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Ecological indicators for system-wide assessment of the greater everglades ecosystem restoration program

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ABSTRACT

Developing scientifically credible tools for measuring the success of ecological restoration projects is a difficult and a non-trivial task. Yet, reliable measures of the general health and ecological integrity of ecosystems are critical for assessing the success of restoration programs. The South Florida Ecosystem Restoration Task Force (Task Force), which helps coordinate a multi-billion dollar multi-organizational effort between federal, state, local and tribal governments to restore the Florida Everglades, is using a small set of system-wide ecological indicators to assess the restoration efforts. A team of scientists and managers identified eleven ecological indicators from a field of several hundred through a selection process using 12 criteria to determine their applicability as part of a system-wide suite. The 12 criteria are: (1) is the indicator relevant to the ecosystem? (2) Does it respond to variability at a scale that makes it applicable to the entire system? (3) Is the indicator feasible to implement and is it measureable? (4) Is the indicator sensitive to system drivers and is it predictable? (5) Is the indicator interpretable in a common language? (6) Are there situations where an optimistic trend with regard to an indicator might suggest a pessimistic restoration trend? (7) Are there situations where a pessimistic trend with regard to an indicator may be unrelated to restoration activities? (8) Is the indicator scientifically defensible? (9) Can clear, measureable targets be established for the indicator to allow for assessments of success? (10) Does the indicator have specificity to be able to result in corrective action? (11) What level of ecosystem process or structure does the indicator address? (12) Does the indicator provide early warning signs of ecological change? In addition, a two page stoplight report card was developed to assist in communicating the complex science inherent in ecological indicators in a common language for resource managers, policy makers and the public. The report card employs a universally understood stoplight symbol that uses green to indicate that targets are being met, yellow to indicate that targets have not been met and corrective action may be needed and red to represent that targets are far from being met and corrective action is required. This paper presents the scientific process and the results of the development and selection of the criteria, the indicators and the stoplight report card format and content. The detailed process and results for the individual indicators are presented in companion papers in this special issue of Ecological Indicators.

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1. Introduction

Measuring the general health, ecological integrity (sensu Harwell et al., 1999; Parrish et al., 2003), restorative capabilities and trends of ecosystems (Griffith and Hunsaker, 1994; Karr and Chu, 1997; Urquhart et al., 1998) is a major challenge for environmental managers. For scientists, communicating the results of scientific inquiries to managers, policy makers and the public is equally challenging (Chess et al., 2005). National indicators for pollution and the economy have been used for many years to convey complex scientific and economic principles and to present data in easily comprehensible conceptual forms (NRC, 2000). Identification of indicators must include but cannot be limited to the delineation of the values driving environmental management or restoration (Ruitenbeek, 1991). This can be a challenging process that requires the identification of management goals and resolution of competing value systems in a project (Gray and Wiedemann, 1999). Failure to pinpoint management goals and stakeholder values has long been linked to failure of environmental projects (Yount and Niemi, 1990).

Human pressures on natural ecosystems have reached unprecedented levels, while concurrently appreciation of the aesthetic and functional values of natural areas has increased. In response, the repair and rejuvenation – generally termed restoration – of natural areas have become increasingly important. In the last quarter of the twentieth century the majority of restoration projects have focused on single ecosystem components or on relatively small spatial and temporal scales (NRC, 2000; Vigmostad et al., 2005). During the first two decades of this century, large-scale ecosystem restoration projects have been initiated that focus on entire watersheds. Examples include Chesapeake Bay, South Florida Everglades, Great Lakes, California Bay–Delta Restoration Program, and Columbia River in the United States of America (Busch and Trexler, 2003; Vigmostad et al., 2005), and Negril Marine Park, Jamaica (Porter et al., 2000). New hurdles in implementation accompany this large-scale ecosystem focus, including integration of science with management and policy, establishment of suitable monitoring programs, and development of strategies to assess restoration success (NRC, 2000, 2003; Hyman and Leibowitz, 2001).

Ecological systems are complex, and developing effective strategies for measuring and communicating restoration success (or failure) is an extremely difficult but essential task in any large, complex regional restoration program (Dale and Beyeler, 2001; Schiller et al., 2001; Lausch and Herzog, 2002; Niemi and McDonald, 2004; Ruiz-Jaen and Aide, 2005; Thomas, 2006). Ecological indicators, motivated by conceptual ecological models (CEM) that are derived from key ecological drivers and attributes, grounded in ecological theory and empirical information from the restoration region, and linked to ecological targets are fundamental components of assessing restoration success (Harwell et al., 1999; Noon, 2003). Science may sometimes be data rich and information poor due to ineffective communication of complex data (NRC, 2006). Thus, tools to communicate the status of restoration to a diverse audience of managers from agencies with different agendas, multiple stakeholders, and the general public are essential. In keeping with the adaptive management framework adopted by the management agencies charged with the restoration, managers must decide on possible revisions to the initial restoration plan as the long, complex, and therefore uncertain restoration progresses. Government and public support is essential to maintaining financial support for the restoration. Ideally, the set of indicators selected and the means by which their status is communicated should speak effectively to all relevant parties (Johnson and Chess, 2006).

A central element of the South Florida ecosystem restoration program is the Comprehensive Everglades Restoration Plan (CERP; see www.evergladesplan.org), a multi-billion dollar federal-state partnership that seeks to restore historical hydrological attributes of the Everglades. The overall South Florida ecosystem restoration program, which includes CERP and other South Florida restoration efforts, encompasses over 200 components addressing water management and ecosystem restoration needs over the southern third of peninsular Florida (Fig. 1).

Large, complex regional restoration programs such as this must include a means for determining how well restoration goals are being met (Niemi and McDonald, 2004; Thomas, 2006; Ruiz-Jaen and Aide, 2005; Vigmostad et al., 2005). The National Research Council (NRC) (2003, 2006) has recommended that a small set of system-wide ecological indicators be developed for assessing Everglades restoration.

The South Florida Ecosystem Restoration Task Force (Task Force; see www.sfrestore.org), established by the U. S. Congress in section 528(f) of the Water Resources Development Act (WRDA) of 1996, was created to provide a coordinating organization to harmonize activities of the agencies involved in South Florida ecosystem restoration. The Task Force consists of 14 members: seven federal, two tribal, and five state and local government representatives. As a result of the NRC (2003, 2006) and GAO (2003, 2007) recommendations the Task Force requested the Science Coordination Group (SCG—a team of managers and scientists) to help facilitate the development of a small set of system-wide ecological indicators to evaluate the performance of restoration projects toward achieving Task Force Strategic Plan and CERP restoration goals (see SFERTF, 2004). This process had to meet four criteria; (1) develop a set of ecological indicators that would provide an ecosystem-level scale for assessment of restoration, (2) provide for public and other state-holder involvement through attendance at meetings and public comment, (3) be independently reviewed by a panel of qualified scientists, and (4) include a system for communicating the science of the indicators in a simplified manner that made the connection between the detailed science in the assessment reports and the simplified interpretations transparent.

