16 November 2007

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South Florida Water Management District
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Attention: Stu Appelbaum, USACE and Ken Ammon, SFWM

SUBJECT: RECOVER 2007 System Status Report

The REstoration COordination and VERification (RECOVER) Leadership Group (RLG) is pleased to transmit the 2007 System Status Report (SSR). The Comprehensive Everglades Restoration Plan (CERP or Plan) Programmatic Regulations (33 CFR 385) direct RECOVER to provide the U.S. Corps of Engineers and the South Florida Water Management District with periodic technical reports to assess the hydrological, water quality, biological, ecological, water supply and other responses of the South Florida ecosystem to implementation of the CERP. The SSR plays a key role in achieving the goals of the CERP by providing a technical basis for assessing the success of the CERP in restoring the South Florida ecosystem and by providing information needed to identify improvements to the Plan.

The 2007 SSR is the first comprehensive technical assessment of monitoring data developed by the Assessment Team under the RECOVER Monitoring and Assessment Plan (MAP). Because few CERP projects have been implemented at this time, the 2007 SSR provides estimates of pre-CERP conditions for ecosystem indicators monitored by the MAP, in conjunction with data from other sources. Currently, many data sets used in the 2007 SSR are limited to a few years, and these pre-CERP estimates remain uncertain pending completion of needed monitoring. Sustained multi-year monitoring is a prerequisite for establishing sound estimates of pre-CERP conditions and trends.

The role of the MAP and the SSR in the CERP Adaptive Management program is essential. Results of this and future SSRs as well as monitoring are necessary for assessing positive responses to CERP actions and essential for identifying management actions that may be necessary to adjust the CERP to achieve its goal of restoring the Everglades and the south Florida ecosystem.

Sincerely,

RECOVER Leadership Group

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November 2007

Final
2007 SYSTEM STATUS REPORT

Prepared by: REstoration COoordination and VERification
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ACRONYMS

> greater than
< less than
= equal to
% percent

A
AC alternating current
ac-ft acre-feet
AGL Above Ground Level
AM Adaptive Management
AMO Atlantic Multidecadal Oscillation
Anosim Analysis of Similarity
AOML Atlantic Oceanographic and Meteorological Laboratory
APA Alkaline Phosphatase Activity
ARC/INFO ARC/INFO Geographic Information System
ASR Aquifer Storage and Recovery
AT Assessment Team

B
BB Braun-Blanquet
BCNP Big Cypress National Park
BCP Big Cypress Preserve
BMB Blackwater, Manatee, and Barnes Sounds

C
C&SF Central and Southern Florida
CA Correspondence Analysis
CCA Canonical Correspondence Analysis
CBB Central Biscayne Bay
CD compact disc
CDOM Color Dissolved Organic Matter
CEM Conceptual Ecological Models
CERP Comprehensive Everglades Restoration Plan
cfs cubic feet per second
CI Condition Index
cm centimeter
Corps United States Army Corps of Engineers
CRE Caloosahatchee River Estuary

D
dB decibels
DEP/FDEP Florida Department of Environmental Protection
DERM Miami-Dade County Department of Environmental Resources Management
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EXECUTIVE SUMMARY

The 2007 Assessment Team (AT) System Status Report (SSR) provides an in-depth assessment of the monitoring data provided by: (1) the Restoration Coordination and Verification (RECOVER) Monitoring and Assessment Plan (MAP) in conjunction with historical data and (2) data from other sources (e.g., universities, federal/state/local agencies). This monitoring data is assessed to establish pre-Comprehensive Everglades Restoration Plan (CERP) conditions and trends and is essential for determining whether the changes resulting from CERP implementation are effective in restoring the Everglades ecosystem. However, because many of the data sets are limited to a few years, estimates of the pre-CERP conditions for many hypotheses and associated performance measures (PMs) remain uncertain. Furthermore, since many CERP projects have not yet been implemented, this report will not provide conclusions or recommendations regarding success in achieving CERP restoration goals.

A key goal of the assessment process is to determine if observed changes in variables are true deviations from natural variability and ultimately whether those changes might be caused or remedied by CERP. The time needed for expression of ecological responses is another important factor that influences the ability to estimate status, trends and detect change. For example, when fundamental changes occur in an estuarine ecosystem, the responses of aquatic prey populations may occur over time scales of months to years; changes in the areal extent of oyster reefs or seagrass beds may take several years and changes in mangrove forests may occur over several decades. It is important to recognize the variability of temporal responses in order to fully appreciate the limits to establishing pre-CERP conditions at this stage in Everglades restoration.

Assessing Pre-CERP Conditions by MAP Module

Lake Okeechobee Module

Present research and monitoring efforts for Lake Okeechobee (LO) are likely sufficient to detect significant changes expected to result from restoration activities. LO is an important component within the south Florida aquatic ecosystem both in terms of the habitat it provides for wading birds and recreational fish and in the quality of its water, which is transported throughout the ecosystem. Although historic biological data (prior to c.a. 1985) for LO is patchy and often anecdotal, most of the existing evidence suggests that the lake has undergone rapid eutrophication over the past 60 to 80 years. A number of CERP and related non-CERP projects are currently underway in the watershed in order to reduce nutrient influxes to LO and to improve LO hydrology. Currently, routine monitoring is in place for lake water quality and hydrology, submerged and emergent aquatic vegetation, fish, macroinvertebrates and phytoplankton. In addition, the littoral portion of LO is included in system-wide monitoring for wading birds and their prey species, and for the Everglades snail kite. Results indicate that there is a wide range of variability in some of the parameters and while some of this variability can be clearly associated with known natural and man-made physical perturbations, much of it cannot. As such, it is becoming increasingly clear that extensive, long duration monitoring will be required to clearly differentiate the impacts of restoration activities from the “noise” of normal environmental variability. With this in
mind, it appears that submerged aquatic vegetation (SAV) and macroinvertebrates may be
the most responsive to change and the best long-term integrators of variability.

Northern Estuaries Module
While an overall conclusion for the Northern Estuaries (NE) is difficult to make because the
four different waterbodies included in this module (Caloosahatchee Estuary, St. Lucie
Estuary, Loxahatchee River Estuary and Lake Worth Lagoon) often have very different types
and levels of stress affecting them in any given year, the NE monitoring plan has been
successfully implemented. Although monitoring data for some indicators is limited to just
one or two years, important observations have been made as to the overall condition of the
estuaries’ pre-CERP condition. In estuaries where several different indicators are being
monitored and monitoring of different salinity zones and habitats occurs, multiple lines of
evidence can be used to begin to characterize baseline conditions of the individual
waterbodies. An important finding from this assessment is that catastrophic natural events,
such as recent hurricane landings along the southeast coast, have a major impact on natural
resources and often overshadow any pattern of response attributed to anthropogenic
disturbances or restoration efforts. Long-term data sets will be necessary to discern natural
variability from CERP related changes.

Salinity is clearly the most important stressor shaping the ecology of seagrass beds and oyster
reefs in the NE. Monitoring data for SAV in the NE indicates a need to understand the affect
that the timing (duration and time of occurrence) of a freshwater discharge may have on
SAV; specifically, understanding the causal mechanisms that control SAV growth as it
relates to changes in water quality with respect to controlling freshwater discharges in the
NE. Flows that are altered beyond historic conditions have negatively impacted SAV in the
NE. Managing the frequency and duration of freshwater discharges with relation to the
species-specific physiological requirements of seagrasses, should reduce light attenuation
through a reduction in turbidity and color and thus relax this stressor on seagrass growth.
While current research may provide insight as to the range of salinities that SAV species may
tolerate, little data are available that describe the response of SAV to rapid salinity changes,
as might be the case when controlling freshwater discharges in the NE. SAV models and
Geographic Information Systems (GIS) applications need to be developed and linked to
hydrodynamic water quality models to refine predictions. Establishing linkages between
water quality/quantity and SAV requires real-time in situ monitoring of key water quality
parameters. A network of sampling units within the NE will be necessary in order to relate
assessments to goals and targets.

Oysters are another system-wide ecological attribute that are important in the NE and have
been selected as one of the Interim Goals (IGs) for evaluating the efficacy of CERP progress.
While the existing sampling design and sampling frequency can adequately assess the
direction and magnitude of change in the oyster hypothesis cluster, the sampling protocol
may be adjusted to better capture the spatial variation of responses. A significant
relationship exists between freshwater inflows and salinities at various points in the
Caloosahatchee Estuary. Flows below 3500 cubic feet per second (cfs) into the estuary will
result in a salinity regime that will enable oysters to survive and grow. Disease prevalence
was lower at upstream locations and increased with distance downstream, suggesting that
higher salinities result in increased disease incidence. Limited freshwater releases for durations of less than two weeks will result in lower disease prevalence and intensity of oysters as well as higher survival. Managing freshwater releases to less than (<)3500 cfs during the months of spawning activity will limit flushing of oyster larvae to downstream locations and create a favorable salinity regime for spat recruitment and survival. Since the extent of oyster coverage has been chosen as an IG, oyster mapping should be conducted on a five-year schedule that corresponds to the schedule of assessment of IGs.

Greater Everglades Module
The Greater Everglades (GE) wetlands include a mosaic of inter-connected freshwater wetlands and estuaries located primarily south of the Everglades Agricultural Area (EAA). This habitat mosaic has been subjected to disruption of sheet flow and associated hydropatterns, sea level rise, nutrient inputs, and invasive non-native plants and animals. Two important ecological attributes of the GE are its potentially massive wading bird colonies and endangered alligator and crocodilian populations.

Results from the SSR clearly indicate that the wading bird/aquatic fauna predator prey relationships were influenced by hydrologic conditions across the Everglades during the 2005 wet season and 2006 dry season. Wading birds nesting and nesting success was high throughout most of the system in comparison to recent historical levels, but still nearly an order of magnitude less than occurred in this region pre-1920. Water levels were well above average at the start of the dry season and a steady and prolonged water level recession during the dry season was unimpeded by major reversals. Furthermore, the late onset of the wet season in 2006 continued to provide ample foraging patches for fledging birds late in the nesting season. This resulted in a successful year for wading bird nesting. Wading bird colony locations and nest numbers during 2006 were concentrated in the A.R.M. Loxahatchee National Wildlife Refuge, the Water Conservation Areas (WCAs) and the LO littoral zone where fish biomass was moderate to high during the previous wet season.

The exception to the successful 2005-2006 wading bird season was the lower rates of nesting in southern Everglades National Park (ENP). High crayfish biomass in western ENP did not support extensive wading bird nesting in the southern Everglades during 2006, since relatively few individuals of all wading bird species nested near the region of high crayfish biomass. A possible explanation for the low rates of nesting initiation in coastal regions of the ENP in 2006 was that low wet season fish biomass was insufficient to produce dry season prey concentrations adequate to support nesting, despite the occurrence of water recession rates conducive to prey concentration. This episode of low marsh fish biomass in what is typically a productive marsh-mangrove ecotone in southern ENP was surprising. The correspondence between low fish biomass and low wading bird nesting in the southern Everglades is consistent with the hypothesis that collapse of traditional coastal nesting colonies is caused by declines in prey populations along the freshwater/estuarine interface of the southern Everglades.

Crocodilian populations occurred in high densities during 2005-2006. Alligators occurred in higher relative densities in canals in comparison to marsh and estuarine survey areas throughout most of the Everglades during 2005-2006. The forty to fifty crocodile nests
recorded in ENP during 2005 and 2006 represented a continued trend of increased nesting in ENP since 2000 when saltwater intrusion was reduced by plugging access to saltwater.

Southern Estuaries Module
Florida’s Southern Estuaries (SE) are of enormous ecological and economic value and are operating at less than their full potential, largely due to anthropogenic changes to freshwater flow that began more than a century ago. CERP aims to restore more natural salinity regimes to nearshore environments, which, in turn, will have positive consequences for the region’s flora, fauna, and fisheries.

The SE component of the SSR concluded that the approaches and methods used for assessing water quality, salinity regimes, SAV and nursery functions are appropriate and efficient relative to the size, complexity, and value of the systems in question. Therefore, data obtained from SE sampling will prove critical, not only in a monitoring and assessment context, but also for advancing the understanding of how subtropical ecosystems respond to incremental reductions in anthropogenic stress. Some of the most important scientific conclusions in the SE are listed below:

Water Quality and Salinity: Baseline conditions indicate that most of the SE are oligotrophic with median Chlorophyll $a$ concentrations of less than or approximately one part per billion (ppb). These baseline data were used as the reference condition to assess the 2006 data, and only the Barnes, Manatee, and Blackwater Sound sub-region was found to have chlorophyll $a$ biomass significantly higher than the baseline. This test case demonstrates that the approach and methods used are sensitive to water quality changes now and into the future as CERP is implemented.

Understanding how CERP affects water quality in the SE will facilitate adaptively managing and guiding restoration efforts. The current continuous salinity monitoring network clearly demonstrates the instability of the existing (pre-restoration) salinity regime along the western coastline in southern Biscayne Bay. These conditions make it difficult for a variety of estuarine floral and faunal communities to either colonize or optimally utilize these regions.

Submerged Aquatic Vegetation: Results of the present assessment suggest that the methods adopted can detect changes in SAV from pre-CERP conditions when there are sufficient reference data, and that the present trends are consistent with hypothesized causal relationships. Results of the present assessment suggest that the methods adopted can detect changes in SAV from pre-CERP conditions when there is sufficient reference data, and that the present trends are consistent with hypothesized causal relationships. Partitioning the relative contribution of the causal factors will require judicious application of the mechanistic SAV model currently being developed for the SE module, as well as some sensitivity analyses. It will also require a considerable time series of data after CERP is implemented. Implicit is the quantitative understanding of the relationship between water management changes and both salinity and water quality. Developing these relationships throughout the SE module will almost certainly depend upon integrated water quality monitoring and modeling (including hydrodynamic and hydrological). The present analysis suggests that it will require a decade or more of
monitoring to obtain an adequate amount of data to detect and interpret ecosystem change related to CERP activities. Fortunately given the present implementation schedule, such a time series will be available if MAP monitoring is sustained as planned.

**Nursery Function:** Three concurrent field efforts are providing substantial, long-term data that are relevant to assessing the suite of nursery hypotheses. The species under examination: (1) are among the most ecologically and economically important species in the SE system; and (2) display responses to salinity (and therefore, to changes in freshwater flow) in terms of their distribution and/or abundance.

Establishing baseline levels of abundance of these estuarine species and detecting the impacts of CERP requires longer time series than currently possessed. It is critical to associate abundance with habitat and environmental conditions. Salinity variation over time needs to be quantified for the sampling domain, and variation, itself, needs to be tested as a factor influencing faunal abundance. Ideally, monitoring for MAP should be supported by laboratory salinity/temperature tolerance, growth and preference experiments with species and life stages of interest. Other species in the pre-CERP database should be examined for relationships with salinity and habitat.

**Linkages Between The 2007 SSR And Other CERP Components**

In addition to assessing the pre-CERP condition, the SSR addresses a series of topics that directly relate to the role of the MAP and linkages of the SSR to other system-wide CERP components. These topics include: (1) the relationship of the SSR to the CERP Adaptive Management (AM) Program; (2) the refinement of the MAP; (3) the role of the MAP and the SSR in water supply and flood protection (WS/FP); (4) the role of human ecology in the MAP and the SSR; (5) the coordination of the SSR with CERP IGs and (6) the role of management in the MAP and for use in the assessment process. Each of these topics is intimately linked to the development of this as well as future SSRs and is addressed here in order to provide a context for the SSR in the face of changing priorities.

**The CERP AM Program**

The role of AM in complex ecosystem restoration programs such as CERP is to substantially improve the likelihood for restoration success. This is accomplished by providing a process for addressing the uncertainties that occur during project planning, implementation and assessment. The SSR plays a critical role in the CERP AM Program, which is described by the CERP AM Strategy [http://www.evergladesplan.org/pm/program_docs/adaptive_mgmt.aspx](http://www.evergladesplan.org/pm/program_docs/adaptive_mgmt.aspx). Monitoring and assessment are key features of the CERP AM Program and results from the SSR will be used to establish pre-CERP conditions and trends, as well as determine the success of CERP as projects and programs are brought online. The assessment of ecosystem responses contained in the SSR become the basis for identifying structural and/or operational components of the Plan that should be modified to improve the chance of CERP restoration success.

Once monitoring data has been assessed, there are three possible outcomes in the AM process: (1) there is insufficient data and/or time available to establish pre-CERP conditions
and identify trends; (2) monitoring and research are inconsistent (i.e., do not meet assessment targets) and/or do not support the conceptual ecological models (CEMs), hypotheses or IG/IT; and (3) monitoring and research results are consistent with PM targets indicating consistency with the CEMs, hypotheses and support the interim goals/interim targets (IG/IT). Because very few MAP datasets extend beyond a few years, the 2007 SSR represents the first outcome–insufficient data and/or time available to establish pre-CERP conditions and identify trends, which could lead to changes in Plan performance. In the future, the MAP module teams will develop triggers, which can be loosely defined as unmet CERP system performance needs. The CERP AM Implementation Guidance Manual, currently under development, will provide details about how analyses in the SSR will be used to initiate an AM response if there are deviations from the expected performance of the Plan.

**MAP Refinement**

RECOVER, through the AT, has begun the process of developing a strategic approach to refine the MAP; this approach will include development of a white paper addressing the theoretical constructs of the MAP (i.e., developing a consensus on what a revised MAP will accomplish and the environment in which it will operate), as well as focusing on the process used for conducting the revision of the MAP. RECOVER will consider using either a bottom-up or top-down approach to MAP revision, or some hybrid that combines attributes of both approaches. A bottom-up approach utilizes science-based results from the SSR as one tool for weighting and ranking MAP hypotheses in the refinement process; use of this approach creates a hierarchal ranking which provides flexibility for the MAP as well as establishes assessment priorities. Alternatively, a top-down approach is also being considered as a mechanism for refining the MAP; this approach uses a suite of total system attributes, derived from the Total System CEM, which will be used as the IGs, and serve to help prioritize future monitoring and subsequently assessment for the MAP.

