

Discussion

Restoring the Everglades ecosystem and protecting the existing users of water in south Florida requires extensive efforts to manage the waters. Because of the conflict in this particularly critical area of the south Florida a solution that accounted for the needs of the park and of the agricultural users was required.

Longer Term Science Needs

Additional research and science is required to continue to fine-tune and evaluate this indicator. The following longer-term science needs reflect anticipated information and analysis requirements.

- Continued refinement of the SFWMM to ensure that assumptions are correct regarding floods.
- Continued refinement of the CSOP model to ensure that assumptions are correct regarding flood protection and predictions of sustained water levels within the park
- Determine potential impacts from global climate change and its effects on hydraulic regime (increased or decreased rainfall, sea level rise, timing and frequency of rain, intensity of rain) and resultant flood conditions in selected areas.

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INDEPENDENT SCIENTIFIC REVIEW

The SCG completed an independent scientific review of the suite of System-wide Indicators. It is available as the Report Of the Review Panel Concerning Indicators for Restoration Report to the South Florida Ecosystem Restoration Task Force, May 2006, see: . http://www.sfrestore.org/scg/documents/index.html. For details on the objectives of the review please see reviewer guidelines and questions below.

GUIDELINES FOR REVIEWERS

The Task Force has requested a set of "system-wide" indicators that will help them understand in the broadest terms how the ecosystem, and key components, are responding to restoration and management activities via implementation of CERP and other "non-CERP" projects. Experience indicates that the Task Force and congressional members who will be using the information generated by these indicators take clearer and more definitive action when this kind of information is presented as a condensed and concise summary. Where individual management or policy decisions may require further information or detail, additional information is usually provided either in report form or through a workshop venue with a sub-set of members identified to further evaluate an issue.

The CERP and RECOVER programs are and will be monitoring many additional aspects of the ecosystem including such things as; rare and endangered species, mercury, water levels, water flows, storm-water releases, dissolved oxygen, soil accretion and loss, phosphorus concentrations in soil and water, algal blooms in Lake Okeechobee, hydrologic sheet flow, increased spatial extent of flooded areas through land purchases, percent of landscape inundated, tree islands, salinity, and many more. The set of indicators included here are a sub-set from a larger monitoring and assessment program being established to provide a broad array of parameters that respond at different temporal, spatial, biological, and ecological scales from which managers will be afforded information for adjusting restoration activities as these many scales.

See: (http://www.evergladesplan.org/pm/recover/recover_map.cfm);.

This suite of indicators is being developed to provide a "top-of-the-mountain-view" of restoration for the Task Force. The approach we used to select these indicators focused on individual indicators that we felt integrated numerous physical, biological and ecological levels, interactions, and bioregions to try to capture that broader "mountain-view". Too many indicators is recognized as one of the more important problems with using and communicating them (National Research Council 2000, Parrish et al. 2003). Identifying a limited number of focal conservation targets and their key ecological attributes improves the successful use and interpretation of ecological information for managers and policy makers and enhances decision-making (Schiller et al. 2000, Parrish et al. 2003).

Our goal has been to develop a suite of indicators composed of an "elegant-few" that would achieve a balance among; feasibility of collecting information, sufficient and suitable information to accurately assess ecological conditions, and communicating the information in an effective, credible, and persuasive manner to decision makers.

WHAT WE HOPE TO GET FROM THIS REVIEW

1. An evaluation of the value of this set of indicators for the purpose of helping the South Florida Ecosystem Restoration Task Force use the results from the individual and integrated assessments of these indicators to make informed programmatic and policy level decisions about the restoration program.
2. An evaluation of the approach and methods (the four steps) the SCG used to find, evaluate and select the suite of indicators.
3. Recommendations for improving or refining the approach we used
4. Recommendations for improving or refining the suite of indicators
5. An evaluation of the example (exotic plant) communication tool for conveying very complex concepts and information in a simple yet accurate, useful, informative and effective manner.
6. An evaluation of the identified "indicator gaps" and suggestions for filling additional gaps that the reviewers feel are critical to the purpose of this task
7. An evaluation of the relative value of the individual indicators as part of this suite and any recommendations for replacing indicators with others deemed more valuable or eliminating those deemed of no great value to the suite and its purposes.

AS PART OF YOUR REVIEW, PLEASE BE SURE TO RESPOND TO THE FOLLOWING QUESTIONS.

1. **Are there enough, too few or too many indicators for this integrative suite to be useful**? If you feel there are either too few or too many and this somehow jeopardizes the use of this suite of indicators, please explain your concerns and provide suggestions to address them. <u>(Please keep in mind that there will opportunities for additional indicators to be added in 2008)</u>

2. **Is the approach (the four steps), including the guidelines and methods used to evaluate and develop the suite of system-wide indicators, reasonable and appropriate?** If not, how might we improve upon them?

3. **How do you think the indicators might best be used or interpreted to integrate across geographical and ecological lines? Do you think that reporting the indicators at three level; individually, aggregating results into modules (see Figure 1), and aggregating results ecosystem wide is a reasonable approach to integration?** If not, how would you suggest we integrate the results of individual indicators.

4. **Do you think the suite of indicators is representative enough of the different ecological and biological dimensions of the Everglades' system that they are also likely to be representative of components and**

conditions of the system that are not or can not be measured? We feel it is important that the indicators we choose are most likely to integrate biological information of things we cannot monitor, in terms of the response of the indicator to restoration activities. If not please explain your concerns and provide us with guidance on how to improve or modify the suite in order to enhance this aspect if possible.

5. **If used, will this suite of system-wide ecological indicators provide a reasonable and useful way to signal that we are or are not meeting our ecological restoration goals and targets?** If not please explain why not, and how they might be used or modified for this purpose?

6. **If you agree with question number five, that this suite of indicators will provide a useful communication tool, do you think it will also provide a means for indicating progress (or lack thereof) over time?** If not please explain why not and provide us with suggestions to do this.

7. **Do you feel that the example communication tool (red light, yellow light, green light) developed for the invasive exotic plant indicator is a good method for simplifying and communicating complex data from many disparate data and sources? If you agree do you have any recommendations on how we might further develop and improve this approach for use with the entire suite of indicators?** If you disagree with using this design what other method(s) or design would you use or prefer for integrating and summarizing disparate pieces of information and communicating it to a policy-maker and manager audience?