The indicators selected for system-wide assessment by the Task Force are organism based (Gerritsen, 1995; O'Connor et al., 2000) and represent attributes in the conceptual ecological models developed to guide ecosystem restoration in South Florida (Ogden 2005) (Fig. 2). Additional indicators that are not organism based, such as hydrology, may be utilized in the future. Hydrologic performance measures, such as duration and intensity of dry-downs, are currently used when evaluating the projected performance of project alternatives under CERP (see: www.evergladesplan.org/pm/

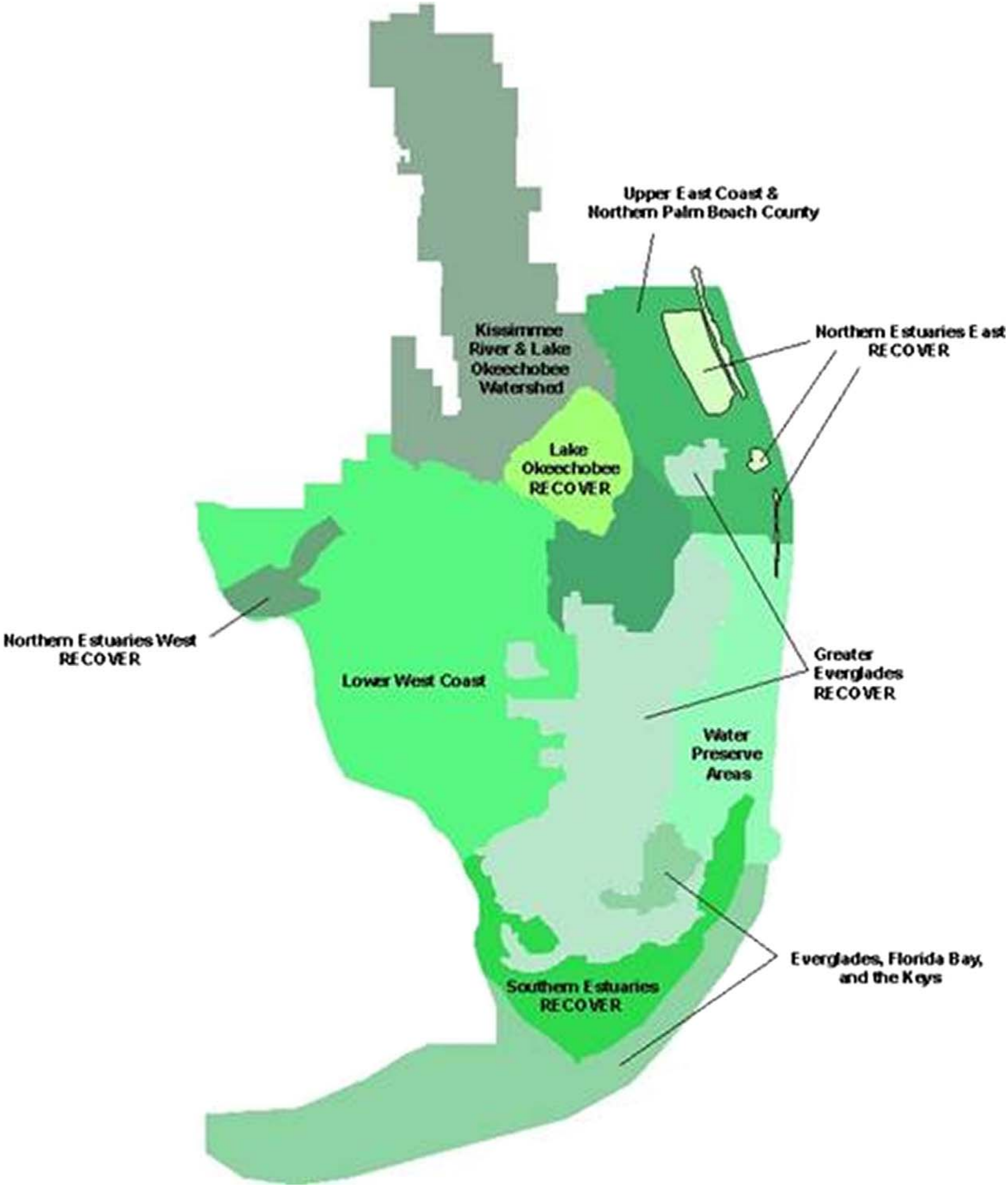


Fig. 1 – Map of South Florida illustrating the boundary of the South Florida Water Management District, and the regional assessment modules.

recover/eval_team_perf_measures.aspx for details). The current suite of indicators was chosen to provide the Task Force and Congress with the broadest scale of information for a "top-of-the-mountain" assessment of ongoing restoration activities. This approach is intended to reduce the influence of distracting granularity at finer scales of data resolution, while being mindful not to lose critical information contained in the detailed science.

Adaptive Ecosystem Management (AEM) (referred to as Adaptive Management in CERP) has become a common theme of regional ecosystem initiatives (Holling, 1978; Walters, 1986; Stevens and Gold, 2003) and holds a central role in CERP and South Florida ecosystem restoration. AEM is a collaborative, iterative and deliberate process of design, implementation, monitoring, and assessment used to reduce uncertainty and to direct ecosystem management toward agreed upon targets

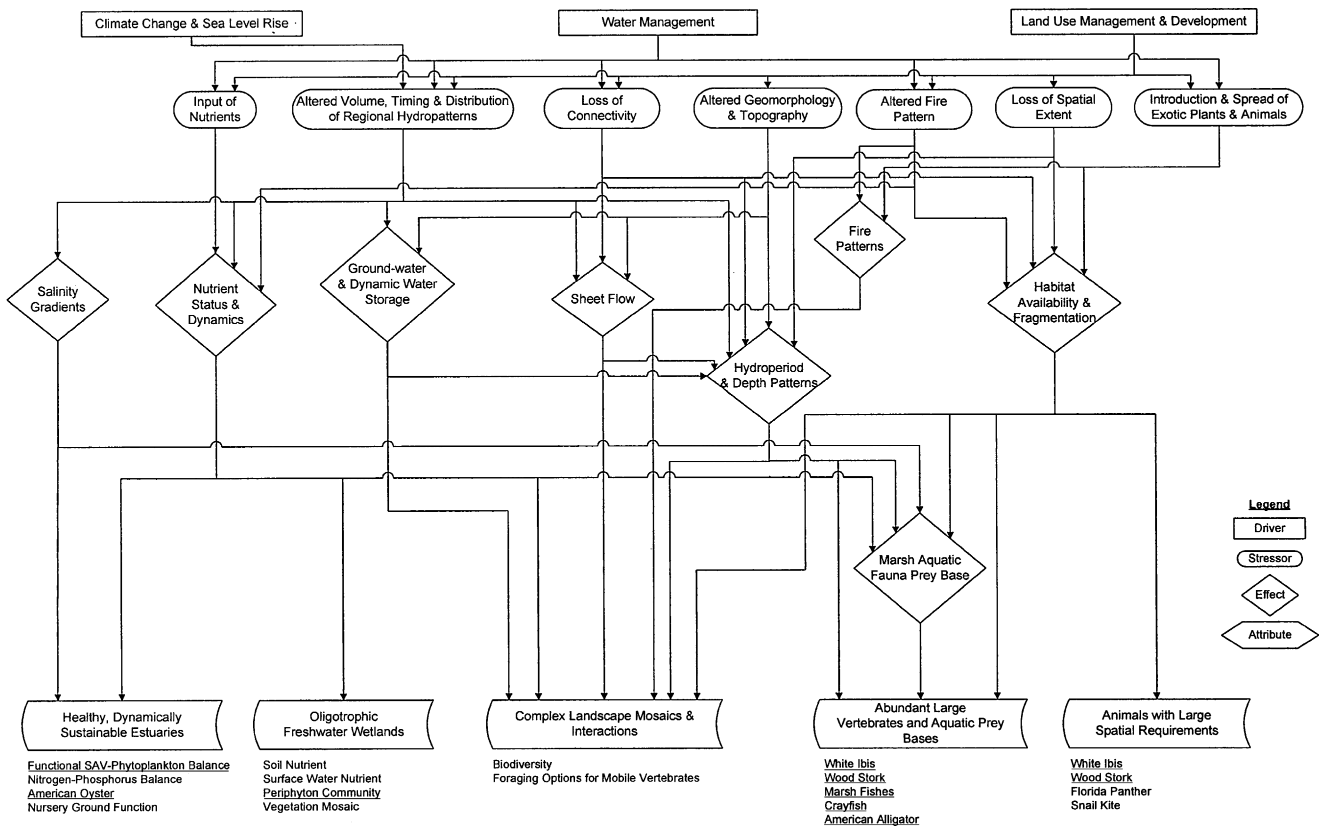


Fig. 2 – Total System Conceptual Ecological Model Diagram (from Ogden et al., 2005). This figure illustrates the hierarchical nature of the CEM with Drivers (rectangles) and Stressors (ovals) connecting to Ecological Effects (diamonds) and the Attributes (lowest two sets of boxes) being affected. The lowest boxes list the individual attributes for the Total System. The indicators that are part of this system-wide suite are underlined.