**Water Supply and Flood Protection**

WS/FP are the two major purposes of water management at the South Florida Water Management District (SFMWD) and the U.S. Army Corps of Engineers (Corps). Currently, the assessment process utilized in the SSR does not assess the potential impacts to WS/FP on the implementation of the MAP. It is the intent of RECOVER to address this issue using a strategy that links WS/FP to the CEMs at both the beginning of the assessment process (i.e., hydrology is an essential attribute of all MAP monitoring components and there is a need to assess whether CERP impacts affect WS/FP via monitoring) and the end of the assessment process (i.e., if there are unanticipated results detected via MAP monitoring, which can be attributed to hydrology, then any recommended changes in hydrology should be evaluated within the context of potential impacts to WS/FP).

**Human Dimensions Science**

Currently, the MAP and the SSR do not directly interface with human dimensions science. Human dimensions science can be broadly defined as the complex interrelationships of people and the environment. The process of integrating human dimensions research into RECOVER is one aspect of an overall larger, and important, effort that will be needed to develop and implement a socio-ecological framework and strategy for restoration of the south Florida ecosystem. In fall 2006, the RECOVER Leadership Group (RLG) established
a sub-team to explore the scope of human ecology in the context of CERP and to provide recommendations to the RLG about the appropriate role, if any, of RECOVER. This sub-team developed the following recommendations, which ultimately will impact the MAP (i.e., SSR) from a socio-ecological perspective; these recommendations pinpoint tasks appropriate to RECOVER in terms of both its role and mission: (1) develop socioeconomic indicators that can serve as restoration PMs; (2) identify which metrics (both natural system and those addressing human-dimensions science) can be used to develop a report card to help the public evaluate restoration success; and (3) develop mechanisms within RECOVER to help incorporate human dimension science into the CEMs, the effort to define success for Everglades restoration, the CERP AM Strategy, and the MAP via development of Human Dimension Science Module and its assessment as part of future SSRs.

It is important to note that RECOVER and the RLG have not made any decisions about how to proceed with respect to human dimensions science; as of November 2007, this list of tasks only represents recommendations that may be addressed in some way by RECOVER in the future.

Interim Goals

The Programmatic Regulations (Prog Regs) for CERP (Department of Defense [DOD], 2003) have tasked RECOVER with recommending a set of IGs for the restoration of the natural system. IGs are defined as “a means by which restoration success of the Plan may be evaluated throughout the implementation process.” RECOVER, in response to the National Research Council’s (NRC’s) recommendations, has begun the process of developing a suite of system-wide IGs. There are two steps in this process: (1) identifying a parsimonious suite of total system IGs that capture the essential and defining characteristics of the total system; and (2) linking those goals to the MAP monitoring and assessment process to ensure that the necessary data is being collected to conduct the evaluation of IGs. The IGs will be assessed in future SSRs.

Data Management for the SSR

Data management support of the SSR assessment process occurs at the principal investigator (PI) level, the MAP module level, and the system-wide level. The data life cycle spans all three levels of the assessment process. Particular elements of the data life cycle are inherent to one level, such as data collection in the MAP monitoring component or PI level, whereas other elements, such as quality assurance/quality control (QA/QC) and analysis, apply at all levels. The goal of RECOVER’s data management system is to automate elements of the data life cycle, as well as improve integration of assessments across the MAP domain. Implementation of an automated data management system for the SSR enhances the integrity of the data throughout the life cycle and maximizes the efficiency of the assessment process.

SSR System-wide Recommendations

In summary, the 2007 SSR provides the following system-wide recommendations for MAP and the role of AM.
- Multi-decadal restoration programs on the scale of the Everglades and the south Florida ecosystem require dedicated interagency programmatic, scientific and funding support.
- Sustained multi-year monitoring is a pre-requisite for the establishment of pre-CERP conditions and trends. Multi-year monitoring will support hypotheses and IGs and is an essential first step in the ability to determine changes in the physical, chemical and ecological variables that will result from implementation of CERP projects.
- The MAP has proven to be a scientifically robust and successful strategy for planning, assessing, and managing a large-scale restoration program. Lessons learned during management of such a large-scale monitoring and assessment program as well as the interface of this program with AM will be addressed in a revised version of the MAP.
- The SSR has resulted in the refinement of monitoring priorities, a reduction in the number of PMs and hypotheses being evaluated, and has highlighted the importance of using system-wide indicators of performance that support the IGs. The information and lessons learned from the 2007 SSR will be incorporated into future SSRs.
- While the 2006 and 2007 SSR has focused on establishing pre-CERP conditions, future assessments will require forecasting changes based on understanding the functional relationships between stressors and ecological effects and to distinguish CERP-impacts from non-CERP influences.
- The role of the SSR in the CERP AM Program is critical. Results from the SSR will be used to initiate management actions that are necessary to adjust the Plan to meet desired performance expectations. Additionally, new knowledge gained from the SSR may also be used to update the CEMs, hypothesis clusters, PMs, and/or modeling tools utilized by CERP. Finally, the information derived from the SSR will be used by MAP module teams to develop triggers, which will be used to initiate an AM response if there are deviations from the expected performance of the Plan.

These recommendations will not only be used to refine the MAP and to inform the assessment process (i.e., future SSRs), but will be taken into account as the CERP AM program is developed and implemented.
1.0 INTRODUCTION

The Comprehensive Everglades Restoration Plan (CERP or Plan) is one of the largest ecosystem restoration programs in United States. Authorized by the Water Resources Development Act (WRDA) of 2000 and the Programmatic Regulations (Pro Regs) (Section 601(h)(3)) (WRDA 2000), the goal of the Plan is to restore the Everglades and the south Florida ecosystem while meeting the other water related needs of the region including water supply and flood protection (WS/FP). Per the Pro Regs, Restorat ion COordination and VERification (RECOVER) is charged with implementing a system-wide monitoring and assessment program to assess implementation of the Plan. This monitoring and assessment plan is essential to determining the success of CERP and is an integral feature of the CERP Adaptive Management (AM) Program.

Formal assessments of data generated from the RECOVER Monitoring and Assessment Plan (MAP), Part 1 (Monitoring and Supporting Research) are reported in the System Status Report (SSR), which is developed biennially by RECOVER as part of CERP reporting requirements. Assessments of MAP monitoring data (i.e., MAP monitoring data is augmented with historical and experimental data as well as non-CERP data provided by partner agencies) are done using the assessment strategy detailed in the MAP, Part 2 (2006 Assessment Strategy for the MAP). The SSR plays an important role within CERP and represents the accumulation of multiple years of data on the status, condition and trends of performance measures (PMs) critical to Everglades restoration. Ultimately, future SSRs will present an assessment of whether the goals and purposes of the Plan are being achieved, including whether the interim goals and targets (IG/IT) are being achieved or are likely to be achieved. The SSR will be a major component of the RECOVER Technical Report mandated by the Pro Regs in 2010, and also will be used to provide information to the National Research Council’s (NRC) Committee on Independent Scientific Review of Everglades Restoration Progress, the IG/IT Report, the Five Year Report to Congress and the CERP Report Card.

1.1 Context for the 2007 System Status Report

The SSR is intended to provide the following: (1) a synthesis of findings across MAP modules and across years to provide a holistic description of the status of the Everglades ecosystem; (2) an evaluation of assessment results in relation to supporting system-wide hypotheses and achieving system-wide IGs; (3) a summary of those changes in the ecosystem that are consistent with the goals and purposes of the Plan and the MAP hypotheses; (4) if necessary, a discussion of why the goals and purposes are not being met and/or why the MAP hypotheses should be revised; and (5) the identification of major unanticipated findings that may require attention and correction via processes outlined in the CERP AM Strategy. If unanticipated findings are identified during the assessment process, the RECOVER will provide details about these findings and formulate potential options to address them. These details will be addressed by RECOVER and vetted through the AM process developed for CERP.

The 2007 SSR is only intended to provide an assessment of the pre-CERP condition of the individual MAP modules and the south Florida ecosystem given currently available data.
Because many of the data sets are limited to a few years, estimates of the pre-CERP condition for many hypotheses and associated PMs remain uncertain. Furthermore, since many CERP projects have not yet been implemented, the 2007 SSR will not provide conclusions or recommendations regarding success in achieving CERP restoration goals or assessing IG/IT. Nevertheless, the analyses that comprise this assessment have resulted in recommendations for improving the MAP, Part 1 and 2 and will contribute to future SSRs.

The 2007 SSR focuses on the following objectives:

- Conducting an assessment of each of the hypothesis clusters: Lake Okeechobee (LO), the Northern Estuaries (NE), Greater Everglades (GE) and the Southern Estuaries (SE) using the assessment strategy describe in the MAP, Part 2.
- Establishing pre-CERP ecological, hydrological and water quality conditions by assessing MAP and non-MAP data (historical and experimental data as well as data generated by other agencies).
- Assessing the ability to detect change by evaluating sampling design, data quality objectives (DQOs), variability and relevant spatiotemporal patterns.
- Characterizing the status of monitoring and data availability for the MAP modules (by individual module and collectively as a whole).
- Evaluating and providing recommendations on data acquisition, dissemination and management.
- Providing recommendations on the assessment process and coordination among principal investigators (PIs), participating agencies, members of the RECOVER Assessment Team (AT) and RECOVER Leadership Group (RLG), and the NRC.

1.2 Environmental Characteristics of the 2007 Water Year

Hydrology is a key driver shaping the structure and function of the south Florida ecosystem. Therefore, knowledge of the hydrologic dynamics, in space and time, provides a context for interpreting the results of the 2007 SSR. The following is a brief summary of the hydrologic data and analysis for Water Year 2007 (WY2007; May 1, 2006–April 30, 2007). Details of WY2007 hydrology are available in the 2007 South Florida Environmental Report—(SFER) Volume I (Abtew et al. 2007a: http://www.sfwmd.gov/sfer).

Water management in south Florida has many objectives and must be prepared to face the challenges created by annual and inter-annual hydrologic variation. WS/FP are the two major purposes of water management at SFWMD. Although south Florida is a wet region, serious droughts have occurred such as the current drought (summer 2007), and there is potential for periodic water shortages. During the dry season, the water management system operates primarily to satisfy various water supply demands that include environmental deliveries, irrigation and utilities requirements, and the prevention of saltwater intrusion in groundwater.

The hydrology of south Florida for WY2007 can be summarized as a severe drought year with rainfall below average in all areas and far below average in most of the areas. LO, East Everglades Agricultural Area (EAA) and Martin St. Lucie experienced a 100-year drought.
The Southeast region (Broward, Miami-Dade, Everglades National Park [ENP]), the Big Cypress Preserve and the Southwest Coast received below average rainfall. Upper Kissimmee and Lower Kissimmee were dry resulting in only 619,189 acre-feet (ac-ft) inflow to LO. This inflow is 29 percent of the historical average and 17 percent of WY2006 inflow. Outflows were also reduced due to the limited storage in LO and the reduced inflows. WY2007 outflow from LO was 907,527 ac-ft, 60 percent of the average outflow and 16 percent of WY2006 outflow. LO water level declined to 9.65 feet National Geodetic Vertical Datum (NGVD), the second lowest stage since 1931. The low lake level restricted gravity discharge and 14 temporary pumps were installed to discharge water from LO into the major canals to the south and pumped 52,174 ac-ft from March to April 2007. The low lake level and deficit of rainfall resulted in a series of water conservation measures that included restrictions to water use (2007 SFER).

The drought resulted in significant reduction of flows throughout the region. Lake Kissimmee did not have significant discharge for 173 consecutive days and the water year total outflow of 121,156 ac-ft is 17 percent of the historical average. Lake Istokpoga water year outflow of 64,372 ac-ft is 29 percent of the historical average. Discharge into the estuaries also decreased as a result of the drought. The St. Lucie Canal discharged 21,340 ac-ft through the S-80 structure, four percent of the historical average. Discharge through the Caloosahatchee Canal into the estuary through the S-79 structure was 694,124 ac-ft, less than half of the historical average. Inflow into the A.R.M. Loxahatchee National Wildlife Refuge (LNWR) was 50 percent of the historical average. Inflow into WCA 2 was 584,391 ac-ft and outflow was 468,598 ac-ft (65 percent and 42 percent of WY2006, respectively). Inflow into Water Conservation Area (WCA) 3 was 849,324 ac-ft and outflow was 464,818 ac-ft (50 percent and 26 percent of WY2006, respectively). Inflow into ENP was 48 percent of the historical average and 30 percent of WY2006 (2007 SFER).

Unlike WY2005 and WY2006, there were no hurricanes in south Florida during WY2007. The lack of extensive tropical system rains in the summer and a drier dry season were the primary causes of the severe drought. The only significant rainfall from a tropical system was from Tropical Storm Ernesto. Ernesto landed in southwestern Miami-Dade County on August 30, 2006 and passed through the center of south Florida, exiting to the northeast near Cape Canaveral. In WY2007, south Florida received an area average of 40.62 inches, which is 12.13 inches below the average for the area. All 14 rainfall areas and ENP experienced below-average rainfall (Table 1-1). The driest area is Martin/St. Lucie with a rainfall deficit of 22.26 inches. The areas with the least rainfall deficit are Big Cypress Preserve (BCP), the Southwest Coast and the ENP. SFWMD-wide rainfall for WY2007 was lower than the WY2006 rainfall (54.75 inches) by 14.13 inches (Table 1-1). Rainfall data from several stations computed as Thiessen averages was obtained from the SFWMD’s Operations rainfall data report (see July 23, 2007, data from the SFWMD website at www.sfwmd.gov under the Weather & Water Conditions, Historical Data section, under the Rainfall tab) (2007 SFER).

The balance between rainfall and evapotranspiration maintains the hydrologic system of south Florida and determines whether wet or dry conditions prevail. Evapotranspiration is actual evaporation for lakes, wetlands and any feature that is wet year round. In south Florida, most of the variation in evapotranspiration is explained by solar radiation (Abtew, 1996). Regional estimates of evapotranspiration from open water and wetlands, which do
not dry out, range from 48 inches in the SFWMD’s northern section, to 54 inches in the
Everglades (Abtew et al., 2003; Abtew, 2005). Available evapotranspiration data from the
closest site to a rainfall area was used to estimate evapotranspiration for the area. This year,
evapotranspiration was 11.7 inches higher than rainfall (Table 1-1). The only systems that
stayed wet year round were those with enough storage and surface water inflow. The driest
rainfall areas with greater than 15 inches rainfall deficit are Upper Kissimmee, LO, East
EAA, Martin/St. Lucie and Palm Beach (Table 1-1).

Clearly, WY2007 has been one of significantly reduced rainfall throughout the south Florida
ecosystem. The following interpretations of pre-CERP condition should be viewed within
this context.

Table 1-1: Spatial Comparison of WY2007, WY2006, Historical Average Annual
Rainfall (inches) and WY2007 Potential Evapotranspiration (PET) for Each Rainfall
Area

<table>
<thead>
<tr>
<th>Rain Area</th>
<th>WY2007</th>
<th>WY2006</th>
<th>Historical Average</th>
<th>WY2007 PET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Kissimmee</td>
<td>34.48</td>
<td>52.91</td>
<td>50.09</td>
<td>54.47</td>
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<td>Lower Kissimmee</td>
<td>33.64</td>
<td>48.5</td>
<td>44.45</td>
<td>54.12</td>
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<td>LO</td>
<td>28.51</td>
<td>47.33</td>
<td>45.97</td>
<td>54.94</td>
</tr>
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<td>East EAA</td>
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<td>51.39</td>
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</table>

(Modified from Abtew et al., 2007)
1.3 Long-term Climate Variability

The environmental characteristics of south Florida, especially hydrology, are influenced not only by annual variations in weather, but also by long-term climatic change and variability. Long-term climatic change and variability have become increasingly important during the last two decades. The immediate focus of the 2007 SSR and subsequent SSRs is to establish pre-CERP conditions as well as status and trends for a variety of PMs. Long-term climatic patterns will likely influence pre-CERP conditions as well as changes resulting from the implementation of CERP. Understanding the respective contributions of climate to restoration of the Everglades ecosystem will allow discrimination between CERP and non-CERP effects. The following summarizes important climatic cycles and how their effects are being incorporated into south Florida water management and CERP.

Several climatic indicators, such as global sea temperatures (including the data that derive the Atlantic Multidecadal Oscillation [AMO] and the Pacific Decadal Oscillation [PDO] periods), rainfall, soil moisture and solar radiation are being studied by the SFWMD, the U.S. Geological Survey (USGS) and the U.S. Army Corps of Engineers (Corps) to understand their potential influence on CERP. El Niño/Southern Oscillation (ENSO), AMO and PDO are large-scale climatic indicators that have implications for water resources and planning in south Florida. Of these three indicators, ENSO, which follows a three to seven-year cycle, has the strongest effect on south Florida climatic conditions and has received the most study. The PDO may last for decades and affects south Florida weather in a manner similar to ENSO but is much less influential. The AMO has a weaker effect on south Florida than ENSO but its effects could last up to several decades. The AMO warm phase is associated with slightly higher, but possibly more variable, rainfall conditions in south Florida. Research on AMO and PDO influences indicates a significant variability in the periodicity, duration and magnitude of these multi-decadal climatic indicators and their effects on south Florida weather. Furthermore, the relationships between these cycles and regional weather patterns or rainfall conditions in south Florida cannot be accurately predicted.