(Norris, 1995). Within an active AEM framework (sensu Holling, 1978) monitoring and experimentation are used to help minimize scientific uncertainties associated with specific restoration hypotheses in such a way that they experimentally provide data needed to reduce uncertainty in models of how the system is likely to respond. However, as noted by the National Research Council (2006, 2003) much of the adaptive management in Everglades restoration is passive and thus much less effective at reducing uncertainty.

As more robust data sets become available, providing both increased spatial and temporal resolution, we gain a better understanding of natural variability within the ecosystem. This allows for refinement of previous parameter estimates, thereby improving both model predictions and system management (Karr, 2000). Ideally, this process yields an ever-improving understanding of ecosystem responses to management which may further reduce uncertainty in project design and operation (Karr, 2000). Development and implementation of a suite of readily accessible and widely applicable indicators is a critical component of AEM. Because they also serve as good communication tools they help form the basis for choices for successive steps in the restoration program.

In this special issue of Ecological Indicators, we report on an ecological indicator program developed by South Florida scientists and resource managers to communicate progress toward South Florida ecosystem restoration. Because much of the current restoration in South Florida is focused on the Everglades (including Lake Okeechobee, northern estuaries, greater everglades and southern estuaries (Fig. 1) this special issue focuses on an abridged set of indicators for the Everglades. Although the current set of indicators is applicable outside these defined regions of the Everglades, over time additional indicators may be needed to represent progress toward restoring ecosystem structure and function in other parts of the South Florida ecosystem. The goal of this effort is to capture key pieces of ecosystem function, tied to the values underpinning this restoration program, for communication to the widest possible audience. Clearly, this is an abridged version of information needed by managers in their day-to-day activities, selected with the goal of informing and engaging the broader community in the multi-decadal program of management of the regional ecosystem. In this introductory chapter, we describe the underlying concepts used to develop this list of indicators. Also, how and why they were chosen, how individually and collectively they link to restoration goals, and how they facilitate communication of restoration progress while both retaining the depth of technical information necessary to make them credible for experts, and summarize results at levels appropriate for laypersons. This article and the detailed companion articles in this special issue provide a template that other large-scale ecosystem restoration programs may follow to select relevant indicators and to develop tools to effectively communicate the status of restoration. Some key questions addressed here include: What is an indicator? What is the indicator supposed to indicate? What makes a good indicator? Will the indicator be explicable to managers and policy makers? How many indicators are optimal to make reasonable assessments for the system? How do these indicators integrate into the ''big picture'' (i.e., ecology, management and policy) for restoration?

2. Development of system-wide indicators

One of the biggest challenges in creating a system of indicators is selecting a manageable list from the myriad possible metrics (Harwell et al., 1999; Kurtz et al., 2001; Noon, 2003). Once the indicator is selected, it is still necessary to determine what metrics (i.e., measured parameters) most effectively represent the indicator's response. Ecological indicators come in many different formats, forms, levels of detail or resolution, and organizational schemes (Jackson et al., 2000; NRC, 2000). They also have different purposes and applications and no method of application or means of developing indicators applies in all situations. Furthermore, uncertainty about the usefulness of particular indicators to communicate success and progress is at its highest point early in the restoration program. Therefore any proposed reduction or limitation in the suite of indicators should be done cautiously. Past experience suggests that it is better to start out complex and work toward informed simplicity (Dale and Beyeler, 2001). The number and diversity of indicators may decline as the project continues and less informative measures are dropped or replaced and understanding of linkages between management actions and project goals increases in an ever more data-rich environment (Trexler and Busch, 2003).

The SCG used the following 4-step approach to select this initial suite of South Florida system-wide indicators of restoration success:

Step 1 Evaluate existing restoration efforts from various applicable sources for indicators for possible application to the Task Force suite of system-wide indicators (Table 1). Keeping in mind that this process involved many different scientists and managers and required consensus or general agreement prior to the next steps being initiated, this step took approximately 6–8 months.

Step 2 Using established guidelines (Table 2), select relevant indicators for Everglades Ecosystem applicability; evaluate the list of Indicators for individual and collective value and coverage of different characteristics, trophic interactions, and ecosystem functions for the different regions within the Everglades ecosystem. Selected indicators should meet most of the identified criteria where possible. This step took approximately 4–6 months.

Step 3 Identify ''indicator gaps'', and where feasible develop new indicators to fill identified gaps. This step was concurrent with step number 2.

Step 4 Select a final system-wide suite of indicators and develop indicator documentation and communication protocol. This step took approximately 6–8 months.

Table 1 – This list includes the six programs, out of twenty-three, that were deemed by the SCG to be the most relevant for the development of a suite of system-wide indicators for Everglades restoration.

- 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)

Table 2 – The twelve criteria developed by the SCG that were used to select indicators for system-wide assessment of Everglades restoration.

1	Is the indicator relevant to the ecosystem?
2	Does it respond to variability at a scale that makes it applicable to the entire system or a large or important portion of it?
3	Is the indicator feasible to implement (i.e., is someone already collecting data)? Is it measureable?
4	Is the indicator sensitive to system drivers, and is it predictable?
5	Is the indicator interpretable in a common language?
6	Are there situations where even an optimistic trend with regard to the indicator might suggest a pessimistic restoration trend?
7	Are there situations where a pessimistic trend with regard to the indicator may be unrelated to restoration activities? If so, can the responses due to these activities be differentiated from restoration effects?
8	Is the indicator scientifically defensible?
9	Can clear, measurable targets be established for the indicator to allow for assessments of success of ecological restoration and effects of management actions?
10	Does the indicator have specificity (strong and interpretable effect of stressor on the indicator)? Does it indicate a feature specific enough to result in management action or corrective action?
11	What level of ecosystem process or structure does the indicator address?
12	Does the indicator provide early warning signs of ecological change? (Noss 1990)

2.1. Step 1: evaluate existing restoration efforts for indicators

Evaluating international or national indicators for application to a particular region provides broad input to a strategic approach to indicator development and implementation. However, carefully reviewing regional efforts is most likely to reveal indicators of direct relevance in a particular regional context such as the Everglades (Jackson et al., 2000). Programs for review were chosen by a team of south Florida scientists using an ''expert panel-based'' approach (sensu Oliver, 2002). After reviewing 23 different restoration initiatives that encompassed several hundred individual indicators, the SCG focused on six programs as useful for its work (Table 1). Since much work on indicator development for South Florida Ecosystem Restoration had already been accomplished under CERP, the SCG's leading source for indicators was the Restoration Coordination and Verification (RECOVER) team's *Recommendations for Interim Goals and Interim Targets for the Comprehensive Everglades Restoration Plan*, the RECOVER Monitoring & Assessment Plan (MAP), and the RECOVER: CERP system-wide performance measures (see: http://www.evergladesplan.org).

Unfortunately, many of the international and national level projects and programs that were evaluated for indicators either had none that were applicable to our purpose or included variables that did not apply to the Everglades. Even so, these programs provided valuable conceptual models and strategic elements that helped refine indicators and identify gaps.

2.2. Conceptual ecological models in the development of indicators

Predictions of the effects of South Florida restoration projects are assessed using ecological drivers or stressors (such as hydrology) identified in the Conceptual Ecological Models (CEM) developed for Everglades restoration (Wetlands, 2005 (special issue)). The indicators are assessed using ecological attributes noted in the CEMs (i.e., organisms) and relevant associated parameters (see also Ecological Indicators, 2001) (Fig. 2). Selected indicators ideally have predictive as well as monitoring components. For example, performance measures for indicators of the Greater Everglades have a hydrological component that includes measures of inundation duration, dry-down duration, extreme events (high and low water depths), flow, distribution, timing and continuity (Fig. 2). Hydrologic modeling is used to forecast ecosystem responses to project implementation, while assessment focuses on measuring organism and habitat structural and functional responses to changes in hydrology. Developing stronger, more explicit relationships between drivers/stressors and attributes will be an important step toward improving the accuracy and precision of the indicators for managing and adapting the restoration projects and operations (Karr, 2000).

The 11 ecological indicators in Table 5 (note that Wading Birds are reported as two indicators (Roseate Spoonbill and White Ibis/Wood Stork/Great Egret)) are designed to describe the collective status of organisms that represent individual components (Karr, 2000) (i.e., structural and functional ecological responses) of the portion of the South Florida ecosystem that will be impacted by restoration projects (Hughes et al., 1990; Dale and Beyeler, 2001). The components of the South Florida ecosystem embodied in the organisms that make up this suite of indicators include characteristics distinctive of the Everglades landscape, trophic constituents, biodiversity, physical properties, and associated ecological structure and function (Fig. 2, Table 3; also see Wetlands, 2005 (special issue)).

The CEMs developed for South Florida ecosystem restoration are hierarchical and based on identifying ecological drivers, human stressors, ecological effects and specific measurable attributes that reflect the ecological effects and their linkages (Harwell et al., 1999; Ogden et al., 2005; Fig. 2). Drivers are major environmental forces that have large-scale influences on the natural system (e.g., climate, hydrology, major natural disturbances); stressors, which are also drivers, are the human induced perturbations that have large or regional scale influences on the natural system (e.g., water

Table 3 – List of South Florida Ecosystem Features used in combination with the criteria in Table 2 to ensure the selected set of indicators covered the system-wide aspect of the Everglades ecosystem.

Landscape characteristics
- Hydropatterns
- Hydroperiods
- Vegetation pattern & patchiness
- Productivity
- Native biodiversity
- Oligotrophy
- Pristine-ness
- Intactness (connectivity/spatial extent)
- Trophic balance
- Habitat balance/heterogeneity

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

Physical properties
- Water quality
- Water management (i.e., when, where, & how much water is moved)
- Invasive exotic species
- Salinity
- Nutrients (e.g., Nitrogen, Phosphorus, Sulphur)
- Contaminants (e.g., pesticides, pharmaceutical chemicals)
- Soils

Ecological regions (see Fig. 1)
- Greater Everglades
- Southern Estuaries
- Northern Estuaries
- Big Cypress
- Kissimmee River Basin
- Lake Okeechobee
- Florida Keys

Temporal scales (see Figs. 2 and 4)
- Indicators that respond rapidly to environmental changes (e.g., periphyton)
- Indicators that respond more slowly to environmental changes (e.g., crocodilians)

management, contaminants, invasive species); ecological effects are the biotic and abiotic responses caused by the drivers and stressors; and the attributes are a subset of the components of the natural system that represent the overall ecological conditions of the system, some of which may be useful as indicators (Fig. 2; see also Wetlands, 2005 (special issue)). The Everglades conceptual ecological models are spatially explicit and model processes that occur in a landscape (e.g., ridge and slough; Ogden et al., 2005) or regional (e.g., Florida Bay; Rudnick et al., 2005) context. Our system-wide indicators are individual attributes noted under the broader attribute categories in the CEM. As illustrated in Fig. 2 (lower boxes) the system-wide suite of indicators is comprehensive but is not exhaustive in covering all aspects of Everglades restoration.

2.2.1. *Lessons learned from other indicator programs*

The programs we evaluated provided us with important findings beyond just lists of possible individual indicators. For example, the California Bay Delta Program provided important organizational examples for succinctly and unambiguously justifying and describing individual indicators, their metrics, performance measures, targets, and research findings and gaps.

The Everglades Modified Water Deliveries Project provided hydrological research and modeling for the region, and existing research on indicators where hydrological criteria were critical to indicator responses. It also included invasive exotic plants and animals (see Doren, Richards, and Volin, this issue).

The Chesapeake Bay Program has a mature monitoring program that has undergone extensive external review by the public, peer review panels, and government agency oversight. They provided good examples of communication tools using summary graphs with targets. This program also provided valuable insights into target development and justifications and the complexity and non-trivial aspects of setting and communicating meaningful targets. A 2005 GAO report highlighted concern that the Chesapeake Bay Program had too many indicators that were not integrated (GAO, 2005). Because substantial scientific information was available to reduce previous scientific uncertainties associated with Everglades restoration, and because the Task Force requested a small set of indicators to assess system-wide restoration, we sought to reduce the number of indicators to an elegant few, and ensure their integration to be able to "tell the bigger story". Over time, as uncertainties are addressed through monitoring, assessment, experimentation and modeling a more refined set of indicators may be selected. Finally, The Ecological Indicators for the Nation (NRC, 2000) provided general guidelines, concepts and recommendations for nationally accepted approaches related to ecological measurement and appraisal.

2.3. *Step 2: use guidelines to select relevant indicators*

The RECOVER program (see www.evergladesplan.org) established a science strategy that links restoration values and goals to environmental drivers influenced by managers (Ogden et al., 2005; Fig. 3). The RECOVER program relies on the use of existing data to identify indicators measured in the field that represent causal linkages between environmental drivers and restoration goals. These linkages are made from statistical models derived from field-measured parameters, whose role in restoration can be evaluated through simulation models (DeAngelis et al., 2003; Trexler et al., 2003).

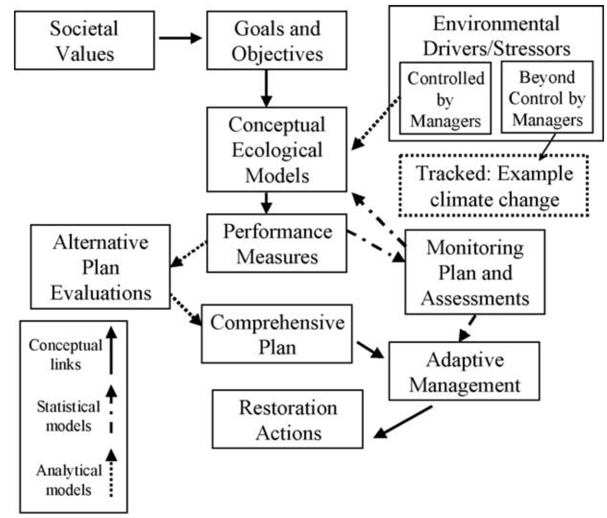


Fig. 3 – Conceptual model of science strategy for CERP.

To evaluate potential applicability, and to determine that the suite of selected indicators collectively provided sufficient coverage of Everglades features (i.e., regions, characteristics, trophic interactions, structures, properties and functions) the SCG assembled a set of criteria for selecting the system-wide suite of indicators (Jackson et al., 2000; Kurtz et al., 2001; Rice and Rochet, 2005) (see Figs. 1 and 4, and Tables 2 and 3). The SCG used these guidelines to rank the individual indicators from restoration programs we evaluated (Dale and Beyeler, 2001; Carignan and Villard, 2002; Burger and Gochfeld, 2004; Ruiz-Jaen and Aide, 2005; Burger, 2006; Niemeijer and de Groot, 2008).

To determine if the existing indicators evaluated during Step 2 provided relatively comprehensive spatial and temporal coverage of present day South Florida geography, ecosystem properties and functions (Tables 3 and 4), the SCG matched applicability of the candidate indicators with key eco-regions of the ecosystem (Figs. 1 and 4) (see Wetlands, 2005 (special issue)).