CERP is incorporating climatic trends into modeling and operational decision-making processes. Notable examples include the application of the water supply and environmental (WSE) schedule and position analysis techniques to guide the regulation of water releases into and out of LO. The USGS, SFWMD and Corps use complex regional models as tools to aid in water resources planning and management in conjunction with standard engineering practices. For example, the South Florida Water Management Model (SFWMM) incorporates a period of the south Florida hydrologic record (1965–2000) that includes a broad range of wet and dry years. SFWMD will continue to expand the modeling period forward to include the current AMO warm cycle as new data become available. By periodically extending the simulation period, the modeling efforts can continually incorporate recent climatic trends and re-evaluate proposed infrastructure changes, including CERP projects that will be designed and constructed over a period of several decades. This approach follows standard engineering and operational planning practices and provides a means to reduce the risks of facility implementation when climatic changes are inherently uncertain.
1.4 Summary

The SSR is a biennial assessment and analysis of MAP-generated monitoring data, historical data, and non-CERP monitoring data. This data is used to establish pre-CERP conditions and is essential for determining whether the changes resulting from CERP implementation are effective in restoring the south Florida ecosystem. The SSR provides a synthesis of monitoring data and is a forum where major unanticipated findings will be identified that may trigger the AM process. A key goal of the MAP assessment process is to determine if observed changes in variables are true deviations from natural variability and to differentiate between CERP and non-CERP effects. The WY2007 was highlighted by a regional drought that varied in intensity based on geographic location. The absence of tropical storm activity in central Florida during the 2006 hurricane season caused a dramatic shift in water resource availability. The interpretation of pre-CERP conditions presented in the 2007 SSR need to account for this reduction in rainfall and dry conditions in south Florida for during WY2007. The SSR provides an opportunity to detect change in ecosystem structure and function in response to changing climate, as well as in response to CERP implementation. Incorporating climatic trends into modeling and operational decision-making processes, as well as the analysis of monitoring data, will allow discrimination between CERP and non-CERP effects.
1.5 References


2.0 SYSTEM-WIDE SYNTHESIS

The intent of this section is to provide a summary of the lessons learned from the 2007 SSR, to examine options for addressing topics not currently being assessed within the SSR framework, and to present system-wide topics that are critical to the success of the SSR that are not part of the assessment process itself.

2.1 Total System-Level Lessons Learned

Identifying lessons learned is an important component of the SSR. Generally two categories of lessons learned emerge: (1) those directly associated with the conduct of the science itself (implementation of the MAP), specifically implementation at a regional scale (i.e., MAP module level); and (2) those that can be characterized as overarching or system-wide lessons learned that cross regional (module) boundaries. The following is a summary of the lessons learned at the MAP module level.

2.1.1 Lake Okeechobee

- Extensive, long-term monitoring will be required to clearly identify the impacts of restoration activities within the significant range of normal environmental variability.
  - Submerged aquatic vegetation (SAV) and macroinvertebrates may prove more responsive to environmental restoration than others, and these organisms should be the central focus of long term monitoring efforts.
- Through time, it may become possible to monitor fewer parameters without sacrificing assurances that the entire ecosystem is benefiting from restoration activities.

2.1.2 Northern Estuaries

- Long-term data sets are necessary to distinguish between natural variability and CERP related changes because natural events, such as hurricane landings, often overshadow any pattern of response attributed to anthropogenic disturbances or restoration efforts.
- More frequent water quality (i.e., temperature, salinity, nutrient and dissolved oxygen [DO]) sampling is required to capture episodic events and help explain cause and effect mechanisms that drive changes in key indicators such as seagrasses.
- Salinity is an important and controlling environmental variable for SAV that CERP has to consider especially when setting desired flow levels in the NE. Of additional importance are interactions between salinity and light attenuation and tolerances to rapid salinity changes to the health and distribution of SAV in the NE. There is a need to better understand species-specific growth responses to the dynamics of freshwater discharge rates and timing, especially on different stages of plant development.
- The existing sampling design and sampling frequency can adequately assess the direction and magnitude of change in the oyster PMs; however, the sampling protocol may be adjusted to better capture the spatial variation of responses.
• Oyster reefs occupying the various estuaries in southeast Florida are not isolated entities but are instead linked to one another via exchange of larvae. An understanding of larval exchange is a necessary precursor to the proper management of oyster reefs in Florida.
• A plan to map the extent of oyster reef development (spatial coverage in acres) needs to be developed and implemented in order to support the evaluation of oyster areal extent as an IG.
• Emphasis should be placed on specific fish PMs that are likely to aid management decisions using the present assessment evaluation. The seagrass fish fauna is the richest and most environmentally sensitive regional estuarine fish fauna and should respond both positively and negatively to various water management scenarios.

2.1.3 Greater Everglades

• Hydrological patterns and water quality must be assessed simultaneously since their interaction is the keystone process that formed and sustains Everglades function.
• Periphyton may prove to be a more sensitive integrator of nutrient load than water column measures.
• Groundwater hydrology of the coastal mangroves must be investigated to provide a basis for understanding upwelling and nutrient fluxes.
• Geostatistics will be required for future assessments to provide effective evaluation of data across spatial and temporal scales.
• The pre-CERP condition of the Everglades mangrove estuaries is characterized by saltwater intrusion into headwaters of most coastal tributaries, and by low to non-existent soil accretion in mangrove forests of the Shark River basin.
• Seasonal water levels and recession rates are a major driver for aquatic prey abundance and dry season concentration. Wading bird nesting success is directly linked to prey abundance and concentration, and there is significant hydrologic interaction between the freshwater marshes and tidal creeks in the southern part of the Everglades ecosystem. These linkages directly affect prey abundance.
• Hydrologic conditions across the Everglades during the 2005 wet season and 2006 dry season supported a successful year for wading bird nesting and nesting success throughout much of the system (LNWR, WCAs, and LO littoral zone). Water levels were well above average in these areas at the start of the dry season which allowed prey fishes to remain in the marsh and available to the wading birds. Wading bird colony nesting was lower in southern ENP, where the pattern of drydown was optimal for success, but marsh fish standing crop was depressed. The low fish standing crop appeared to be a carryover effect of low standing crops during the previous wet season.
• Preliminary evidence suggests that even relatively small changes in existing structural and operational hydrologic controls have had a direct and immediate biological effect. The 40-50 crocodile nests recorded in ENP during 2005 and 2006 is a continuation of the trend of higher numbers of nests in ENP since 2000. Reduced saltwater intrusion in ENP was a result of plugs placed in the Cape Sable area, especially East Cape and Buttonwood canals.
2.1.4 **Southern Estuaries**

- The ability to detect change, distinguish CERP-impacts from non-CERP impacts, make realistic assessments and predictions of system status, and implement AM is directly proportional to sampling intensity and duration in the SE.
- The 2007 SSR assessment highlighted the importance of developing, testing and applying appropriate analytical approaches, which is essential for realistic ecosystem modeling at different spatio-temporal scales.
- Several physical, chemical and ecological community components must be monitored concurrently in the SE because of: (1) the many uncertainties regarding the timing, magnitude and form of future restoration effects and responses; and (2) the general lack of quantitative, spatially-explicit, historical data.
- A separate salinity hypothesis cluster is needed to ensure that nearshore salinity regimes are considered not only as an ecological driver, but also as measures of operational performance.
- The sudden, unexpected algal bloom, which occurred in Barnes Sound, Card Sound and southern Biscayne Bay in 2006, illustrates the importance of routine monitoring in these interconnected, highly-dynamic systems and the ability of this techniques to adequately detect changes in water quality stemming from CERP implementation.
- Given the size, complexity and high value of the SE, sustained ecological monitoring to develop long-term, continuous time series combined with focused, short-term research is key to tracking restoration progress and ultimately guiding restoration towards success.

2.2 **System-wide Lessons Learned**

In addition to MAP module-specific results, the 2007 SSR provided the following system-wide lessons learned:

- Multi-decadal restoration programs on the scale of the Everglades and the south Florida ecosystem require dedicated interagency programmatic, scientific and funding support.
- Sustained multi-year monitoring is a pre-requisite for the establishment of pre-CERP conditions and trends. Multi-year monitoring will support hypotheses and IGs and is an essential first step in the ability to determine changes in the physical, chemical and ecological variables that will result from implementation of CERP projects.
- The MAP has proven to be a scientifically robust and a successful strategy for planning, assessing, and managing a large-scale restoration program. Lessons learned during management of such a large-scale monitoring and assessment program as well as the interface of this program with AM will be addressed in a revised version of the MAP.
- The SSR has resulted in the refinement of monitoring priorities, the reduction in the number of PMs and hypotheses being evaluated, and has highlighted the importance of using system-wide indicators of performance that support the IGs. The information and lessons learned from the 2007 SSR will be incorporated into MAP revisions and future SSRs.
While the 2006 and 2007 SSR has been focused on establishing pre-CERP conditions, future assessments will require forecasting changes based on understanding the functional relationships between stressors and ecological effects and to distinguish CERP-impacts from non-CERP influences.

The role of the SSR in the CERP AM Program is critical. Results from the SSR will be used to initiate management actions that are necessary to adjust the Plan to meet desired performance expectations. Additionally, new knowledge gained from the SSR may also be used to update the CEMs, hypothesis clusters, PMs, and/or modeling tools utilized by CERP. Finally, the information derived from the SSR will be used by MAP module teams to develop triggers, which will be used to initiate an AM response if there are significant deviations from the expected performance of the Plan.

### 2.3 MAP Refinement

The MAP (MAP 2004) was conceived as the primary tool by which RECOVER will assess the performance of CERP. The overarching goal for implementation of the MAP is to have a single, integrated, system-wide monitoring and assessment plan that could be used and supported by all participating agencies and tribal governments as the means of holistically tracking and measuring the performance of CERP. The scientific and technical information generated from MAP implementation will be organized to provide a process for RECOVER to not only evaluate CERP performance and system responses, but to produce assessment reports describing and interpreting the responses.

It was recognized both during development of the MAP in 2004 and as monitoring and research has proceeded, that new insights and changing priorities would require periodic updates to the document. With the recommendations of the NRC (NRC 2006), the completion of the 2007 SSR, the proposed incorporation of CERP project-level monitoring into the MAP, and uncertainties regarding funding, it is clear that refinement of the MAP 2004 is in order.

RECOVER, through the AT, has begun the process of developing a strategic approach to refine the MAP; this approach will include development of a white paper with three sections. The first section will discuss the theoretical constructs of MAP refinement; that is, developing a consensus on what a revised MAP will accomplish and the environment in which it will operate (e.g., identify all the activities that affect the MAP and should be considered during revision). Based upon the results from the 2007 SSR, there is agreement among scientists that the structure of the assessment process (MAP, Part 2 2006), the use of the CEMs, the establishment of pre-CERP conditions, the ability to detect change and answering both what and why questions via monitoring and assessment should be included in a revised MAP. Additionally, the system-wide approach to monitoring and assessment will be preserved. Finally, a proposed attribute of a revised MAP will be its flexibility in responding to scientific and management changes.
The second section of the white paper will provide details on the several different approaches being considered to guide MAP refinement. The MAP 2004 was developed using a bottom-up approach that began with the development of CEMs, in order to understand the science that would be needed to direct system-wide monitoring and assessment and ultimately Everglades restoration. This bottom-up approach weighted all hypotheses, PMs and attributes equally. During MAP refinement, RECOVER is considering using a hierarchal approach (a variation of the bottom-up approach), a top-down approach, or a hybrid approach that incorporates elements of each. A hierarchal approach utilizes science-based results from the SSR as one tool for weighting and ranking MAP hypotheses and PMs in the refinement process; use of this approach creates a hierarchal ranking which provides flexibility for the MAP as well as establishes assessment priorities. This approach also helps identify a minimum core level of science that is required below which an assessment cannot be made and finally examines the concept of sequencing (e.g., sequencing of monitoring) and the use of AM to adjust science to shifting priorities. A top-down approach is also being considered in response to recommendations by the NRC. RECOVER is developing a suite of total system-wide attributes; this approach uses a suite of total system attributes, derived from the Total System CEM, which will be used as the IGs, and serve to help prioritize future monitoring and subsequently assessment for the MAP. The IGs will be the measures of restoration success and therefore must be closely coupled to the SSR with respect to what is monitored and assessed via implementation of the MAP. Consequently, using the IGs as a basis for focusing the MAP refinement process is an important option to be evaluated. Finally, it is likely that the MAP refinement process will employ a hybrid approach—a combination of top-down and bottom-up approaches to identify the core science base that is essential for assessment via the SSR and ultimately evaluation of the success of CERP implementation.

Finally, the third section of the white paper will identify other CERP topic areas with potential relevance to the MAP and the MAP refinement process. These topics include but are not limited to: (1) flood protection and water supply; (2) human dimensions science; (3) CERP project-level monitoring and its impact on the MAP; (4) linkages to AM (specifically the topic of developing and defining triggers); and (5) how to address stochastic events. The MAP refinement process will be initiated in late 2007.

2.4 Water Supply and Flood Protection

Water supply and flood protection are the two major purposes of water management at the SFWMD and Corps. During the wet season, the primary purpose is flood protection. During the dry season, the water management system operates primarily to satisfy various water supply demands that include environmental deliveries, irrigation and utilities requirements, and the prevention of salt-water intrusion in groundwater.

An important question emerging with implementation of CERP is: how does MAP monitoring and assessment interface with and affect WS/FP? Currently, the assessment process utilized in the SSR does not assess the potential impacts to WS/FP from the implementation of the MAP. It is the intent of RECOVER to address this issue using a process to link WS/FP to both the CEMs at the beginning of the assessment process and at the end when modifications to hydrology become necessary to address unexpected findings.
Chronologically, the first interface between WS/FP and restoration activities is during the project planning phase of CERP. During this phase, scientists and managers on a given project delivery team (PDT) identify the causal linkages between the project alternatives and WS/FP that require evaluation. Alternatives are screened to ensure the selected plan will not lower the current level of service. During the SSR assessment process, WS/FP constraints must be taken into consideration when evaluating the system-wide effects of restoration. This may be of particular importance when intended ecological lift is not occurring as anticipated due to anthropologic influences.

The second point of interface with WS/FP during the assessment process and subsequent analyses is if there are unanticipated results that are attributed to hydrology. Any recommended changes in hydrology should be evaluated within the context of potential impact to WS/FP. Applying this process will assure that RECOVER scientists responsible for the implementation of the MAP will collaborate with SFWMD and Corps scientists responsible for projects which have impacts to WS/FP.

2.5 Human Dimensions Science

Currently, the MAP and the SSR do not directly interface with human dimensions science. Human dimensions science can be broadly defined as the complex interrelationships of people and the environment. The process of integrating human dimensions research into RECOVER is one aspect of an overall larger, and important, effort that will be needed to develop and implement a socio-ecological framework and strategy for restoration of the south Florida ecosystem. In fall 2006, the RLG established a sub-team to explore the scope of human dimensions science in the context of CERP and to provide recommendations to the RLG about the appropriate role, if any, of RECOVER. This sub-team developed the following recommendations, which ultimately will impact MAP (SSR) from a socio-ecological perspective; these recommendations pinpoint tasks that may be appropriate to RECOVER in terms of both its role and mission, but decisions about to what extent they will be addressed have not yet been decided: (1) develop socioeconomic indicators that can serve as restoration PMs; (2) identify which metrics (both natural system and those addressing human dimensions science) can be used to develop a report card to help the public evaluate restoration success; and (3) develop mechanisms within RECOVER to help incorporate human dimension science into the CEMs, the effort to define success for Everglades restoration, the CERP AM Strategy (via stakeholder engagement and involvement), and the MAP via development of Human Dimension Science Module and its assessment as part of future SSRs.

There are two points of potential intersection between MAP assessments and the human dimensions science (i.e., the public). The first is during the planning phase when stakeholder involvement is solicited to help define the goals of the assessment as well as provide input to the selection of the important monitoring attributes. The second point of intersection is when the results of the assessment are evaluated to determine if there are any unanticipated impacts to important species or habitats that are highly valued by the public (i.e., system services). For example, a societal activity can act as a driver (e.g., housing development) to the system and creates a hydrologic stress that has an undesirable result (e.g., reduces salt marsh area). The loss of marsh area increases the likelihood of flooding, which in turn affects a system
service (e.g., flood protection). This simple four-component model is a useful way to visualize how a perceived desirable societal activity intersects and, in some cases, defines the trajectory of an assessment. At both these points of intersection there is an opportunity for direct involvement between the public and scientists to ensure restoration success.

2.6 System-Wide Interim Goals

The Pro Regs for CERP (DOD, 2003) have tasked RECOVER with recommending a set of IGs for the restoration of the natural system and a set of ITs to provide for other water-related needs of the region, including WS/FP. The Pro Regs define IGs as “a means by which restoration success of the Plan may be evaluated throughout the implementation process.” IGs provide a means of tracking restoration performance and progress, providing a basis for reporting on the progress made at specified intervals of time towards restoration of the south Florida ecosystem and for periodically evaluating the accuracy of predictions of system responses to the effects of CERP. The IGs can be expressed as either predictions of ecosystem response to the implementation of CERP projects, or as desired levels of performance, and reflect incremental accomplishments towards achieving CERP goals. Evaluations of the anticipated hydrologic and water quality changes in the south Florida ecosystem brought about by CERP implementation, with the attendant ecological responses, provided the basis for the RECOVER recommendations for IGs. In 2005, RECOVER finalized its first set of recommendations for IG/IT (http://www.evergladesplan.org/pm/recover/igit_subteam.aspx).

RECOVER, in response to the NRC’s recommendations, has begun the process of developing a suite of system-wide IGs. There are two steps in this process: (1) identifying a parsimonious suite of total system IGs that capture the essential and defining characteristics of the Everglades ecosystem; and (2) linking those goals to the monitoring and assessment process to assure that the necessary data is being collected to conduct the evaluation.