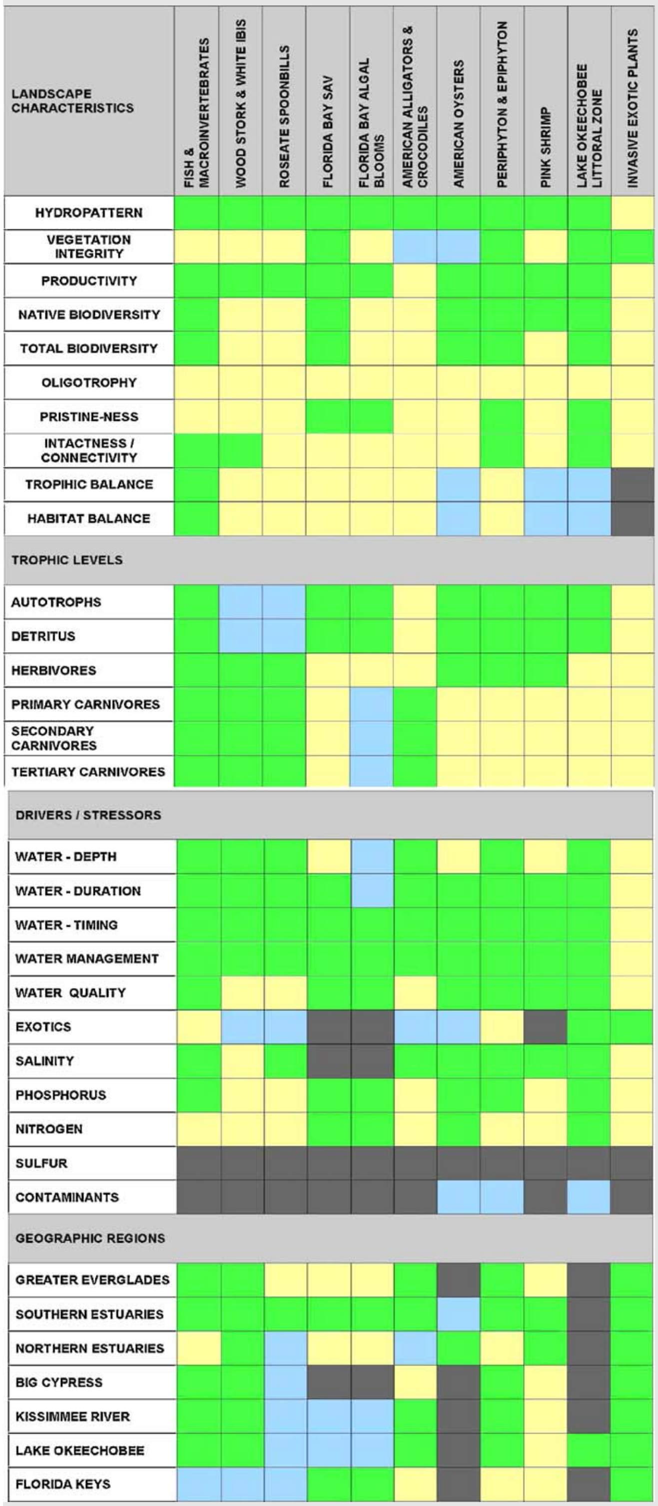
2.4. *Step 3: identify indicator gaps*

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 (Slocombe, 1998; Karr, 2000; Dale and Beyeler, 2001; Tables 3 and 4). Where our indicators did not cover a key feature, our process allowed us to identify and where possible fill the key gaps noted below.

2.5. *Key system-wide gaps*

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

Table 4 – Our relative level of knowledge regarding the indicators in relation to the different landscape characteristics and their geographic coverage. Light Green indicates (a) empirical research has been done establishing a direct statistical correlation to the indicator metrics for that landscape characteristic or (b) the area or regions are monitored for this indicator. Light Yellow indicates that either (a) a link between the indicator and the ecosystem characteristic is identified by the Conceptual Ecological Models but there is no statistical correlation established by empirical research, or (b) only part of this region is monitored for this indicator. Light Blue 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. Dark Gray indicates either (a) this ecological characteristic is not being studied, or (b) that this region is not monitored for this indicator.



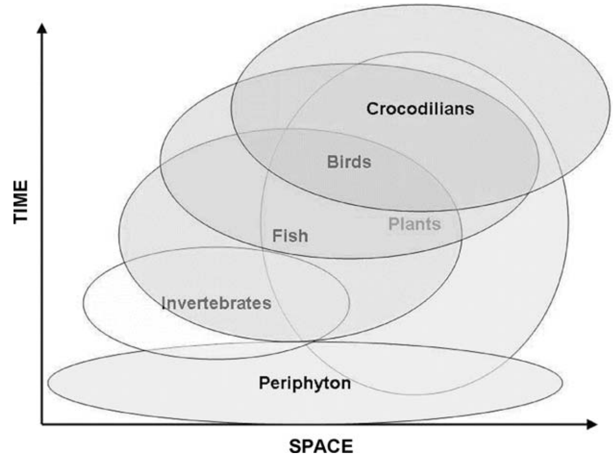


Fig. 4 – This is a graphical representation of how indicators may integrate with the temporal and spatial aspects of the ecosystem and ecological drivers. For example: periphyton responds very rapidly at both large and small spatial scales (e.g. periphyton uptake of phosphorus occurs in seconds over very small and very large spatial scales), while crocodilians respond more slowly and at larger spatial scales (e.g. climate warming may alter sex ratios of hatchlings over the next several decades). This figure shows only six of the indicators presented in this special issue and is not meant to capture the literal aspects of spatial and temporal interactions with any exactness.

some preliminary research studies on pesticides being conducted by the US Geological Survey, Everglades National Park, and Florida International University). The CERP element of the Everglades restoration program is focused on the timing, distribution, quantity and quality of water entering the natural system. Although contaminant loading can be correlated to increased flows, reduction in contaminants other than nutrients is not a stated CERP goal.

2. There are no indicator(s) related to the spread of exotic animals.
3. There is no vegetation pattern/mosaic/integrity/patchiness indicator that covers a sufficiently large geographic region and includes uplands although there are data sources that allow for development of vegetation indicators for specific regions and habitats (Rutchey et al., 2006; Smith and Whelan, 2006) or areas of nutrient impacts (US EPA, 2002) that may serve as starting points (also see Wetlands, 2005 (special issue)). There is currently ongoing work to develop a vegetation mosaic performance measure that would span ridge and slough, tree-island and marl prairie habitats that has the potential to be expanded to a whole system metric based on structure and patchiness (see Rutchey et al., 2006 for a description of these habitats). RECOVER has completed the development of the first phase of the vegetation metric focusing on wet prairie communities within marl landscapes. Continued and future performance measure development will expand this metric to neighboring ridge and slough and tree island communities (see Greater Everglades Wet Prairie Performance Measure for details—www.evergladesplan.org).

Table 5 – The final list of selected ecological system-wide indicators.

Aquatic Fauna (Fish & Crustaceans)
Wading Birds (Roseate Spoonbill)
Wading Birds (Wood stork, White Ibis, Great Egret)
Florida Bay Submerged Aquatic Vegetation
Florida Bay Algal Blooms (Chlorophyll *a*)
Crocodilians (Alligators & Crocodiles)
Oysters
Periphyton-Epiphyton
Juvenile Pink Shrimp
Lake Okeechobee Near-shore and Littoral Zone
Invasive Exotic Plants

2.6. *Step 4: select suite of system-wide indicators*

The final recommended suite of 11 integrative ecological indicators that will be used as a group by the Task Force to assess restoration goals and targets are listed in Table 5. Detailed write-ups of the individual indicators are provided as companion papers in this special issue of Ecological Indicators.

3. Communicating the ecological indicators

How much, and what kind of information a person needs before he or she can make a decision may relate more to the background of the individual. However, it also depends on the quality of information and the manner of its communication (Chess et al., 2005). The quality of information and the method of communication are especially critical where scientific information is involved because most of the people making management or policy decisions using this information are usually not scientists themselves (Durnil, 1999).

Effective communication of indicator results to policy makers (i.e., the Task Force and Congress) and the public is as important as the performance of the indicators themselves (Chess et al., 2005; McElfish and Varnell, 2006; Dennison et al., 2007). When assessing the performance of an indicator, scientists collect data related to the metrics that statistically link environmental parameters to indicator performance (Figs. 5 and 6). These data are usually detailed and complex, requiring various levels of analysis and interpretation even for use by other scientists (Harwell et al., 1999; Astin, 2006). The role of the suite of indicators presented in this special issue is two-fold. To serve as a synthesizing tool for assessing Everglades restoration, and to facilitate interpretation of the results into a common language to effectively communicate the status of restoration. Individual indicators provide discrete pieces of information about one, or perhaps a few, (for example fish) constituents of the ecosystem while the suite of indicators in combination is intended to reflect the status of the larger system. For example, similar ecological responses noted for individual indicators (e.g. Fish, Wading Birds, Alligators) collectively would indicate correspondingly broad ecological responses among organisms (Gerritsen, 1995; Karr, 2000; O'Connor et al., 2000; Schiller et al., 2001; Rice and Rochet, 2005; Rapport and Singh, 2006). Our goal is to communicate collective ecological responses in a simple

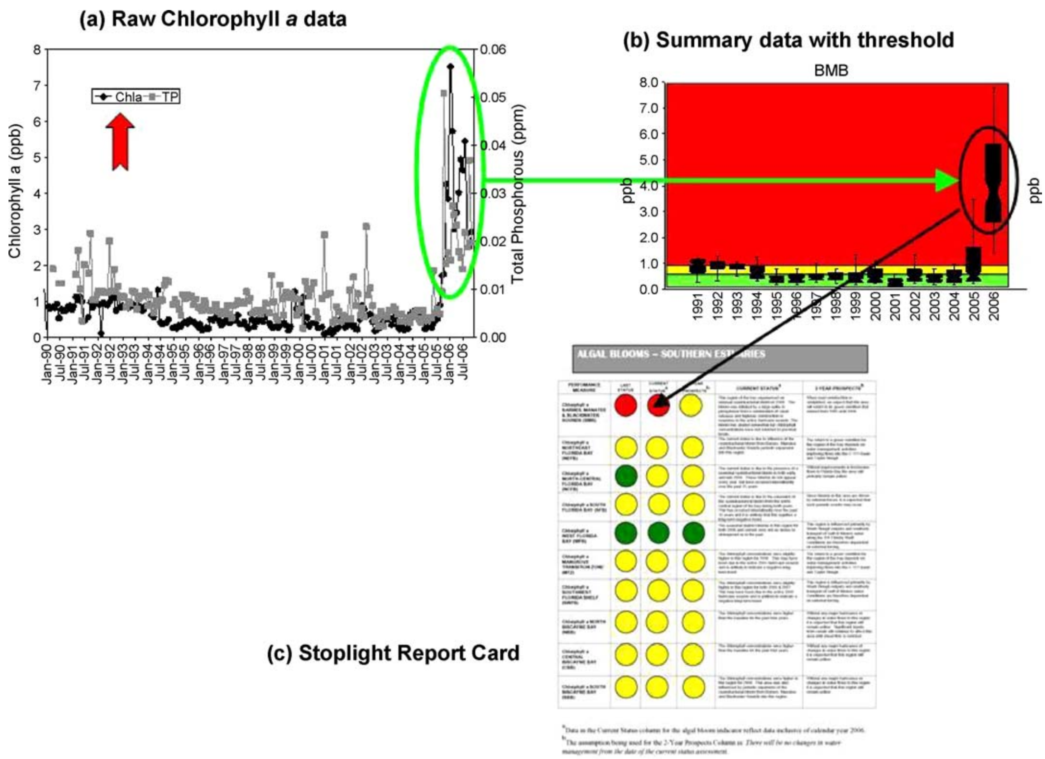


Fig. 5 – Three graphic elements illustrate the hierarchical structure of the link from complex field data (direct observations that capture variation, a), through target setting (statistical analysis, summarizing data, and defining ranges, b) and finally to report card stoplight colors (c). This example uses data on Chlorophyll *a* from the Barnes Sound, Manatee Bay (BMB) region of South Florida (see Boyer et al., this issue).

and straightforward manner that does not compromise the fidelity of the science.

Schiller et al. (2001) developed and tested processes for translating indicators of regional concern into a common language for communication with the public and decision-making audiences. They found that people did not want to know the complex details about what the indicators measured or how the indicators performed. Rather, the audiences wanted to know what such measurements told them about environmental conditions. Furthermore, the researchers found that indicator results that were most positively received were descriptions of the kinds of information that indicators provide about broad ecosystem conditions. Schiller et al. (2001) also found that study participants preferred to let scientists decide what should be measured as long as these measures were reliable and could be communicated in a way the participants could understand. We concur with Schiller et al. (2001), and others (see Dennison et al., 2007) that describing environmental conditions is a key element of indicator use and application. Determining how to describe and communicate indicator results to the Task Force, Congress and the public has been an integral part of the development of this suite of indicators.

Any method of communicating complex scientific issues and findings to non-scientists must: (1) be developed with consideration for the specific audience; (2) be transparent as to how the science was used to generate the summary findings (Figs. 5 and 6); (3) be easy to follow the simplified results back through the analyses and data to see a clear and unambiguous connection to the information used to roll-up the results (Figs. 5 and 6); (4) maintain the credibility of the scientific results without either minimizing or distorting the science; and (5) should not be, or appear to be, simply a judgment-call (Norton, 1998; Harwell et al., 1999; Dale and Beyeler, 2001; Niemi and McDonald, 2004; McElfish and Varnell, 2006; Dennison et al., 2007).

To effectively communicate the results we must sum up data from the many disparate monitoring elements into an accurate reflection of the status of the ecosystem in a straightforward digest. The detailed science behind the indicators presented in this special issue of Ecological Indicators is either derived from, or related to many different influential reports including:

1. The biennial RECOVER System Status Report (www.evergladesplan.org).
2. The annual South Florida Environmental Report (www.sfwmd.gov).
3. The Task Force Biennial Report (www.sfrestore.org).
4. CERP's five year report to congress (www.evergladesplan.org).
5. CERP/RECOVER Interim Goals and Interim Targets report (www.evergladesplan.org).
6. The annual South Florida Wading Bird Report (https://my.sfwmd.gov).
7. The US EPA's R-EMAP reports (www.epa.gov).

8. Peer reviewed manuscripts (e.g., Smith and Whelan, 2006; Rudnick et al., 2005; Trexler and Busch, 2003; Trexler et al., 2003).

All of these various reports use the same scientific information to report on and assess restoration trends. Preparing different reports requires additional work by scientists' to reorganize and reformat the same scientific data and information for the different reports and audiences. As more harmonious assessment and stoplight reports are developed, the trail of analytical development portrayed in Fig. 5 has the beneficial outcome of producing several products of differing levels of complexity, which can be more simply extracted without major modifications for a variety of reports. The science information being used in many of these reports may someday be developed as a single multi-agency science report that agencies may then use for different reporting needs as required. The stoplight report-card presented here represents a common format for displaying high-level, highly-aggregated information and represents a universal format for scientists and managers. Equally important, as part of any decision-making process, it is essential to direct audiences toward additional details via access to additional supporting information and documentation (e.g., Harwell et al., 1999; Trexler and Busch, 2003; SFERTF, 2004; GAO, 2005; RECOVER, 2006a)

3.1. *The stoplight restoration report card*

Experience indicates that the managers, policy-makers and the public who will be using the information generated by these indicators take more definitive action when it is presented with

KEY FINDINGS – SOUTHERN ESTUARIES

SUMMARY FINDING: Re-suspension of nutrients from the 2005 hurricane season resulted in algal blooms in many regions of the southern estuaries and may cause continued algal blooms in the bay for some time. However, this is expected to subside within a few additional years in lieu of further significant hurricane activity and if water flows to the southern estuaries is improved should return to predominantly green for all regions with the possible exception of BMB. If water flows do not improve the areas will probably remain yellow.