Using the Total System CEM (Ogden et al. 2005) as a starting point and applying eight criteria, the IG Sub-team reviewed the 2005 RECOVER Recommendations for IGs and several other relevant documents to identify a suite of candidate system-wide IGs. The review and final selection of the total system IGs is expected to be complete early in 2008.

Once the suite of total system IGs have been identified, the next step will be to develop linkages between the IGs and the appropriate suite of PMs and metrics; these PMs and metrics will in turn support the assessment of one or more hypotheses included in the MAP. By developing and making these explicit linkages, RECOVER will assure that the assessments being conducted by the AT in the SSR will provide the data required for evaluating the IGs. It is currently anticipated that the 2009 SSR will be used as the scientific base for the evaluation of the total system IGs.

2.7 Data Management

Future assessments will depend on accessing and integrating biological, chemical, and physical data collected by multiple organizations (i.e., universities, agencies, non-profits entities etc.) and scientists. Integration of information to answer restoration–based questions
will be complicated and will require significant effort on the part of the principal investigators (PIs) and the MAP module teams. Standards for data, documentation and coding have been established in order to facilitate a seamless integration of the datasets used in the assessment process. Information technology tools and applications for setting standards are presently being evaluated and implemented. The establishment of a collaborative information technology (IT) environment for amalgamating data sets is being piloted. Ecological metadata language (EML) has been adopted to standardize documentation of ecological data sets. A metadata creation and maintenance utility will be the mechanism for ensuring standardized documentation of ecological data follows EML guidelines.

Data management support of the MAP assessment process occurs at the MAP monitoring component or PI level, the MAP module level and at the system-wide level. The data life cycle spans all three levels of the assessment process. Particular elements of the data life cycle are inherent to one level, such as data collection in the MAP monitoring component or PI level, whereas other elements, such as quality assurance/quality control (QA/QC) and analysis, apply at all levels. The goal of RECOVER’s data management system is to automate elements of the data life cycle, as well as improve the overall assessment process. Implementation of an automated data management system enhances the integrity of the data throughout the life cycle and maximizes the efficiency of the assessment process. Ideally, successful data management systems facilitate sampling design evaluation, establish DQOs, estimate variability, conduct power analysis, characterize spatial-temporal patterns, establish reference conditions (pre-CERP conditions) and provide predictive modeling support. These systems are the origin for components of data that support an integrated assessment and evaluation process for MAP.

The Data Management Process
The data management process begins in the box representing MAP and the CERP AM Strategy (see bottom of Figure 2-1). Management of data, data relationships, and data processes begin at this level by applying data management constructs to the CEMs; the hypotheses clusters, the PMs, and the IG/IT.
The MAP monitoring component/PI level of the data management process (see middle of Figure 2-1) includes multiple data management systems that are utilized by the PIs. These data management systems include primarily MAP data, but can also include non-MAP data. The data ranges in sophistication from simple spreadsheets and field notebooks to automated remote field data collection systems and formal information management applications, including:

- Florida Coastal Everglades Long Term Ecological Research (FCE-LTER)-A program established in 2000 as part of the LTER Network sponsored by the National Science Foundation (NSF). This Florida International University (FIU) research...
Section 2    System-wide Synthesis

The collaborative environment necessary to effectively and efficiently develop the SSR (as well as other CERP documents) at the module/PI and system-wide levels is depicted at the top of Figure 2-1 by a number of applications (ellipses). The CERPZone is part of the IT infrastructure (for CERP) that is evolving to support RECOVER data management as well as provide a collaborative environment for implementing the MAP and assessing data in a complex multi-agency context. Overlaps of the ellipses highlight integration among the applications and their functionality. Briefly, the applications involved at this level include:

- MAPTRACK–An application developed to track and manage information pertaining to MAP monitoring and research components (e.g., project titles, resources, funding and implementing agencies) Plans for increased integration with other applications are under development, while integration with Documentum exists currently.
- Documentum–A management and archival mechanism for all CERP documents. Documentum is continually being enhanced to facilitate document management, and search and retrieval capabilities.
- Data Access, Storage and Retrieval (DASR)–A utility that provides a permanent digital file management and archival mechanism for data deliverable files. The archive has been organized by MAP module and subsequently their monitoring components. This file management application contains an archive of digital information supporting each monitoring component including, but not limited to, photography, maps, reports, raw and processed data, and metadata.
- Electronic Data Catalog (EDCat)–A utility intended to serve as a searchable electronic index of information, as well as an integration mechanism between DASR and Documentum.
- Geographical Information System (GIS) database and GIS metadata tools–These tools provide data mapping, preliminary geospatial analysis and modular spatial data integration support. Additional GIS data integration tools are under consideration and development, including a vegetation mapping utility, expanded application of an

program focuses on understanding ecosystem processes in the estuarine ecotone of Shark River Slough and Taylor Slough in ENP.

- Everglades Depth Estimation Network (EDEN)-An application for integrating the hydrologic monitoring networks of four separate agencies: ENP, the SFWMD, the USGS, and Big Cypress National Preserve (BCNP). This application delivers online water depth information for the freshwater portion of the GE, providing needed information for monitoring plan design, recording hydrologic responses and supporting ecological assessments. Migration of the user interface for the EDEN application into CERPZone for central access is being considered.
- Interagency Modeling Center (IMC)-A modeling center providing programmatic and project-level modeling support for CERP. Modeling products from the IMC provide predictive modeling information for the Evaluation Team (ET) of RECOVER.
- South Florida Information Access (SOFIA)-suite of information systems and tools enabling the selection, organization, documentation, dissemination and storage of data and other information products for the restoration of the south Florida ecosystem. SOFIA is sponsored by the USGS Priority Ecosystems Science Initiative (PES).
oyster habitat suitability index (HSI) model, expansion of EDEN data interfaces within the CERPZone, and a geospatial monitoring locator application.

- The Assessment application—the mechanism intended to be used for effecting data integration and analysis for module and system-level analysis. The application continues to be formulated as individual assessments are defined.

- The Evaluation application—application intended to support the predictive and planning portions of CERP and be the conduit for assessment information input into models and model analysis. The definition of this application is also formulating as the evaluation process is defined.

- Aquifer Storage and Recovery (ASR) database—data management for ASR pilot studies.

Ideally, this combination of applications at a module and system-wide level will be integrated and assist with interpretations of data, specifically MAP data and analysis. Additionally, these applications will help evaluate the utility of non-MAP research and monitoring, measure progress toward achieving IG/IT and identify unexpected and episodic events.
3.0 THE ROLE OF THE SSR IN THE CERP ADAPTIVE MANAGEMENT PROGRAM

The role of AM in complex ecosystem restoration programs, such as CERP, is to substantially improve the likelihood for restoration success by providing a structured process for addressing the many uncertainties that occur in program planning, implementation, and assessment. The CERP AM Strategy (CERP, 2006) establishes a framework for addressing important unanswered questions about how natural systems will respond to various project plans and the most effective design to meet hydrological extremes. When ecosystem responses do not meet predictions or are undesirable, AM can help scientists and managers identify management actions needed to modify the Plan. The SSR assesses the health of the ecosystem as CERP projects and operations are brought on-line. The ecosystem responses and interpretations contained in the SSR become the basis for identifying structural or operational components of the Plan that should be modified to improve the chance of restoration success for CERP. This summary on the role of AM is supported by the definition of AM stated in the CERP AM Strategy:

“AM is a science and performance-based approach to ecosystem management in situations where predicted outcomes have a high-level of uncertainty. Under such conditions, management anticipates actions to be taken as testable explanations, or propositions so the best course of action can be discerned through rigorous monitoring, integrative assessment, and synthesis. AM advances desired goals by reducing uncertainty, incorporating robustness into project design, and incorporating new information about ecosystem interactions and processes as our understanding of these relationships is augmented and refined. Overall system performance is enhanced as AM reconciles project-level actions within the context of ecosystem-level responses.”

The SSR fulfills this performance assessment function as step two of the CERP AM Strategy (Box 2–Performance Assessment; Figure 3-1). When appropriate, results of these system-wide performance assessments will be used to initiate management actions within Box 3 (Management and Science Integration) that are necessary to adjust the Plan to meet desired performance expectations. New knowledge gained from the SSR also may be used to update the CEMs, hypothesis clusters, PMs, and/or modeling tools utilized by CERP (Box 1–CERP Planning) for predictive purposes. SSR data may be used to revise monitoring and assessment approaches used in the MAP (Box 2).
3.1 Performance Assessment

Conceptually, there are three plausible outcomes from interpretation of results from system-wide assessments (Figure 3-2) (RECOVER 2006). Each outcome from the SSR and interpretation of MAP data is illustrated below using a decision framework. The details of this decision framework will be addressed in the future as part of the CERP AM Implementation Guidance Manual and within the context of future MAP refinement.

1. **Outcome 1**: Characterized by insufficient data and/or time being available to establish statistical trends, to allow critical examination of MAP hypotheses, and to review the effectiveness of assessment PMs. In the case of inadequate time, the monitoring should continue until there is sufficient data to assess the status and trend of the PM and to establish pre-CERP conditions. In the case of incorrect assessment PMs, metrics, and/or monitoring methods, the option exists to modify the MAP (Box 2).

2. **Outcome 2**: In this case, monitoring trends and research results are inconsistent (assessment targets are not met) with and/or do not support the CEMs, hypotheses, or the IG/IT. This could result in the following options: (1) modify the hypotheses, CEMs and/or the associated PMs; (2) modify the assessment and evaluation tools (e.g., hydrologic, water quality, or ecological models); and/or (3) identify system-wide hydrological and/or ecological needs to improve performance of the Plan. Options 1 and 2 involve updating the Plan (Box 1) and refining the design of the monitoring plan (MAP) (Box 2). Option 3 provides the basis for initiating the next step of the AM Strategy (Box 3-Management and Science Integration) to develop options that address performance issues identified in the SSR.
3. **Outcome 3**: This outcome is realized when monitoring trends and research results reveal PM targets are met as predicted indicating that results are consistent with the CEMs, hypotheses, and support the IG/IT, thus no action is required. These PMs should continue to be monitored, as long as they provide valuable information on the status of the ecosystem and the ability to detect CERP induced changes.

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**Figure 3-2: Synthesis and Interpretation of MAP Monitoring Data**

- **Outcome 1**: Insufficient Data and/or Response Time to Determine Trend
  - Continue Monitoring

- **Outcome 2**: Monitoring Trends and Research Results Inconsistent with Hypotheses, Goals, and Targets
  - Modify MAP
  - Box 2 - MAP Refinements
  - Modify Assessment and Evaluation Tools (e.g., hydrology models)

- **Outcome 3**: Monitoring Trends and Research Results Consistent with Hypotheses, Goals, and Targets
  - No Action Required
  - Identify Unmet System Needs
  - Technical Recommendations To Box 3 - Management and Science Integration for Assessment Report

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**Box 1 - Planning and Box 2 - MAP Refinements**
While Outcome 2 in Figure 3-2 identifies unmet system needs to be addressed by Management and Science Integration (AM process-Box 3), the magnitude and/or duration of system performance deviations used to trigger a management response still needs to be developed. As CERP moves toward the full implementation of the MAP and completes its second biennial assessment of pre-CERP condition in 2009, an analysis framework will be developed to determine the magnitude and duration of performance deviation from PM targets and IGs conveyed in the SSR; this will trigger the need to move from Performance Assessment (Box 2) to Management and Science Integration (Box 3).

Weinstein et al. (1997) illustrates such a decision framework as it relates to the restoration of degraded salt marshes within Delaware Bay. An AM process was used to conduct the restoration effort due to large temporal and spatial scale uncertainties. Using a strategy analogous to the MAP, the salt marsh was conceptualized as a landscape greatly influenced by hydrological forces. From this conceptualization, Weinstein et al. (1997) identified three primary restoration endpoints that served as performance criteria for measuring restoration success. Response thresholds were identified for each of the endpoints to evaluate the progress of the restoration and to trigger a need for corrective measures and an AM response. Applying this type of decision framework and similar AM processes to the MAP will: (1) assist with revising the monitoring and assessment program for CERP; and (2) provide the criteria and rules for establishing system-wide performance triggers that require corrective measures and management intervention.

3.2 AM Conclusions

In general, the results of the 2007 SSR can be categorized as Outcome 1-insufficient data and response time to establish the pre-CERP condition necessary to detect and compare changes in performance. For example, in the GE module, most monitoring components have only one or two years of data which is insufficient to establish pre-CERP conditions or identify trends. However, in some cases, the MAP results when supplemented with extensive historical information, allow for the establishment of pre-CERP conditions; this allows verification of CERP hypotheses and assessment of system-wide performance changes once CERP projects are implemented and operational (Outcome 2 and 3). An example of Outcome 3 is current pre-CERP conditions and trends for crocodilian populations in ENP. The SSR analysis indicated that the number of crocodile nests recorded in ENP during 2005 and 2006 is consistent with the trend of higher nest numbers in ENP since 2000. This increasing trend appears to be associated with a decrease in salinity levels that were a result of non-CERP project plugs placed in the East Cape and Buttonwood canals to reduce saltwater intrusion. This example illustrates the value of long-term monitoring in establishing a baseline that can be used to evaluate the efficacy of potential management actions such as will be evaluated in CERP.

A revised version of the MAP will identify how data generated by the SSR relates to meeting triggers, which will be identified by the MAP module teams. These triggers indicate unmet CERP system performance needs. The CERP AM Implementation Guidance Manual, currently under development, will provide details regarding science application as well as the interpretation of SSR data; specifically, it will provide guidance on the magnitude and duration of performance deviations that initiate Box 3 activities (Management and Science Integration).
Finally, the SSR data will be used to inform AM decisions and management actions at CERP project and/or program levels.

3.3 References

CERP 2006. CERP Adaptive Management Strategy:  
http://www.evergladesplan.org/pm/recover/recover_docs/am/rec_am_strategy_brochure.pdf

Department of Interior (DOI) 2007. DOI Adaptive Management Technical Guide and Training:  


4.0 LAKE OKEECHOBEE MODULE

4.1 Brief Description and Background Information for the Lake Okeechobee Module

The recovery of LO is critical to the success of the Everglades restoration plan, as the lake is the heart of the south Florida ecosystem. Failure to realize effective measures to restore LO will adversely affect or delay efforts to restore downstream wetland systems and estuaries that either rely on or are affected by water deliveries from the lake.

LO is a large (1,730 square kilometers [km²]), and for its size, an extremely shallow (average depth generally <3 meter [m]) freshwater lake located at the center of the interconnected Kissimmee River-LO-Everglades ecosystem in Central and Southern Florida (C&SF) (Figure 4-1). On a geologic scale, LO is very young, having originated about 6,000 years ago during the most recent oceanic recession. Under pre-settlement conditions, LO is thought to have been eutrophic (Steinman et al. 2002b) and was considerably deeper than it is today (Aumen 1995). Outflows from the lake were largely restricted to sheetflow to the south and east. A southern marsh comprised the northern headwater of the Florida Everglades, with the lake often supplying water during periods of high lake levels or lake-wide seiches as a result of tropical storms (Gleason 1984). The ability of the lake to provide a large volume of water storage, in concert with the natural storage of wetlands in the upper part of the basin and the relatively slow flow of the historic meanders of the Kissimmee River, allowed for moderation of the effects of wet-dry rainfall cycles on water levels in the sawgrass marshes and prairies of the Everglades to the south (NRC 2005).

Wright (1911) estimated the historic high stage for the lake at approximately 22.5 feet and a low stage of 19 feet. Along the western side of the lake, Heilprin (1887) reported the presence of a substantial sawgrass community, historic observations buttressed by recent research (McVoy et al. 2005). The historic presence of this shoreline community has direct relevance to historic lake stages given that water depth requirements to support a sustained sawgrass community strongly suggests an eight month hydroperiod for the area. Lake stages may have risen above the marsh ground elevation around two feet in the wet season and would fall up to a foot by the end of the dry season (McVoy et al. 2005).

Modern-day LO differs from the historic lake in size, range of water depth and connection with other parts of the regional ecosystem (Steinman et al. 2002a). Connecting LO to the Caloosahatchee River and construction of the St. Lucie Canal in the early 1900s greatly reduced system-wide water storage and sheetflow to the south during drier periods (NRC 2007). Construction of the Herbert Hoover Dike (HHD) around the lake reduced the size of LO’s open-water zone by nearly 30 percent, and resulted in a considerable reduction in average water level (Havens and Gawlik 2005). The current littoral zone vegetative community, which consists of emergent, floating and submersed macrophytes, developed in response to post drainage lake stages (Pesnell and Brown 1977); that is, the lowering of water levels due to levee systems and control structures in both the Everglades and in the lake over the past 100 years (Richardson and Harris 1995). Perhaps more importantly, the dike also hydrologically disconnected the surrounding marshes from LO’s historical littoral zone (Aumen 1995, Havens and Gawlik 2005), especially along the northwest side of the lake. This effectively reduced the extent of the littoral zone and disrupted both the ecologic and
hydrologic connectivity to the Indian Prairie marsh system, which has been described as historically being one of the largest marshes in the Kissimmee River, Lake Istokpoga-Indian Prairie and Fisheating Creek basin complex.

During the last century and until relatively recently, when aggressive efforts to improve quality of runoff have been undertaken, LO was the recipient of increasingly excessive inputs of nutrients primarily from agricultural activities in the watershed (Flaig and Havens 1995, Havens et al., 1996). The sustained influx of these nutrients has resulted in dramatic undesirable changes in water quality. In the open water or pelagic region of LO, large algal blooms have occurred. Vast quantities of soft organic, nutrient-laden sediments have accumulated which are easily resuspended in the shallow lake by even moderate winds (Maceina and Soballe 1991). This has caused LO to become both increasingly turbid and has served to exacerbate water-column nutrient concentrations via release of those nutrients present in the resuspended sediment.

Despite an onerous series of human impacts, LO continues to be a vital aquatic resource of south Florida, with irreplaceable natural and societal values. LO is one of North America’s most unique and economically valuable natural resources. LO’s location and size has resulted in its being expected to support the demands of a variety of user groups that range from supplying potable water for several cities on the lake’s perimeter, supplying water to recharge surface water wells in Florida’s densely populated southeast coast and supporting commercial and recreational fisheries important to local economies. Unfortunately, commercial fisheries were suspended following the 2004 and 2005 hurricanes due to reduction in fish stocks and the attendant effect on profitability. The annual combined recreational and commercial asset value of LO has been estimated to be in excess of 180 million dollars (Bell 1987, adjusted to 2007 dollars).

As a consequence of being a key resource relied upon by both agricultural and urban concerns, as well as its ecological effect on all south Florida including the Everglades, Florida Bay and the other estuaries, the importance of LO’s health cannot be overstated. The quality of LO’s water and habitat has been influenced by a number of factors. During the period from the early 1970s through the 1980s, LO’s phosphorus (P) concentration doubled (Havens and James 2005). Large frequent blue-green algae blooms in the late 1980s prompted concerns that LO was becoming hypereutrophic, and fueled fears in the press of an impending collapse.

As a result of the varied and widely-held concerns, CEMs were developed for LO to provide a science-based path forward toward restoration (SFWMD 2006). These models succinctly depict the interrelationships that exist between water level and nutrient condition, and those key flora and faunal communities that respond to or are affected by them. The models account for LO’s three sub-regions that are functionally dissimilar, and as a consequence may respond to changes in water level and/or water quality quite differently, namely: a littoral marsh, a nearshore region and an open water region (Figure 4-1). The models also reflect LO's present spatial extent, rather than the larger historical boundaries.
Figure 4-1: Lake Okeechobee
4.2 Lake Okeechobee Hypothesis Cluster–Water Quality

4.2.1 Abstract
An evaluation of the water quality condition of LO was performed utilizing data from pelagic water quality monitoring stations 1988 to present. These stations characterize the vast majority of the volume of water within the lake and thus stand as the harbingers of change within this system as restoration efforts are successfully implemented. Nutrients, and in particular P remain elevated. Resuspension of sediment, which has become a large reservoir of potentially available P and nitrogen (N), is a major factor driving nutrient concentration. Increases in N concentration are correlated to increases in water color and chlorophyll a. P and total suspended solids (TSS)/turbidity measures signal slowly increasing trends, chlorophyll a shows a decreasing trend and N evinces no detectable trend. This suggests that diminished water clarity has served to damp algal blooms. The ability to detect beneficial change afforded by restoration efforts is high, since (1) current trends though small are in the wrong direction, and (2) major versus incremental changes in nutrient status are required. Implementation of CERP projects is expected to result in improved water quality attributes, such as reduced water column N and P concentrations, reduced TSS and chlorophyll a concentrations. The success of Everglades restoration hinges to a significant degree on the realization of effective measures to address and improve LO’s water quality.

4.2.2 Background Description
The importance of water quality in LO in its role in the restoration of the south Florida landscape cannot be overstated. LO is the primary source of water for restoration in the southern half of the system, and attaining reduced nutrient levels in the lake is a critical and an essential requirement toward enabling treatment facilities south of the lake to attain the treatment efficiencies required to supply the southern system with water not exceeding ten parts per billion (ppb) P in concentration. Realizing the infrastructure necessary to improve the quality of water entering and leaving LO, as well as possessing the physical ability and flexibility required to better control lake stage (which affects water quality) is repeatedly identified as a prerequisite for restoration of both the Everglades and south Florida’s estuarine ecosystems. Key water quality characteristics of concern for LO are the concentration of the nutrient P and the water column ratio of N to P, algal bloom frequency and composition, turbidity, sedimentation rates, sediment resuspension and cycling of nutrients sequestered in the bottom sediments (Figure 4-2). Of overarching concern is increasing P nutrient concentrations in LO which over the last 40 years have nearly doubled, and in consequence have been associated with periodically large algal blooms. Large blooms are a concern because of toxins that can kill fish, in addition to affecting taste and odor of drinking water.
Dotted lines denote important feedback loop. Undesirable algal species can fix atmospheric N; sediment cycling of P exacerbates basin P loads.

**Figure 4-2: Inter-relationships of Key Water Quality Characteristics**

Excessive loads of P to LO originate from agricultural and urban activities that dominate land use in the watershed. Total P (TP) loading now averages 714 metric tons per year (mt/yr) averaged over WY2002–WY2006. This loading is more than five times higher than the total maximum daily load (TMDL) of 140 mt/yr (five-year rolling average) considered necessary to achieve the target in-lake total phosphorus (TP) goal of 40 ppb (FDEP 2001, Havens and Walker 2002). The loadings from WY2006 were 795 mt of P which included the influence of Hurricane Wilma; 237 mt of this load originated from the Kissimmee River. This is lower than the previous year, WY2005 (960 mt), which included impacts from hurricanes Charley, Frances and Jeanne. However, the total flow to LO was greater in WY2006 than WY2005. This is attributed to the wetter spring and summer season in WY2006 compared to WY2005, which offset the flows from the September 2004 hurricanes. The lower load in WY2006 is attributable to lower TP inflow concentration.

Reducing nutrient loading to LO from its surrounding basin is only part of the process leading to an ecologically healthier system. As a result of excessive nutrient loading, primarily over the past 60 years (Brezonik and Engstrom 1998), over 30,000 tons of P is sequestered in LO’s sediment (Reddy et al., 1995). Since LO is relatively shallow compared to its surface area, these sediments can easily be resuspended and through equilibrium processes, release P into the water column. The release of P into the water column through resuspension is of particular concern during hurricanes when massive disturbance of the shallow sediment can result in large spikes in post-hurricane water column P concentration.

Internal P loading also is of concern, as diffusive soluble reactive phosphorus (SRP) release from the sediments to the overlying water column is significant (Fisher et al., 2005). Sediment P assimilative capacity appears to be diminishing, thus contributing to increases in P concentration in the water column, despite an overall reduction in external P loading since the 1980s (SFWMD 2002, Havens and James 2005). Clearly, understanding the role that sediments play in lake restoration is paramount in developing restorative measures to reduce in-lake P concentrations. The current known set of feasible options to reduce P concentration...
includes dredging, chemical treatment and simply allowing natural processes to proceed. The latter is the currently selected course of action (Blasland, Bouck and Lee Inc. 2003). Expectations are that if loads can be reduced in the near-term, an acceptable degree of nutrient reduction and hence ecological recovery may be realized within the ensuing decades (Havens and James 2005). The current estimate for the no action horizon for positive impacts, without LO remediation is 70 years.

The presence of an easily resuspended organic mud on the bottom of the central area of LO presents additional water quality concerns. Frequently elevated suspended solids in the water column reduce light penetration. When conditions are favorable for transport of these sediments to the nearshore zone, which happens when lake levels are high, corresponding negative impact on plants may result, which in turn may affect those organisms that utilize the plant communities as a food source or for habitat. The basis of life in any system is conversion of the sun’s energy to biomass that may then be utilized by all the subsequent trophic levels up the entire food chain. Lake turbidity prevents light penetration resulting in little photosynthetic activity except in the shallower areas or where plants have succeeded in stabilizing the sediment. If pelagic zone turbidity remediation occurred without nutrient remediation, severe algal blooms might result. LO’s pelagic food chain is currently dominated by heterotrophic bacteria, indicating a switch in carbon source could have potential far reaching effects. Ultimately, ecological improvements in LO are dependent on reduction in nutrient loads and allowing lake sediment stability to improve through natural processes (e.g., compaction).

4.2.3 Methods and Analysis
A multitude of investigative studies and long-term monitoring efforts are underway, both to examine processes occurring in LO and within the lake’s watershed. Details of these efforts may be found in the most recent version of the 2007 South Florida Environmental Report (SFER) (SFER-www.sfwmd.gov). Water quality data for LO is stored and is available in the SFWMD’s “dbHydro” database. A subset of the available data was used for this report, namely grab sample data from the eight long-term monitoring (in-lake) stations (Figure 4-3). These sites have been identified by the State of Florida Department of Environmental Protection (DEP) to track progress in achieving the imposed TMDL which seeks to reduce P loads entering LO with the goal of reducing in-lake P concentration. Correlations between water quality data were determined on ranked data using the nonparametric Spearman rank method. Water quality trends were evaluated utilizing the nonparametric Seasonal Kendall Trend test, using the twelve months as individual seasons. Where trends were significant (p≤0.05), rates of trend were estimated using Sen’s Slope technique on the series of monthly averages of the eight sites combined.
4.2.4 Discussion

*A thorough discussion of water quality issues surrounding LO can be found in the SFER for 2006 and 2007 (available online at www.sfwmd.gov) and the 2008 SFER (draft available September 2007).

There has been a tremendous amount of concern expressed regarding the accelerated eutrophication of LO, with the principal focus being rising P concentrations within the lake since the 1970s when SFWMD began monitoring water quality. The P load entering LO is closely related to the volume of water flowing into the lake from its tributaries (Figure 4-4). Numerous control efforts are underway or already have been instituted in the LO watershed to capture a percentage of nutrients which would otherwise enter the lake, further fueling worries regarding accelerated eutrophication of the lake (LO Protection Plan 2007). However, the concentration of P in the water column is merely part of the issue; a vast reservoir of P is sequestered in LO’s sediments. The decreasing trend in assimilative capacity of the sediments to bind P suggests the counterintuitive response that once CERP watershed projects are completed and inflow P concentrations and loads to the lake decline,
there may be a decades-long lag before in-lake concentrations similarly begin to decline (Figure 4-4).

Timelines (top graphic) of WY P load (in blue) and volume (in green) of surface water entering LO, and five-year moving average (bottom graphic) of inflow and in-lake TP concentrations (from 2007 SFER). Note decrease in inflow concentration from 1982 through 1997 and apparent rebound in some years thereafter. Internal concentrations 2005-2006 were for the first time observed higher than inflow concentrations.

**Figure 4-4:** Timelines (top graphic) of Water Year Phosphorus Load (in blue) and Volume (in green) of Surface Water Entering Lake Okeechobee and Five-year Moving Average (bottom graphic) of Inflow and In-lake Total Phosphorus Concentrations

Data does not reflect conditions occurring during or immediately after hurricane impact

**Figure 4-5:** Mean Pelagic Total Suspended Solids and Turbidity Versus Year
The passage of the 2004 and 2005 hurricanes is readily apparent in the amount of unconsolidated sediment resuspended in the water column (Figure 4-5), despite the fact that samples were not taken during, or immediately following, the storms. It may be that the quantity of suspended sediment in the water column during the storms was orders of magnitude greater than that depicted (Figure 4-5). Spikes in concentration present in non-hurricane years (i.e., 1990, 1994, and 2000-01) serve to convey the ease with which the sediments in this large shallow lake are affected by wind-induced waves and currents (Maceina 1990). Both TSS and to a greater extent turbidity are correlated (P<0.01) to mean daily wind speed. The periods of non-hurricane attributable to increases in sediment resuspension coincided with lowered lake stage in 1990 and to a lesser extent in 1994, but stage and measures of resuspension of bottom sediment are not significantly correlated. There is a slight but significant (P=0.001) upward trend in TSS which remains even when the 2004 through 2006 hurricane influenced data is removed. A similar trend (P=0.02) is apparent in turbidity.

![Graphs showing data](image)

Depicted are individual sampling data (top left), means and 95 percent confidence intervals by year (top right), by month (lower left), and trophic state index for phosphorus by year.

**Figure 4-6: Pelagic Total Phosphorus Concentration, January 1988–September 2006**

P concentration in LO (Figure 4-6) is correlated (P<0.005) to TSS and turbidity, which corresponds with the resuspension of the P otherwise sequestered in the sediments. A large fraction of the P reported as TP is in the particulate form (TP analyses are performed on
unfiltered samples); however, the increases in resuspended sediments were also associated with increases in soluble P (P<0.005). The similar but magnified effect of the 2004 and 2005 hurricanes can be seen in the marked upward jump in P concentration seen in both of those years. The failure of the 2006 concentration to return to pre-2004 levels is of concern, and is explained by the sediments being less consolidated than they were pre-hurricanes Frances and Jeanne in 2004. There is a clear seasonal pattern which is a product of higher wind velocities typically occurring during the winter and spring. The resultant wave action resuspends sediments which in turn result in elevated TP concentrations. Removing hurricane influenced data (i.e., 2004 through 2006) does not remove the significant (P<0.001) upward trend in TP concentration at a rate of two to three ppb/yr (Figure 4-7). The P trophic state index, computed using the formula specified in the Florida Administrative Code (F.A.C.) rule 62-302 evidences a consistent upward trend, which is troubling since higher values indicate worsening trophic conditions.

![Confidence Interval and Prediction Interval](image)

(hurricane-affected years removed)

**Figure 4-7: Estimated Trend in Total Phosphorus Concentration (ppb) at Rate of Two to Three ppb per Year, 1988 thru 2003 Data**
Depicted are individual sampling data (top left), means and 95 percent confidence intervals by year (top right), ortho-P to TP ratios by year (lower left) and by month (lower right).

**Figure 4-8: Pelagic Soluble Reactive Phosphorus (ortho-phosphorus) Concentration, January 1988–September 2006**

The pattern over time exhibited by soluble reactive P (SRP or ortho-P; **Figure 4-8**) mimic those observed for TP. Both the ortho-P concentration as well as the ratio of ortho to TP exhibit significant (P<0.001) increasing trends. The increasing trend in the ratio of soluble to TP indicates that not only is more P present in the water, but more of it is in the more bioavailable form.
Depicted are individual sampling data (top left), means and 95 percent confidence intervals by year (top right), month (lower left) and trophic state index for N by year.

**Figure 4-9: Pelagic Total Nitrogen Concentration, January 1988–September 2006**

Depicted are individual sampling data pairs. Chlorophyll $a$ concentration (not shown) relationship is very similar.

**Figure 4-10: Pelagic Total Nitrogen Concentration Versus Apparent Color and Total Suspended Solids, January 1988–September 2006**

Total nitrogen (TN) concentrations are correlated with TP concentrations (P<0.005), despite no significant trend being apparent in TN concentration when 2004-2006 is removed from the analysis; events where TP are high are often accompanied by higher TN. The general
seasonal and annual patterns in N and P concentration (Figure 4-9 and Figure 4-6) suggest that similar or related factors that affect and drive the P regime similarly affect the N regime. TN (N=2517) is also correlated to TSS ($\rho=0.603$, $P<0.001$), and to a lesser extent apparent color ($\rho=0.186$, $P<0.001$) and inversely to chlorophyll $a$ ($\rho=-0.068$, $P=0.04$)–the latter being easily interpreted insofar as high suspended matter and/or color equate with reductions in light penetration. However, only three of the 25 observed TN values above three milligrams per liter (mg/l) were not accompanied by measures of either high suspended solids (most probable cause), apparent color, chlorophyll $a$ or some combination thereof (Figure 4-10). There is no significant trend apparent in water color.

![Figure 4-11: Pelagic Chlorophyll $a$ Concentration, January 1988–September 2006](image)

A slight downward trend in chlorophyll $a$ concentration remains significant ($P=0.001$) when both the 2004-2006 data as well as the 1988-1989 data are removed (to test whether the trend may be a mathematical artifact arising from early-year documentation of very high chlorophyll $a$ concentrations not reproduced in later years, and by the lower chlorophyll $a$ concentration following the hurricanes) (Figure 4-11). Possible explanations include the decrease in light penetration (as evidenced by trends in TSS and turbidity) which offset the increased availability of P nutrient, and the general lack of trend in TN. Disregarding the overarching role of light penetration in bloom formation, bioassays have indicated that N was the most frequent limiting nutrient controlling phytoplankton growth (Phlips et al. 1997).
which is not surprising given the ubiquity of P availability. East and Sharfstein (2006) reported that light limitation was the dominant factor approximately 60 percent of the time, with N or co-limitation by N and P dominating the remainder of the time. The within-year seasonal trend is not surprising in that warmer summer days were typically less windy than winter months, thus improving light penetration and resulting in more algae (i.e., higher chlorophyll \(a\)). The Lake Trophic State Index was calculated based on nutrients and chlorophyll \(a\) concentrations as referenced in the F.A.C. Values for the lake index above 60 units denote impairment per Florida’s Impaired Water Rule (F.A.C. rule 62-303). All but three of the years evaluated exceeded this threshold.

Dissolved oxygen (DO) regime ranged from 6.5 to 10.2 mg/l for 90 percent of the observations during this period of time. A clear seasonal pattern is present (upper right). Percent DO saturation versus water temperature (lower left) showing increases in variability and probability of super-saturation with warmer temperatures. Mean monthly DO saturation versus mean monthly chlorophyll \(a\) concentration showed overall increasing probability of super-saturation with increasing chlorophyll.

**Figure 4-12: Pelagic Dissolved Oxygen Concentration, 1988 thru 2006** (upper left)

Overall, the DO regime in LO is fairly stable, with 90 percent of the observed values falling between 6.5 and 10.3 mg/l. DO concentration is inversely correlated (P<0.001) with water temperature (i.e., colder water can dissolve more oxygen) as depicted in the seasonal pattern (top right panel of **Figure 4-12**). DO saturation is positively correlated with water temperature (P<0.001) such that warm water conditions are more likely to achieve a saturated or higher condition. In addition, the variability of DO saturation is increased at higher
temperatures (Figure 4-12). The increasing variability and the greater likelihood of achieving saturation are both explainable by the presence of an increasingly dynamic algal community as temperatures rise, alternately generating or consuming oxygen as blooms wax or wane. DO concentration and saturation are correlated with chlorophyll \( a \) (\( P<0.001 \)), and examination of the 179 observations taken during the day where DO exceeded ten mg/l evidenced a corresponding mean and median chlorophyll \( a \) concentration of 30 and 25 micrograms per liter (ug/l), respectively, and are values indicative of bloom conditions. Algal blooms which produce oxygen during daylight will also consume oxygen at night, which can result in oxygen crashes (and in severe cases, fish kills) at night; such diurnal occurrences have been documented in the littoral zone, but significant oxygen swings have not been observed in the pelagic zone.