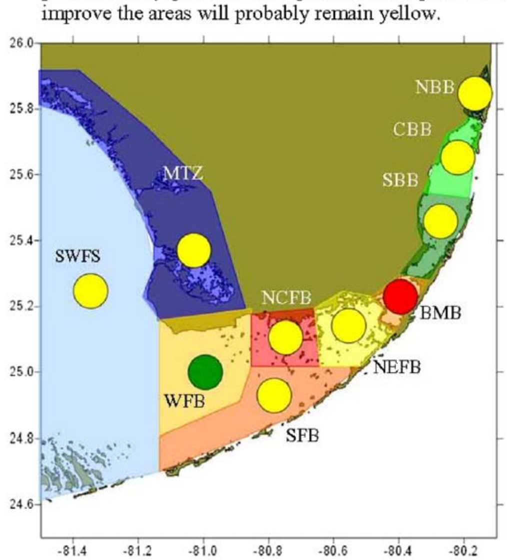
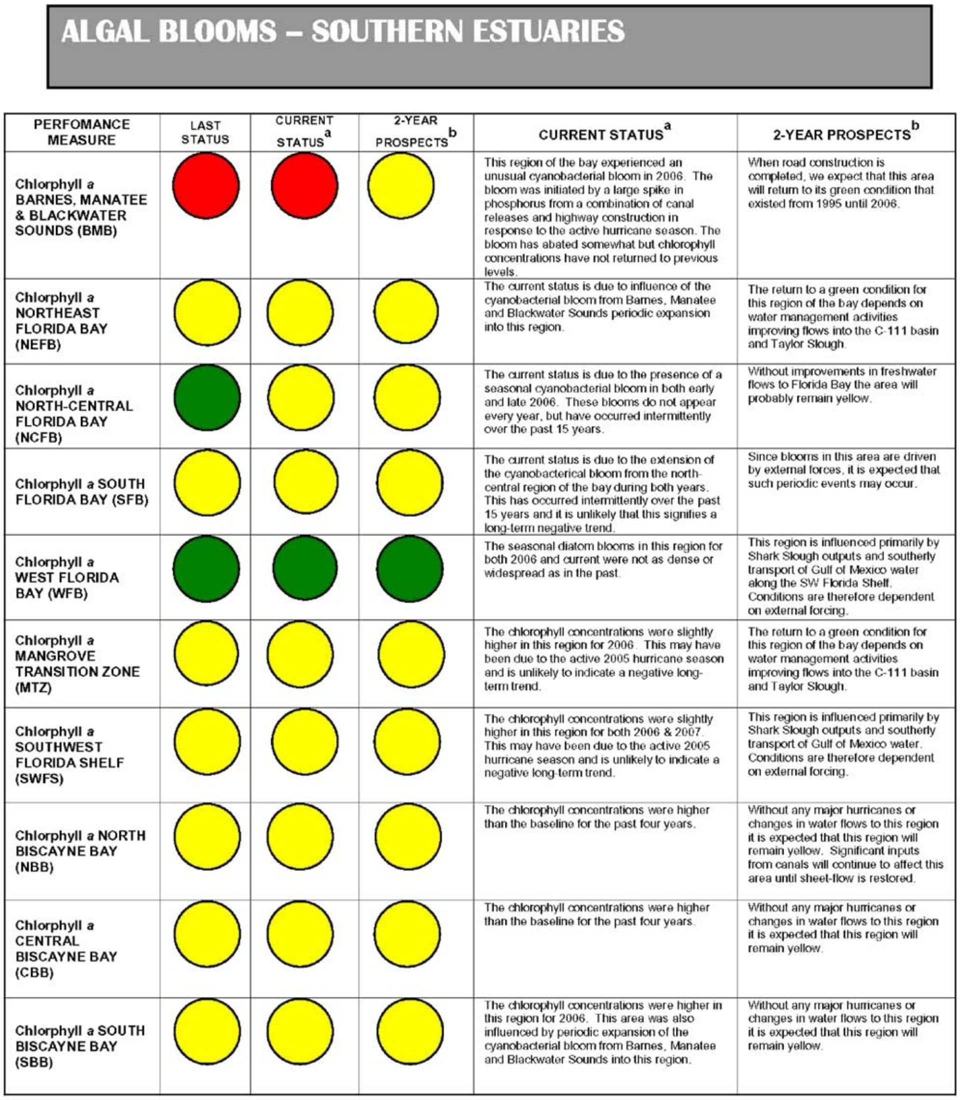


Figure 1. Map of Florida Bay regions with stoplight ratings by region

KEY FINDINGS:

1. The majority of regions assessed had significant algal bloom activity that appears to have been predominantly influenced by the heavy 2005 hurricane season aggravated for the eastern bay by road construction on US 1.
2. The majority of regions assessed had chlorophyll-*a* and algal blooms rated as moderate (yellow).
3. The majority of regions assessed where the chlorophyll-*a* was higher than the median do not appear to be indicative of long-term negative trends.
4. The most commonly occurring condition was large spatial coverage of algal blooms and elevated chlorophyll-*a* concentrations.
5. Overall eutrophic symptom expressions were geographically variable and appear to be explainable from existing phenomenological conditions of hurricane activity overall exacerbated by road construction along US 1 in the eastern areas of the bay.
6. If water flows are improved to the southern estuaries we expect the water quality to improve and the number and scale of algal blooms to diminish. However, under current water flow conditions there will probably be little or no improvement in the conditions in the southern estuaries.
7. Monitoring of Barnes, Manatee and Blackwater Sounds was critical to being able to detect the impacts of road construction along US 1.
8. Monitoring long term consequences of nutrient releases into the southern estuaries from both natural (e.g. hurricanes) and human causes (e.g. road construction) and the interactions of hydrological restoration (e.g. more fresh water flow into the southern estuaries, particularly Florida Bay) is critical to continuing the evaluation and assessment restoration for the southern estuaries.

Fig. 6 – Example Stoplight Restoration Report Card illustrating the 2-page format with Key Findings and the stoplight table. The example is for the southern estuaries region and the performance measure is Chlorophyll *a*. Red = Substantial deviations from restoration targets creating severe negative condition that merits action Yellow = Current situation does not meet restoration targets and merits attention. Green = Situation is good and restoration goals or trends have been reached. Continuation of management and monitoring effort is essential to maintain and be able to assess "green" status.



ALGAL BLOOMS – SOUTHERN ESTUARIES

PERFOMANCE MEASURE	LAST STATUS	CURRENT STATUS[a]	2-YEAR PROSPECTS[b]	CURRENT STATUS[a]	2-YEAR PROSPECTS[b]
Chlorphyll *a* BARNES, MANATEE & BLACKWATER SOUNDS (BMB)				This region of the bay experienced an unusual cyanobacterial bloom in 2006. The bloom was initiated by a large spike in phosphorus from a combination of canal releases and highway construction in response to the active hurricane season. The bloom has abated somewhat but chlorophyll concentrations have not returned to previous levels.	When road construction is completed, we expect that this area will return to its green condition that existed from 1995 until 2006.
Chlorphyll *a* NORTHEAST FLORIDA BAY (NEFB)				The current status is due to influence of the cyanobacterial bloom from Barnes, Manatee and Blackwater Sounds periodic expansion into this region.	The return to a green condition for this region of the bay depends on water management activities improving flows into the C-111 basin and Taylor Slough.
Chlorphyll *a* NORTH-CENTRAL FLORIDA BAY (NCFB)				The current status is due to the presence of a seasonal cyanobacterial bloom in both early and late 2006. These blooms do not appear every year, but have occurred intermittently over the past 15 years.	Without improvements in freshwater flows to Florida Bay the area will probably remain yellow.
Chlorphyll *a* SOUTH FLORIDA BAY (SFB)				The current status is due to the extension of the cyanobacterical bloom from the north-central region of the bay during both years. This has occurred intermittently over the past 15 years and it is unlikely that this signifies a long-term negative trend.	Since blooms in this area are driven by external forces, it is expected that such periodic events may occur.
Chlorphyll *a* WEST FLORIDA BAY (WFB)				The seasonal diatom blooms in this region for both 2006 and current were not as dense or widespread as in the past.	This region is influenced primarily by Shark Slough outputs and southerly transport of Gulf of Mexico water along the SW Florida Shelf. Conditions are therefore dependent on external forcing.
Chlorphyll *a* MANGROVE TRANSITION ZONE (MTZ)				The chlorophyll concentrations were slightly higher in this region for 2006. This may have been due to the active 2005 hurricane season and is unlikely to indicate a negative long-term trend.	The return to a green condition for this region of the bay depends on water management activities improving flows into the C-111 basin and Taylor Slough.
Chlorphyll *a* SOUTHWEST FLORIDA SHELF (SWFS)				The chlorophyll concentrations were slightly higher in this region for both 2006 & 2007. This may have been due to the active 2005 hurricane season and is unlikely to indicate a negative long-term trend.	This region is influenced primarily by Shark Slough outputs and southerly transport of Gulf of Mexico water. Conditions are therefore dependent on external forcing.
Chlorphyll *a* NORTH BISCAYNE BAY (NBB)				The chlorophyll concentrations were higher than the baseline for the past four years.	Without any major hurricanes or changes in water flows to this region it is expected that this region will remain yellow. Significant inputs from canals will continue to affect this area until sheet-flow is restored.
Chlorphyll *a* CENTRAL BISCAYNE BAY (CBB)				The chlorophyll concentrations were higher than the baseline for the past four years.	Without any major hurricanes or changes in water flows to this region it is expected that this region will remain yellow.
Chlorphyll *a* SOUTH BISCAYNE BAY (SBB)				The chlorophyll concentrations were higher in this region for 2006. This area was also influenced by periodic expansion of the cyanobacterial bloom from Barnes, Manatee and Blackwater Sounds into this region.	Without any major hurricanes or changes in water flows to this region it is expected that this region will remain yellow.

[a] Data in the Current Status column for the algal bloom indicator reflect data inclusive of calendar year 2006.

[b] The assumption being used for the 2-Year Prospects Column is: *There will be no changes in water management from the date of the current status assessment.*

Fig. 6. (Continued).

information-rich visual elements in a condensed and concise format (Funkhouser and Maccoby, 1971; Dennison et al., 2007). Where individual management or policy decisions may require further information or detail, additional and more detailed information is usually provided separately, either in an expanded report form (e.g., RECOVER System Status Report; see www.evergladesplan.org), or through a workshop venue, as with the Avian Ecology Workshop series (see NRC, 2006).

However, since scientists may not always be effective communicators, particularly when the audience is non-scientists (Hartz and Chappell, 1997; Weigold, 2001; Thomas, 2006) the stoplight report card provides a framework for technical authors to convey complex results in a straightforward way.

In reviewing the literature on communicating science to non-scientists, we realized that the system of communication we developed for this suite of system-wide indicators must be effective in quickly and accurately getting the point across to our audience in order for our information to be used effectively (Rowan, 1991, 1992; Dunwoody, 1980; Weigold, 2001; Thomas, 2006; Dennison et al., 2007). There are many differing approaches to communicating complex science, engineering and economic information into simpler languages (Weigold, 2001). Symbolic elements commonly have drawbacks, and no single system is appropriate for all situations (Funkhouser and Maccoby, 1971; Rowland and Schweigert, 1989; Rowan, 1991; Dennison et al., 2007). When looking at highly aggregated information, people often focus on a single element (e.g., a red stoplight) of the information and discount the rest, sometimes failing to draw on the complete summary information package central to understanding the message being presented. Despite these drawbacks, most people are still unwilling or unable to examine the more detailed information without condensed presentations. Due to valid concerns of losing critical information necessary for decision making scientists frequently fail to recognize the value of aggregating their information in simple and easily understood ways. Thus, useful science information often fails to pass to those who make funding and policy decisions (Weigold, 2001; McElfish and Varnell, 2006).

Our indicator restoration assessments are summarized in a two-page format using colored traffic light symbols that have a message that is instantly recognizable, easy to comprehend, and has universally understood cultural associations for the responses needed (Fig. 6). This stoplight restoration report-card provides a common format for all eleven indicators noted in this journal. This report card approach evaluates and presents indicator data to managers, policy makers, and the public in a format that is easily understood, provides information-rich visual elements, and is uniform. This helps standardize assessments among the indicators and provides ''apples to apples'' comparisons managers and policy-makers seem to prefer (Schiller et al., 2001; Dennison et al., 2007). We also provide a stoplight restoration report card using Chlorophyll *a* in southern estuaries of South Florida as our example (see Figs. 1, 5 and 6).

4. Future needs

4.1. *Science reporting*

This suite of indicators is better integrated and is reported in a harmonious format. However, many other indicators and reporting formats are still being used by different restoration programs in South Florida (NRC, 2006). Integrating the many other indicators into a uniform system of communication and reporting would improve the overall communication of science information and reduce time scientists spend reorganizing the same information into several formats to satisfy different agency reporting needs. We suggest a strategic approach to developing a uniform and coherent outline for science reporting to natural resource managers and policy makers that would provide the science information necessary for all agencies formats and would give scientists a template in developing reports for their indicators. This does not diminish the importance of the kind of detailed scientific analysis and reporting that goes into the individual reports identified above, rather it identifies avenues for collaboration, consistency, and efficient use of resources to produce a commonly needed product.

4.2. *Targets and target development*

The use of indicators in assessment requires development of targets for evaluation of monitoring data (Harwell et al., 1999; Noon, 2003; Astin, 2006). The identification of targets remains a major challenge for assessment and application of adaptive management in South Florida ecosystem restoration. In the absence of reference areas or historical data, models are needed to project targets as part of the assessment process (DeAngelis et al., 2003). For example, at present, there are many hydrological models fed by rainfall data that are used in South Florida for evaluating alternative restoration scenarios (RECOVER, 2006b). However, model time-series inputs and outputs are not updated frequently enough to aid in the development of rainfall-driven hydrological targets through time (contemporary with management actions and ecological monitoring), or to validate model predictions with field assessment data. Thus, it is not always possible to use these models to develop hydrological targets for assessments using ecological monitoring data. Future efforts are needed for applying hydrological monitoring in a form that can be used for assessments. This model update would provide the ability to characterize extant system structure and function relative to our best understanding of the pre-drainage Everglades. An additional challenge of target development is the need for the target to include natural variability and directional spatio-temporal changes over time (Harwell et al., 1999; Trexler et al., 2003).

5. Conclusions

By anchoring ecological indicators in the larger context of conceptual ecological models, we have developed an approach for presenting ''quantitative, scientifically determined, ecologically relevant, [and] habitat-specific'' ecological indicators (Harwell et al., 1999) as a stoplight communication tool that scientists can use for communicating complex scientific information to managers and the public in a form that can be better utilized (Johnson and Chess, 2006). We recognize limitations of this proposed suite of indicators (Table 4). For example, some are inherently regional in nature and may not reflect broader ecological or physiographic provinces (e.g., Roseate Spoonbill for Southern Estuaries, Oysters for Northern Estuaries). Some of the modules (i.e., geographic regions of the ecosystem) (Fig. 1) are not included in the monitoring areas of all of the selected indicators, and there are some indicator gaps that cannot be filled at this time because of a lack of sufficient science or funding. Additionally, for critical ecosystem goals and processes, some redundancy in indicators may be desirable. As noted previously, past experience suggests that it is better to start out complex and work toward informed simplification/reduction of the suite of indicators.

We believe the selected indicators will remain valuable, and through additional research and assessment, they can be refined and improved. Additional research will promote collaborative efforts across regional modules (Fig. 1), thereby potentially leading to the development of whole-system indicators. Ultimately, it is important to recognize that continued coordination and integration among scientists and policy-makers is critical to optimize monitoring, refine a relatively small suite of key indicators, communicate restoration success and progress to the policy-makers, managers and the public, and to adaptively manage South Florida ecosystem restoration.

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