Conclusions
Water quality in LO is highly variable, and efforts to improve conditions which only make small improvements will be undetectable against the backdrop of year-to-year and intra-year change. Concerted efforts to reduce nutrient loads entering LO will be tempered by the presence and availability of nutrients currently present in the sediments, and especially during the relatively frequent events when wave energy is sufficient to mix those sediments back into the water column; however, dramatically reducing nutrient loads to the lake may permit various benthic processes to mediate the sediment nutrient reservoir and allow near term improvements in condition to occur (Jeppesen et al. 2003). Even if internal loading does delay full recovery, observations of shallow eutrophic systems elsewhere around the world where internal loading was considered a significant factor (Jeppesen et al. 2005) indicate the possibility of establishment of a new P equilibrium and measurable improvement in as little as ten to 15 years. However, many of those familiar with LO consider this forecast overly optimistic and recovery estimates without internal load remediation have been predicted to be on the order of 50 to 70 years (Blasland, Bouck and Lee Inc. 2003). Nevertheless, improved water quality conditions in terms of reduced nutrient, TSS and chlorophyll \( a \) concentrations, coupled with maintenance of appropriate water levels as a result of CERP project completion could result in immediate benefits in the nearshore and littoral zones; zones where most of LO’s ecological functions occur and societal values originate (James and Havens 2005). Regardless of how recovery may in fact proceed, it is clear that realizing the benefits to better manage LO and its basin will require patience. Long-term effective measures will produce benefits, but detecting these changes will require unabated commitment to monitoring that produce quality datasets extending to 2050 and perhaps beyond. The current gradually worsening condition depicted in the pelagic zone data nevertheless holds promise as a mechanism to detect near-term positive changes as a result of restoration initiatives, by removing or reversing these trends.

4.3 Lake Okeechobee Hypothesis Cluster–Stage

4.3.1 Abstract
The current LO WSE Operating Schedule is more restrictive than past lake stage regulation schedules in stipulating conditions in which water is released from LO. This has resulted in an increased frequency and duration of undesirably high lake stages, which in turn have adversely affected key lake ecosystem features such as appropriate coverage of submerged aquatic vegetation (SAV). Revisions to the Lake Okeechobee Regulation Schedule (LORS)
are currently being evaluated by Corps and SFWMD, as part of a cooperative effort including the U.S. Fish and Wildlife Service (USFWS), Florida Fish and Wildlife Conservation Commission (FFWCC), City of Sanibel, and Martin and Lee counties. It is anticipated that the new interim LORS, if approved by the Corps, is expected to sustain a higher frequency of lower lake stages. This interim schedule will promote the health of LO and aid in its recovery as the CERP, Acceler8, Fast Track, and other projects come online between 2010 and 2015, at which time a more permanent schedule will be implemented.

4.3.2 Background and Description

Water level in LO is a primary factor (Figure 4-13) affecting both the aquatic vegetation and the community of animals that utilize these plants for habitat and sustenance (Johnson et al., 2007). Since implementation of the current WSE, LO has experienced an increased frequency of high lake stages (Figure 4-14). Extreme high or low lake levels of any duration, or moderately high or low lake levels of prolonged duration greater than six months can cause significant harm to the ecosystem (Havens and Gawlik 2005). Extreme high stage facilitates the inflow of turbid, nutrient-rich pelagic water into the littoral and nearshore zones. Movement of this P-rich pelagic water into the nearshore region can promote algal blooms, and also is detrimental to emergent and SAV growth and biomass by increased water column depth, turbidity and wave energy. Increased wave energy can cause increased uprooting of vegetation, especially during high-wind and tropical storm events. Increased wave energy has direct negative impacts on emergent vegetation, such as bulrush, in the nearshore zone, and encourages the formation of a nearshore organic berm that can block fish migration into and out of the marsh. Increased water column depth and turbidity also results in poor water column light penetration (Havens 2004b). High stage may result in loss of habitat for fish, birds and other aquatic fauna as a consequence of reduced extent and quality of SAV and emergent plants.

Conversely, extreme low lake stage results in the desiccation of the western littoral marsh, which promotes the spread of exotic vegetation such as torpedo grass and melaleuca. When the marsh becomes dry, fish and wading birds are negatively impacted due to habitat loss. The federally protected and endangered Everglades snail kite also loses critical habitat and their primary food source, the Florida apple snail. Nearshore areas which can support high SAV biomass also can dry out under extreme low lake stage, thus resulting in replacement of SAV with emergent or terrestrial plants, and loss of habitat for fish, birds, alligators and other aquatic fauna. Conversely, extreme low lake stages can encourage the occurrence of brush fires that may help to control invasive and terrestrial taxa, such as cattail and torpedograss, which can quickly become a nuisance when covering large areas of the marsh or shallow nearshore areas. Low lake stages can also permit the oxidation of organic muck sediments exposing the underlying native seed bank and stabilizing material that might otherwise become resuspended where it would increase turbidity and reduce light penetration.
Higher lake stages can increase nearshore wave energy and drown shallow marshes. Although higher water levels have been shown to result in decreased nutrients and TSS, and increased secchi depth in the deeper offshore region, greater depths conversely result in higher nutrients, chlorophyll $a$, and TSS, and decreased secchi depth in the nearshore zone (James and Havens 2005); however, the decrease in offshore TSS and nutrients under high lake stage is small relative to the nearshore decrease in the same parameters under lower lake stages. The importance of these relative reductions in the nearshore versus pelagic areas is further magnified from the standpoint of ecological benefit; the nearshore zone is far more important to the ecology of LO than that of the pelagic zone. Higher stages have been shown to result in decreased water clarity which in turn limits the depth at which SAV can effectively establish (Havens 2003). In areas where SAV does occur, the SAV serves to stabilize sediments and to compete for available nutrients resulting in reduced chlorophyll $a$ and TSS, and increased water clarity allowing for increased SAV cover (Havens 2003). Decreases in chlorophyll $a$ concentration have been correlated with increases in SAV and epiphyton biomass on a seasonal basis (Philips et al. 1993). Higher lake stages have also been shown to result in higher P and chlorophyll $a$ concentrations in the nearshore during the summer, and that as lake stage increased the importance of wind in explaining nearshore P concentration also increased (Maceina 1992). Increased turbulence as a consequence of increased stage results in elevated P concentrations and turbidity in the nearshore zone, which can damage existing SAV communities and stimulate cyanobacterial blooms. It is important to note that these nearshore vegetated zones are where most of the beneficial ecosystem functions occur. Increased wave energy has direct negative impacts on emergent vegetation, such as bulrush, in the nearshore zone, and encourages the formation of a nearshore organic berm that can block fish migration into and out of the marsh. As a

![Figure 4-13: Stage As A Primary Stressor Affecting Multiple Hypotheses](image-url)
consequence of its effects on SAV and emergent plants, prolonged high lake stages may result in loss of habitat for fish, birds and other aquatic fauna.

A certain degree of natural variation in lake stage has been shown to benefit the plant and animal communities in LO (Havens et al. 2001, 2002, 2005; Havens 2003). Declining water levels in late winter and early spring benefit wading birds by concentrating prey resources in the littoral zone where those birds forage (Smith et al. 1995). Water levels near 12.5 feet benefit SAV and emergent vegetation such as bulrush by providing optimal light levels for photosynthesis in the summer months (Havens et al. 2004). Variation in the prescribed lake stage range results in annual flooding and drying of upland areas of the littoral zone, which favors development of a diverse emergent plant community (Richardson et al. 1995). This beneficial variation has been defined as avoiding extreme high water levels (stage greater than \[>\] 17 feet and stage \(>\) 15 feet for more than 12 consecutive months) and extreme low water levels (stage \(<\) 11 feet and stage \(<\) 12 feet for more than 12 consecutive months), increasing the frequency of spring recessions (yearly stage decline from near 15.5 feet in January to near 12.5 feet in June, with no reversal \(>\) 0.5 feet). Although reduction in extreme high and low lake stages is an important goal, one extreme low stage event once per decade is currently believed beneficial to oxidize muck sediment and facilitate germination of the bulrush seed bank.

### 4.3.3 Methods and Analysis

Lake stage is a major driving stressor, and stage directly or indirectly affects the physical and biological quality of LO. Data regarding lake stage is maintained in the dbHydro database.

![Figure 4-14: Lake Stages Between 1990 and Spring 2007](image)
4.3.4 Results and Discussion

Efforts are underway, via the Lake Okeechobee Regulation Schedule Study (LORSS), to optimize LO’s operating schedule within existing structural constraints to meet the diverse requirements of the lake, its receiving waters, and its users. Mean monthly stage data (in black) in feet above mean sea level, 1988 through 2006. Desired recession rates from January high of 15.5 to June low of 12.5 (in red) provided as reference to illustrate extent of deviation from ideal.

Figure 4-15). The goal is to bridge the gap until the CERP, Acceler8 and Fast Track projects begin implementation in 2010. Approval of a revised regulation schedule at this time is on hold temporarily, and contingent upon acceptance by all stakeholders. A revised regulation schedule will be supported by a Supplemental Environmental Impact Statement (SEIS) and selection of the Tentatively Selected Plan (TSP) is based on overall system wide benefits. The benefits are evaluated for the following areas: the Caloosahatchee and St. Lucie River estuaries, Everglades, WCAs and water supply, the Lake Okeechobee Service Area (LOSA), Lower East Coast Service Area (LECSA), snail kite habitat, HHD integrity and navigation impacts. All of the alternative regulation schedules developed to date were evaluated against PMs that were developed as part of CERP and the RECOVER program. Each evaluated alternative regulation schedule includes temporary forward pumps as a water supply component in the event of extreme low lake stages (< 10.1 NGVD) similar to those that arose during the 2000-2001 drought. Lake stage <10.2 NGVD precludes the release of water from the south end of LO to the south via gravity, so at this stage and below, the temporary forward pumps will be used to augment water supply for agricultural and irrigation purposes.

Once a preferred TSP has been selected, the Corps will hold public meetings throughout south Florida following the release of the Draft SEIS. A revised Water Control Plan (WCP) will also be released for a public review period. Once the interim schedule is implemented, efforts will be underway immediately to incorporate the CERP Band 1, Acceler8, permanent pumps and any additional storage projects into a new schedule. It is anticipated that the selected TSP will result in a new lake regulation schedule that will result in the lake being generally shallower and with less extreme lake stage fluctuation than has occurred in the past decade. This new LORS is anticipated to minimize impacts to overall system-wide benefits, such as water quality and quantity, navigation and ecological attributes such as SAV coverage and bird and fish habitat.
Mean monthly stage data (in black) in feet above mean sea level, 1988 through 2006. Desired recession rates from January high of 15.5 to June low of 12.5 (in red) provided as reference to illustrate extent of deviation from ideal.

**Figure 4-15: Mean Monthly Stage Data and Desired Recession Rates**

### 4.4 Lake Okeechobee Hypothesis Cluster–Submerged Aquatic Vegetation

#### 4.4.1 Abstract

SAV and its relationship to the health of LO is assessed by periodically sampling plant biomass and species composition along strategically located fixed transects, and by large-scale mapping of species specific vegetative coverage. Plant community structure can be successfully related to pertinent stressors, in particular to lake stage and factors that affect water clarity and light penetration. As CERP projects and other complimentary efforts improve conditions within LO, detectable trends of expansion in SAV areal coverage and increased biomass are expected. Except perhaps for the impacts of major physical perturbations such as hurricanes, the probability for successful utilization of this assessment tool is high.

A key objective of this long-term SAV monitoring is to understand changes in the SAV community in LO as they relate to changes in water level and transparency. More specifically, it is to provide data to evaluate the relationship of physio-chemical factors (e.g., nutrient concentrations, light availability) to the spatial and temporal dynamics of SAV biomass and species assemblages within the community. Changes in the spatial and temporal extent of SAV are key PMs that will be available for use in CERP-related modeling and evaluation efforts. Data generated from SAV monitoring are mapped and analyzed annually.
and multi-annually for long-term trend analysis to determine if the distribution and abundance is improving as a result of CERP implementation.

4.4.2 Background and Description

SAV plays a key role in shallow lakes, providing diverse spawning and foraging habitat for fish and provides an important food and habitat resource for wading birds and other wildlife (Havens and Gawlik, 2005) (Figure 4-16). SAV can also directly affect water quality attributes such as nutrient concentrations, water column transparency and phytoplankton biomass through a number of processes. Increased transparency and reduced turbidity often result in SAV beds due to the stabilization of the bottom sediment by roots and by reduction of current velocities and shearing stress to sediment surfaces, and as such constitutes an effective positive feedback loop that both benefits existing SAV as well as promotes their expansion (Koch 1996, Sand-Jensen and Mebus 1996, Bartleson and Rodusky in prep). Uptake of nutrients by SAV and associated epiphytes (attached algae) might be an important process in LO in areas where SAV is abundant, as a large colonizable SAV surface can result in abundant periphyton (Steinman et al., 1997; Rodusky et al. 2001). When periphyton is abundant and photosynthesis is intense, pH may sufficiently be elevated such that co-precipitation of P with calcium occurs (Murphy et al. 1983, Dennison et al. 1993, Scheffer 1998, Vermaat et al. 2000) and nutrients being removed from the water column that might otherwise be available to phytoplankton. Lakes with dense SAV, clear water and low phytoplankton biomass can switch to an alternative state of highly turbid water and increased severity of algal blooms if the SAV and associated epiphytes are lost (Scheffer 1989, 1998). Some lakes, including LO, have shallow areas where abundant SAV and clear water can exist adjacent to deeper areas with no SAV and turbid water (Phlips et al. 1993, Scheffer et al. 1994, Havens et al. 2004, James and Havens 2005). While the maintenance of alternative steady states is viewed as being a positive feedback loop, lake level, periodic wind-driven high turbidity and major physical perturbations such as hurricanes act as external forcing functions to drive changes from one state to the other; thus, the nearshore zone switches between a SAV/clear water state when water levels and turbidity are low to a phytoplankton/turbid water state when there are periods of prolonged high water levels with accompanying sediment resuspension and possible physical disruption of the plant community by wind driven waves and seiches (Havens et al. 2001, Havens 2003, Havens et al. 2004, James and Havens 2005).
4.4.3 Methods and Analysis

A SAV monitoring program has been in place in LO since the spring of 1999 and encompasses data collected over a wide range of hydrological and environmental conditions. A change in collection methodology, however, allows a comparison only of the data collected since the summer of 2000. Additionally, historical SAV biomass and distribution data exists from transect studies conducted in the late 1980s and early 1990s (Zimba et al. 1995) that can be used to compare to the current SAV distribution and abundance.
SAV is monitored at two different spatio-temporal scales. Both methods rely on a boat-based sampling methodology, as areas with submerged vegetation are generally characterized by water with poor transparency or that is highly colored by dissolved organics, which has thus far stymied attempts to use remote sensing techniques.

**Annual Mapping**

The total spatial extent, species distribution, and density of SAV are determined by an intensive sampling program (*Figure 4-17*) that is carried out at the end of the peak SAV growing season, i.e., August through September (Havens et al. 2002). Rather than sampling random locations, the entire nearshore area is evaluated at a spatial scale sufficient to detect significant changes. GIS coverage of LO’s surface is overlaid onto a rectangular grid of 1,000 x 1,000 m cells in the GIS program ARC/INFO. GIS coverage of the littoral zone is laid onto the map, and common cells are clipped from the final coverage, as is the deeper central pelagic region. This results in a nearshore grid of approximately 750 sampling sites. Coordinates for the grid cell center-points are loaded into Trimble Pathfinder global positioning system (GPS) units (differentially corrected) for use in navigating to the sampling sites. A simple program is set up in each data logger so that users can enter information regarding water depth, Secchi depth (a measure of water transparency), sediment type, presence versus absence of vegetation by species and a qualitative estimate of overall plant biomass (sparse, moderate, dense). Field data are downloaded from the GPS logger into ARC/INFO, where maps are developed for each of the measured attributes and spatial extents for each dominant plant species are calculated in acres. This sampling effort provides information on the total number of acres of plants that the lake gained (or lost) under the prevailing hydrologic conditions of a given growth cycle year but these data should be used in the context of a coarse temporal scale trend analysis, due to annual growth season fluctuations that might result in months other than August-September containing peak SAV abundance (Havens et al., 2002).
Transect Monitoring
In order to obtain relatively rapid quantitative estimates of plant species biomass, sampling is conducted at up to 78 sites located along 16 transects in areas of LO that support submerged plants (Figure 4-18). The sites represent a subset of sites that were sampled in the LO Ecosystem Study (Zimba et al. 1995) in the late 1980s and early 1990s. This allows for a comparison of historical data. Sampling frequency varies from quarterly to monthly depending on how dynamic anticipated changes are expected to be in the plant population (for example, more frequent sampling is done during periods of recovery from hurricanes) and has been conducted monthly since the fall of 2004. Samples are collected at sites along each transect, starting at the shoreline and progressing lakeward until a site is reached that has no plants. Plant sampling is accomplished using a tool constructed of two standard garden rakes bolted together at mid-point to create a tong-like device (Rodusky et al. 2005). The degree of opening is constrained by placing a chain between the two handles so three replicate samplings with the device remove ~1 square meter (m²) of bottom cover. The harvested material is sorted by species, stripped of epiphyton and dried to a constant weight. This sampling effort provides information on plant responses and relative plant distribution and density to changing water levels on a short time scale, than that for the annual SAV mapping, and can be used as input to real-time operations.
Figure 4-18: Submerged Aquatic Vegetation Transect Locations in Lake Okeechobee

The underlying assumption of the timing of the annual large-scale SAV mapping is that the most active growing season will not deviate significantly from the August-September timeframe; however, stage and photoperiod undoubtedly varies from year-to-year. As a
consequence, the annual mapping data lends itself most appropriately to evaluation of longer-term trends and should only be cautiously employed as regards to between-year differences. Conversely, sampling along transects is better suited for identifying and understanding short-term changes (Havens et al. 2002). The two approaches are thus complimentary, and sufficiently define the appropriate timescales as to allow interpretation.

**Empirical Modeling**

An empirical model has been developed that predicts SAV presence or absence distribution based on light penetration to the bottom as a function of water transparency, as indirectly measured by TSS and lake water levels. This model is intended to be used in conjunction with GIS data layers such as bathymetry and SAV sampling sites to predict areas within LO that are likely locations for SAV colonization when favorable water depth, light penetration, and turbidity conditions occur. Future versions of the model will include attributes such as sediment type, seed bank viability and water quality variables. At the current stage of sophistication, the model only predicts areas containing a favorable light regime for SAV growth, and is not intended to predict finite growth areas. While results indicate conditions where SAV cannot occur (constraints), they do not indicate clearly whether or not SAV will attain high biomass under otherwise presumably favorable conditions.

### 4.4.4 Discussion

**Annual Submerged Aquatic Vegetation Mapping Results**

SAV in August 2006 covered 2,965 acres of LO (*Figure 4-19*). This compares with the highest total coverage of 54,857 acres in late summer 2004. The large decrease in SAV from 2004-2006 likely was a response to poor light conditions, physical disturbance (wind and wave-induced uprooting) and high water levels caused by four hurricanes, three in 2004 and one in 2005. Lake stage increased on average by approximately 1.8 m after hurricanes Frances and Jeanne. It appears that the hurricanes stirred up fine sediments in LO resulting in a long exposure to very turbid, deep water column with very poor light penetration. After the hurricanes it was common to have Secchi disk readings of less than 30 centimeter (cm).

The acreages of dominant plants in 2006, as compared to 2005 are as follows: *Vallisneria*-750 acres, compared to 494 acres in 2005; *Hydrilla*–0 acres, compared to 7,166 acres in 2005; *Potamogeton*–0 acres, compared to 494 acres in 2005; *Ceratophyllum*–495 acres, compared to 7,166 acres in 2005, and *Chara*–2,470 acres, compared to 247 acres in 2005. With regard to the latter, *Chara* is a macro-alga rather than a true vascular plant and is considered a pioneer species in LO, hence its relatively extensive coverage in 2006.
Figure 4-19: Comparison of Actual Submerged Aquatic Vegetation Biomass versus Model Predicted Biomass
Transect Submerged Aquatic Vegetation Mapping Results
The best example of transect mapping’s ability to detect substantial short-term perturbations occurred between July 2004 (pre-hurricanes) and October 2004 (post-hurricanes). Average SAV biomass, as measured at 78 quarterly monitoring sites, declined during this quarter from 32.3 (± 49.9 SD) to 4.7 (± 9.4 SD) g dry weight per square meter (g dry wt m\(^{-2}\)), probably as a result of increased TSS and decreased light penetration as reflected in Secchi to total depth ratios (**Figure 4-20**) brought about by direct wind, wave, seiche, and lake stage impacts. However, from January 2005 to June 2006, SAV biomass continued to decline from 4.46 g dry wt m\(^{-2}\) to less than 0.04 g dry wt m\(^{-2}\) (**Figure 4-21**). Although declines over the winter period are expected due to seasonal conditions such as lower temperatures, increased turbidity, and shorter photoperiod, the significant declines observed are primarily a result of long-term light deprivation related to water quality and lake stage effects.

Analysis
The interplay between SAV biomass, lake stage, and water transparency is complex. Prolonged periods of high stage and poor water column light regime may greatly diminish the spatial extent of native vascular submerged plants. During years of lower lake stages, spatial extent of vascular and non-vascular SAV combined can exceed 50,000 acres. Once significant SAV communities become well established, higher lake stages can occur with little loss of plants unless the higher stages are sustained across many months. In the case where SAV communities have been completely lost, moderate stages will not typically facilitate their return; instead, very low stages may be required to re-establish successful and resilient communities of plants. In years of recovery from high water stress, much of the SAV community may be comprised of pioneer species, such as the non-vascular macro-algae *Chara*, which may provide limited habitat or water quality benefits as compared to the vascular species *Vallisneria, Potamogeton*, and *Najas*, but may promote the clear water state needed for colonization by the slower growing, higher light requiring vascular species. By reducing the frequency of extreme high and low water levels and increasing the frequency of spring recessions through CERP implementation, beneficial water quality and habitat conditions should be created that promote an increase in the spatial extent and density of native vascular submerged plants.

Light penetration defines the area capable of supporting dense SAV. Within a given water clarity regime, higher lake stages equate with decreasing light energy at depth. In addition, higher stages effectively connect the pelagic and nearshore zones resulting in increased turbidity which further exacerbates light availability (James and Havens 2005). Lower lake stages decrease the depth of water that light must penetrate to sustain photosynthetic activity; thus plants can survive despite conditions (e.g., wind and waves) that might decrease water clarity. Thus, lower lake stages and improved water quality conditions (e.g., reduced TSS) as a result of CERP implementation projects may result in larger areas of the lake bottom receiving adequate light to support growth. However, stage alone does not explain water clarity as stage is not directly correlated with either TSS or secchi depth measures of clarity.

Previous studies have shown that the biomass of submerged plants is negatively correlated with water depth and positively correlated with water transparency (Hopson and Zimba 1993,
Steinman et al. 1997). Analyses of recent data (Figure 4-20) substantiate the significant relationships between SAV biomass and water clarity.

![Figure 4-20: Biomass as a Function of Secchi Disk Depth to Total Depth Ratio, and as A Function of Total Suspended Solids](image)

Biomass (g dry wt m\(^{-2}\)) as a function of secchi disk depth to total depth ratio (R\(^2\) = 53%), and as function of TSS (mg/l, R\(^2\) = 40%). Relationships are statistically significant (P<0.005). Values shown are logarithms of sampling event means.

Wind and wave events increase turbidity, but large storms and hurricanes can result in large scale destruction of SAV by direct physical tearing and uprooting of plants. Strong currents can be generated that run parallel to the shore (Havens et al. 2001), and coupled with large wind-driven waves, can uproot submerged plants. Chimney (2005) reported large north to south seiches during Hurricanes Frances and Jeanne in September of 2004. Similarly, Hurricane Wilma caused large east to west seiches in October of 2005. These seiches deposited large quantities of aquatic plants along LO’s shore. Although monthly transect sampling data suggested that the SAV community had been severely affected by all three hurricane events, a direct cause/effect relationship could not be determined because of the delay in sampling relative to the passage of the storms. However, observational and monitoring data collected within two weeks of the passage of Hurricanes Jeanne and Wilma indicated that a rapid decline in SAV density and distribution had occurred. Although this phenomenon would occur sporadically and is independent of CERP effects, it has potential major consequences for the ecological health of LO. SAV coverage of 54,875 acres in late summer 2004 was reduced to 10,872 acres in late summer 2005 and further reduced to 2,965 acres in late summer 2006 as a result of direct and indirect hurricane effects as indicated by the annual mapping surveys. It is as yet unclear what the timing and pattern of SAV recovery from such extreme forcing events will be.
SAV biomass (mean g dry wt m\(^{-2}\) per sampling event) as function of time. Red arrows denote hurricanes Frances, Jeanne, and Wilma (left to right) impacting upon LO. Other meteorological and water management stresses on the SAV are also apparent (e.g., 2001 drought).

**Figure 4-21: Submerged Aquatic Vegetation Biomass as A Function of Time**

**Present Conditions and Trends**
Except for anecdotal information, the only quantitative SAV data available for LO prior to 1999 is the work of Zimba et al. (1995) during a 1989-1991 study. The current SAV transect sites similarly located those that were sampled in that study. This allows for some degree of comparison and use of the historical data in the assessment of baseline conditions. However, the last six years of mapping and transect data indicate that LO’s SAV community is extremely dynamic and highly sensitive to environmental perturbations as demonstrated by the nearly five-fold change in areal coverage that has been observed between 2000 and 2005. Consequently, the concept of an appropriate baseline may be better expressed as the degree of variability reflected in the 2000-2005 data while CERP targets may need to reflect both an acceptable areal distribution and species composition for SAV (as expressed in the revised RECOVER LO Vegetation Mosaic PM) and a persistence or duration goal (for example, inter-annual variability in areal coverage and species composition around the target goal of 49,000 acres of not more than 15 percent). It also may be necessary to exclude data from periods of major physical perturbations and recovery when performing trend analysis to identify the impacts of CERP and associated projects.

Previous studies of SAV in LO identified water depth and transparency as key environmental variables (Steinman et al. 1997, Havens et al. 2002). Using transect data from the first three years of the monitoring effort, Havens (2003) determined that water depth and the concentration of TSS most strongly correlated with SAV biomass. Results also indicated that if water depths in the shoreline region of LO could be maintained at <2 m and TSS held
below 20-30 mg/l, there might be favorable conditions for more widespread SAV growth. This, in turn, might lead to water quality improvements.

Future Developments

- For the foreseeable future, periodic transect and annual mapping data will continue to be collected.
- A number of mesocosm experiments designed to provide inputs for model development are being conducted on subjects including minimum light requirements for individual species growth (e.g. *Hydrilla, Potamogeton, Vallisneria*), seed germination requirements, and species succession and data analysis and manuscript preparation is currently underway.
- Flow data collected along a transect through both a *Hydrilla* and *Vallisneria* bed in 2005 is currently being analyzed and a draft manuscript currently in SFWMD internal review has been prepared. The results will be used in the LO hydrodynamic model. Using these field data will enable a better calibration of the SAV component in the model to better assess the effect of SAV growth on alteration of flow patterns in the nearshore region of LO.
- Mesocosm studies are currently underway to understand the dynamics of interspecific interactions and succession of the most common SAV species in LO; triggered by transect and mapping data that indicates a progression from non-vascular to vascular plants and from mono-specific to multi-specific beds.
- A three year field study is underway to relate fish, macrovertebrate and amphibian abundance and species composition to SAV (and emergent) species composition and distribution in anticipation of being able to derive meaningful values for these key ecosystem components based on regular measurements of plant density alone. This study has been significantly delayed due to drought induced extreme low lake levels which are anticipated to persist at least through the summer of 2008, barring the occurrence of a number of major storm events focused over LO and its watershed between now and then.
- Given the recent increase in frequency of tropical storm passage near LO, development of a pre- and post- wind/wave driven sampling program is important to better capture SAV responses to episodic wind and wave events.

4.5 Lake Okeechobee Hypothesis Cluster-Littoral Zone Vegetation

4.5.1 Abstract

The emergent vegetation provides a variety of benefits, but can be detrimentally impacted by high lake stages especially when coupled with large wind-driven waves. Higher stage conditions provide a pathway for elevated nutrients which can disrupt the normal plant community composition, and allow floating exotic vegetation to invade inshore areas. Low water conditions allow seed banks that might otherwise not germinate to do so, and increase the likelihood of fire which helps maintain balance in the plant community. Aerial photography is successfully used to monitor the littoral zone. Lower overall lake stages as a result of CERP project implementation and a new lake regulation schedule is anticipated to improve ecological conditions for emergent plants by improving system-wide water storage which will reduce the frequency of extreme high and low lake levels.
4.5.2 Introduction and Background
The littoral zone emergent vegetation is a diverse mosaic of native and exotic plants covering an area larger than 400 km². It provides nesting habitat and food resources for economically important fish populations, wading birds, alligator, and the endangered Everglades snail kites. Along the shoreline, emergent plants also help stabilize sediments, support attached algae that help to remove P from the water, and provide a substrate for macro-invertebrates, an important food resource for fish. Dense stands of emergent plants protect submerged plant beds by reducing their exposure to waves. The distribution and abundance of emergent plants are strongly influenced by hydroperiod nutrient inputs and exotic vegetation. The conceptual model below (Figure 4-22) summarizes environmental interactions that are known to affect emergent vegetation density, aerial distribution and species composition in the littoral zone of LO.

Figure 4-22: Littoral Zone Emergent Vegetation Mosaic Conceptual Ecological Model
Prolonged periods of high lake stage have direct and indirect negative impacts on native shoreline including bulrush (*Scirpus californicus*), SAV and interior marsh vegetation. Native shoreline vegetation is more likely to be uprooted by wind driven waves when lake stage is high. Following a reduction in the spatial extent of rooted macrophytes, turbidity will increase, light availability will be reduced and plant growth will be inhibited due to poor water quality conditions. Additionally, the transport of pelagic water (TP > 100 parts per million [ppm]) into interior regions of the marsh where TP concentrations are often less than 15 ppm occurs mostly at higher lake stages (e.g > 14ft m.s.l.). An increase in nutrients in the interior marsh will result in the loss of desirable vegetation such as spikerush and the expansion of cattail and other less desirable vegetation.

Physically, rooted macrophytes help stabilize bottom sediments thereby reducing sediment resuspension during wind/wave events. During the late 1990s shoreline vegetation was commonly exposed to inundation depths > 2 m. This resulted in the uprooting and elimination of thousands of acres of emergent macrophytes. The loss of shoreline vegetation also was accompanied by an increase in turbidity and a decrease in light availability. The negative feedback loop associated with high lake stage, decreases in the spatial coverage of rooted macrophytes, and declines in water quality will further inhibit the growth of desirable rooted vegetation.

Depth and duration of flooding are also important in determining the distribution of emergent macrophytes. In deep water, emergent species may not have enough leaf area above the surface of the water to obtain the oxygen needed for respiration and/or the carbon dioxide needed for photosynthesis. Reduced oxygen uptake through the leaves can lead to inadequate supplies of oxygen to the roots and rhizomes and eventually lead to plant death. Thus, high lake stage creates physiological stress in rooted emergent macrophytes that can result in plant death if the water depth exceeds a plant’s flood tolerance (Van der Valk 1994).

Seeds of a number of desirable emergent species (for example bulrush) will not germinate under flood conditions. Therefore, in the absence of draw downs, recruitment of new plants from the seed bank will not occur. Prolonged high lake stage inhibits/prevents the germination of many desirable plant species in the marsh (Williges and Harris 1995). Without recruitment of new plants from the seed bank, the expansion and persistence of desirable marsh vegetation will occur only from vegetative reproduction.

Additionally, floating exotic vegetation can have a negative impact on bulrush and other native plants which is further exacerbated under high lake stage conditions. High lake stage enhances the wind driven transport of floating exotics (water hyacinth and water lettuce) from previously isolated locations (interior areas of Torry and Kreamer Islands) and from the watershed into open shoreline regions of the marsh. These exotics, especially water hyacinth, commonly form large floating mats that exceed 50 m in length. These mats can cause extensive physical damage through uprooting and/or breaking emergent plant stems (e.g., bulrush) as they are pushed around LO by wind and waves.

Exotic and invasive species including torpedograss, *Melaleuca* and cattail grow well in exposed moist soil environments and shallow water habitats. These species commonly form
dense monodominant communities that out compete and displace native plant communities, due in part to the absence of their native biocontrol organisms that prevent the exotic plants from becoming invasive weeds in their original range. Although low water conditions favor the growth of many non-desirable species, it also promotes seed germination of desirable native plants and allows for natural and controlled fires which can be effectively used with other management tools to control exotic and invasive species. Periodic low water events occurring with a frequency of approximately once per decade are postulated to provide an appropriate balance between the positive and negative effects of low water events.

The occurrence of low water events accelerates the spread of exotic and nuisance invasive vegetation such as torpedograss, *Melaleuca* and cattail. However, low water events also will stimulate the germination of desirable native vegetation (e.g., spikerush, beakrush and bulrush) and encourage the occurrence of fire which may help control non-desirable exotic and invasive species.

Operating LO at lower overall lake stages and providing periodic recession events will reverse these trends and encourage the expansion of desirable native emergent vegetation.

### 4.5.3 Methods and Analysis

Emergent vegetation maps based on aerial photography for the entire LO marsh and for the western bulrush fringe has been collected since the mid-1990s and comprises a thorough baseline data set. However, the emergent vegetation community in LO, much like SAV, appears to be very dynamic, responding in a relatively short timeframe to changes in water depth, physical perturbations such as hurricanes and exotic and invasive control operations. Additional research into herbicide treatment effects, seed germination and viability and hydrologic impacts on the recruitment of bulrush and torpedo grass are also being pursued to better understand the changes documented by ongoing mapping activities.

### 4.5.4 Results and Discussion

**Bulrush**

Giant bulrush (*S. californicus*) stands, located in LO at lake-bed elevations of 10 to 10.5 feet (3 to 3.2 m) NGVD, appeared to suffer damage when exposed to prolonged periods of deep flooding. These bulrush stands provide important fish and wildlife habitat. They also dampen wave energy and stabilize bottom sediments; thus, reducing turbidity and protecting desirable submersed vegetation behind the bulrush barrier. The concern is that excessive inundation of these stands due to prolonged occurrence of high stage levels might cause their failure. Loss of the protective bulrush stands might cause a cascade of events leading to loss of other native vegetation and degradation of water quality and wildlife habitat. An evaluation of the influence of water depth on the persistence of giant bulrush was conducted to support prudent management of LO and minimize adverse effects of stage level manipulation.

The results of this study indicate that undisturbed bulrush can persist at a water depth of three feet or less (lake stage of 13–13.5 ft, or 3.9–4.1 m NGVD); however, prolonged periods of water depths greater than three feet (0.9 m) may cause bulrush stands to fail. Disturbances such as herbivory or strong winds appear to reduce the ability of giant bulrush to persist at
the three feet (0.9 m) inundation. Based on data collected from this study, inundation of bulrush stands should be maintained at less than three feet (0.9 m) to minimize adverse effects of stage level manipulation on the persistence of giant bulrush.

Emergent Aquatic Vegetation–Vegetation Maps
A baseline vegetation map describing the distribution and areal coverage of vegetation in LO’s marsh was developed in the early 1970s (Pesnell and Brown 1977). A second and more detailed vegetation map was developed in 1996. The most recent GIS map was developed in 2005 using color infrared aerial photography collected in 2003 (Figure 4-23). Analysis of these maps indicates that there have been a number of changes in the littoral landscape.

![Figure 4-23: Dominant Emergent Vegetation Pattern](image)

In the 1970s, cattail was located primarily along the lakeward edge of the marsh and covered less than 20,000 acres (8,094 hectares). The dominant emergent vegetation in the interior marsh included beakrush (*Rhynchospora baldwinii*), spikerush (*Eleocharis cellulosa*), mixed grasses and cord grass (*Spartina bakeri*). By 1996, cattail coverage increased to nearly 25,000 acres (10,117 hectares) and was established in some areas of Moonshine Bay. In the upper elevation regions of the interior marsh (shorter hydroperiod) the exotic species
torpedograss (*Panicum repens*) displaced more than 13,000 acres (5,261 hectares) of beakrush and spikerush. In regions with longer hydroperiods (e.g., Moonshine Bay), the coverage of fragrant water lily increased to greater than 8,000 acres (3,237 hectares). In 2003 cattail coverage decreased to 23,840 acres (9,648 hectares). The reduction is attributed to large-scale fires and the record drought of 2001 and 2002. Although the total acreage of cattails decreased, the distribution of cattail increased in Moonshine Bay. At elevations generally greater than 13.5 feet (4.1 m) NGVD, torpedograss coverage increased to greater than 17,000 acres (6,880 hectares) despite the treatment of 10,000 acres (4,047 hectares) of torpedograss with herbicide in 2000 to 2002. The distribution of fragrant water lily increased to nearly 11,000 acres (4,452 hectares). Although fragrant water lily is a native, excessive growth of this plant may not be desirable because large amounts of detrital material can accumulate in dense lily beds.

The distribution of bulrush along the northwest marsh edge has been monitored closely since 1999 (*Figure 4-24*). Bulrush coverage varied from 194 acres (78 hectares) in 1999, 266 acres (108 hectares) in 2001, 193 acres (78 hectares) in 2002, 167 acres (68 hectares) in 2003 to 285 acres (116 hectares) in 2005. The increase in bulrush coverage in 2001 occurred in conjunction with a large reduction in lake stage during the drought. The reductions in bulrush coverage that occurred after 2001 occurred in conjunction with prolonged exposure to extreme dry conditions (sediments exposed > four months) followed by exposure to excessive flooding depths that exceeded two meters.

![Figure 4-24: Aerial Coverage (hectares) and Distribution of Bulrush by Calendar Year (1995–2005) and Elevation Along the Lakeward Edge of Lake Okeechobee’s Northwest Marsh](image-url)
4.6 Lake Okeechobee Hypothesis Cluster-Exotic Plants

4.6.1 Abstract
Control of exotic invasive plants is an important aspect of the successful restoration of LO. An overview of the current status of ongoing efforts is presented. It is anticipated that CERP project completion will result in a reduction of extreme low lake level events, thereby reducing opportunities for rapidly-spreading invasive exotic plants such as torpedograss (*Panicum repens*) to increase littoral zone areal coverage. Conversely, CERP projects are anticipated to contribute to reduced nearshore TSS concentrations, thereby reducing the competitive advantage exotic SAV taxa such as *Hydrilla* has demonstrated in low water column light regimes.

4.6.2 Background Description
Invasive exotic plants cause significant ecological harm by displacing native vegetation, upon which native fish and wildlife depend for food and shelter (*Figure 4-25*). LO contains approximately 100,000 of acres of littoral zone with herbaceous marshes, other emergent wetlands and numerous islands. More than 80 non-native plant species have been identified in LO. Of these, eight are considered serious, invasive, and/or potentially threatening to the LO ecosystem. Despite intensive control programs, dedicated funding and continual monitoring, some species have proven difficult to control. During fiscal year 2006, SFWMD expended $164,000 on controlling Brazilian pepper (*Schinus terebinthifolius*), $282,000 on Melaleuca (*Melaleuca quinquenervia*), and $816,000 on torpedo grass (*P. repens*) in LO.

*Figure 4-25: Conceptual Model of Stressors and/or Factors That Affect Exotic Vegetation*

Floating aquatic plants, such as water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) are managed by a Corps program started in the 1920s. The goal of the
program is to keep plants at the prescribed maintenance level (Chapter 369.22, Florida Statutes). In the past 15 years, LO averaged about 240 acres of combined hyacinth and lettuce, with an average of over 5,000 acres being treated each year. Without continued control, water hyacinth and lettuce would quickly expand and cover large areas, reducing light penetration into the water column. Reduced light penetration could result in shading of native SAV and areas of low DO below the canopy of these exotics. If DO concentrations are reduced, fish habitat might be reduced or lost, depending on the severity of the DO reduction. In addition, these floating aquatics tend to form large wind driven mats or tussocks which can mow down and uproot desirable emergent vegetation like bulrush and other species.

Alligator weed (Alternanthera philoxeroides) has been successfully controlled since the 1960s. Three insects, the alligatorweed flea beetle (Agasicles hygrophila), alligatorweed thrips (Amynothrips andersoni) and alligatorweed stem borer (Vogtia/Arcola malloi) currently keep populations of alligator weed at low levels in LO. Barring any negative impacts to the biocontrol agents, alligator weed is not expected to cause any measurable impacts in the near future, and serves as an example of what successful biocontrol programs can accomplish.

West Indian marsh grass (Hymenachne amplexicaulis) is a perennial, stout semi-aquatic grass native to Central and South America. Invading tropical seasonally wet waterways, wetlands and drainage systems, it impedes flood protection and water management. It has overwhelmed riparian systems in many locations worldwide. In LO, it is increasing its range, particularly in Fisheating Bay. Upstream of LO, in Fisheating Creek, West Indian marsh grass has established dense populations along the edge of the creek and in the cypress forest understory. To date, very little control of West Indian marsh grass has occurred in LO, and estimates of its population already range to 100 acres (Mike Bodle, SFWMD, personal communication). SFWMD initiated a herbicide control program for this species in 2005 within the DEP aquatic plant control program.

Torpedograss (P. repens) has been the target of extensive control in LO’s western marsh. By 1996, torpedograss had displaced more than 16,000 acres of native plants and shallow open water habitat. Torpedograss can tolerate periods of deep flooding but spreads most rapidly on moist soil or when exposed to shallow water column depths. During the 2000-01 drought, the areal coverage of torpedograss increased to greater than 20,000 acres. Despite widespread aerial treatments in 2002 through 2005, large areas remain affected. Since 2000, nearly 25,000 acres of torpedo grass were treated with some areas requiring one application while more stubborn infestations required repeated application; yet despite these efforts about 7,400 acres still remain. Torpedograss coverage was estimated in 2006 to comprise approximately eight percent of the total marsh area in LO. Recent data collected by the SFWMD staff indicates that DO concentrations can be significantly lower and more diurnally variable in torpedograss compared to native spikerush (Eleocharis cellulosa) habitat (Rodusky personal communication). These data suggest that torpedograss may not be as suitable as spikerush as fish habitat. Fish, periphyton, zooplankton and macroinvertebrate data recently collected in both of these habitats are being compared to gain some insight as to the food web structure for higher trophic level organisms that utilize both habitats for food and as a refuge.
Non-indigenous plant species considered a priority in the LO module are listed in Table 4-1. Recently, the first population of Old World climbing fern (*Lygodium microphyllum*) was reported in the western marsh in July 2006. This exotic may be added to future priority lists if control efforts are not undertaken in the near future.

### 4.6.3 Methods and Analysis

Stated hypotheses are evaluated using the most recent data available.

#### Table 4-1: Status and Prognosis Table for Priority Invasive Plant Species

[see Note 1]

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>2006 STATUS</th>
<th>2007 STATUS</th>
<th>1-2 YEAR PROGNOSIS</th>
</tr>
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<td>questions)</td>
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<td>Y</td>
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<td>G</td>
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<td>philoxeroides)</td>
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<tr>
<td><strong>Australian Pine</strong> (Casuarina spp.)</td>
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<tr>
<td><strong>Indian rosewood</strong> (Dalbergia</td>
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<td>sisson)</td>
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<tr>
<td><strong>Water Hyacinth</strong> (Eichhornia</td>
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<td>G Y</td>
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<td>crassipes)</td>
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<tr>
<td><strong>Hydrilla</strong> (Hydrilla verticillata)</td>
<td>Y G</td>
<td>C</td>
<td>C G</td>
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<tr>
<td><strong>West Indian Marsh Grass</strong></td>
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<td>Y</td>
<td>Y R</td>
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<tr>
<td>(Hymenachne amplexicaulis)</td>
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<tr>
<td><strong>Melaleuca</strong> (Melaleuca quinquenervia)</td>
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<td>G</td>
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<td>terebinthifolius)</td>
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</table>

Note 1: [see Note 1]
4.6.4 Results and Discussion

Hypothesis—Under physical conditions that results in low light levels, the exotic SAV species *Hydrilla (Hydrilla verticillata)* may have a competitive advantage over more desirable native SAV species.

Rationale
Mesocosm experiments conducted under natural light indicate that *Hydrilla* has a lower light requirement (*Figure 4-26*) than both *Vallisneria* and *Chara*, the major SAV species tested from LO to date (Grimshaw and Sharfstein in preparation). The minimum light requirements for *Hydrilla, Vallisneria* and *Chara* are 1.8, 4.1, and 4.7 percent of incident photosynthetically active radiation (PAR), respectively (Grimshaw et al. 2002, 2005).

*Hydrilla* has been in LO for about 20 years, but was not a consistent problem. Its acreage varies annually with water clarity, wind, wave action, water level and substrate conditions. In some years *Hydrilla* has expanded rapidly to cover thousands of acres and required mechanical harvesting to open up boat trails. Wave and wind from hurricanes resulted in prolonged periods of elevated turbidity and the corresponding reduction in light availability cannot fully account for the observed reduction in *Hydrilla* populations for the past several years, primarily because *Hydrilla* is very low light tolerant. Arguably, their decrease may largely be because of physical disruption during the storms. Recent Hurricanes Irene (1999), Frances (2004), Jeanne (2004) and Wilma (2005) impacted LO to the extent that virtually no *Hydrilla* was detectable until summer 2006. However, the exponential growth rate of the plant, maintenance of stages favorable to its spread and a few consecutive years free from hurricanes could permit *Hydrilla* to spread rapidly and become a major concern.
Hypothesis-Changes in the extent of mud sediments in the pelagic-littoral fringe zone of LO, resulting from changes in runoff and nutrient loading, influence the potential area available for colonization by desirable SAV.

In LO, SAV colonizes peat and sand sediment but does not grow as well in mud sediments. Changes in runoff and nutrient loading are expected to reduce area of the lake experiencing high turbidity, thereby increasing the area potentially available for colonization by SAV.

Results to date seem to contradict this statement (Figure 4-27). *Hydrilla* and *Ceratophyllum* will colonize mud sediments if they are in an area where sufficient light is reaching the bottom; however, the more desirable native *Vallisneria* appears to prefer sand and peat substrates. The major colonizer of rock substrate is the non-vascular macroalga *Chara*.

Overall, coverage of exotic emergents such as torpedograss and SAV such as *Hydrilla* are anticipated to be reduced after CERP projects are on-line. Reduced frequency of extreme low lake levels favored by torpedograss may result in less littoral area coverage and less effort required to maintain this limited coverage. In the nearshore region of LO, improved light penetration into the water column after CERP project implementation may enhance the ability of native SAV taxa such as *Vallisneria* to outcompete exotics such as *Hydrilla*. 
4.7 Lake Okeechobee Hypothesis Cluster-Phytoplankton Dynamics

4.7.1 Abstract
Phytoplankton monitoring is an important component of LO research. LO is designated as a P Class I drinking water source by the DEP. Approximately 60,000 people rely on LO as their primary source of potable water. Periodic large-scale surficial blooms since the 1980s, the last of which occurred during the summer of 2005, has elevated concern regarding cyanotoxins and potential adverse health effects for wildlife, livestock and humans. In addition, phytoplankton is one of the primary producers at the base of the pelagic and nearshore food webs and as such is an important food source for numerous organisms. Data collected as part of a long-term monitoring program indicates that phytoplankton community has been shifting from one dominated by diatoms in the 1970s to a community dominated by cyanobacteria since the 1990s (Havens et al. 1996). Most of the phytoplankton taxa are not readily grazed by zooplankton, suggesting that energy transfer from phytoplankton up the food web to the higher trophic levels may be less important than along microbial pathways. Continued excessive nutrient loading from the watershed, fluctuating climactic events ranging between excessively dry and wet years and the passage of three hurricanes during 2004-2005 may be factors which are influencing changes in the phytoplankton community. The long-term data set will be useful to establish pre-CERP implementation conditions and to assess if CERP projects contribute to the restoration of a more diverse, heterogeneous
phytoplankton assemblage that is dominated or co-dominated by diatoms rather than cyanobacteria.

### 4.7.2 Background Description

Phytoplankton research has been conducted in the pelagic and nearshore regions of LO since the late 1960s (Joyner 1974). Studies conducted during the 1970s and the early 1980s indicated that phytoplankton assemblages were spatially and temporally heterogeneous (Chichra et al. 1995). Several large surficial blooms during the mid 1980s were interpreted as a shift in the phytoplankton community to that of an increasingly eutrophic lake. Havens et al. (1995) found that bloom frequencies, defined as chlorophyll $a$ concentrations >40 ppb, increased during the 1980s and were positively correlated with water temperature but inversely correlated with total and soluble N and P, and wind velocity. Maceina (1993) identified a positive relationship between lake stage and chlorophyll $a$ concentrations in the littoral and nearshore regions of LO. Maceina (1993) hypothesized that a higher lake regulation schedule, implemented in 1978 for water supply, resulted in greater movement of nutrient-rich pelagic water into the nearshore and littoral regions of LO, thus stimulating increase phytoplankton biomass. Philips et al. (1994) found spatial variability in LO phytoplankton biomass (as chlorophyll $a$) over a 17-year period, and suggested that the phytoplankton were light-limited in the central pelagic region and nutrient-limited in the less turbid nearshore region.

Phytoplankton studies conducted as part of the Lake Okeechobee Ecosystem Study (LOES) from 1988 to 1990 indicated that the phytoplankton community was dominated by cyanobacteria at 14 of the 21 study sites. Diatoms dominated at the six remaining sites, and co-dominated with cyanobacteria at the remaining site (Chichra et al. 1995). During this same period, spatial and temporal changes in phytoplankton biomass were related to variability in nutrients, lake stage, light availability and wind speed (Phlips et al. 1995). Smith et al. (1995) suggested that a significant decline in the TN to TP ratio (TN:TP) in LO from the early 1970s to the 1990s coincided with increased planktonic N limitation and suggested that this may represent an increased potential for blooms of N-fixing cyanobacteria. Bioassays conducted as part of LOES indicated that phytoplankton were generally N-limited, though other factors such as light were also posed as co-limiting factors in roughly a third of the assays (Aldridge et al. 1995). In a subsequent bioassay study conducted from 1997 to 2000, light was the most common limiting factor followed by N and N:P co-limitation (East and Sharfstein 2006). During this period, the phytoplankton in LO were either light-limited or nutrient-limited, with limitation being determined seemingly as a function of irradiance-related parameters. Light limitation was more prevalent during the windier, more turbulent winter months and nutrient limitation was more dominant during the summer.

In response to a legislative mandate to restore LO, a phytoplankton monitoring program in the pelagic and nearshore regions of LO was initiated in 1994 and is currently conducted on a quarterly basis (East and Sharfstein 2006). As part of this research, phytoplankton abundance (as chlorophyll $a$ and biovolume) and community composition are determined at five sites (Figure 4-28). Since 1997, photosynthesis-irradiance (P-I) curves have been generated using in situ water from these five sites, to determine whether light or nutrients are
limiting phytoplanktonic photosynthetic activity. The P-I data suggest that low lake stage is highly correlated with photosynthetic parameters, suggesting an ecological heterogeneity, while under high lake stage, the parameters do not vary, suggesting that phytoplankton are ecologically homogeneous among sites (Maki et al. 2004). Additionally, cyanotoxin monitoring commenced in 2004 and is currently being conducted on a monthly basis at seven sites near major inflows or municipal water intake structures.

Overall Goal
CERP RECOVER targets are to reduce the dominance of cyanobacteria and increase diatoms such that the diatom to cyanobacteria ratio becomes greater than 1.5:1. A decrease in P inputs to LO as part of CERP implementation and basin control efforts is expected to increase the TN:TP ratio to above 22:1, and decrease cyanobacterial bloom frequency and bloom composition, with cyanobacteria comprising < 50 percent of bloom composition. There currently are no biovolume or abundance targets set forth for phytoplankton as part of CERP.
The unlabelled nearshore site was excluded from some of the analyses.

**Figure 4-28: Phytoplankton (Star Shape) and Cyanotoxin (Sun Shape) Monitoring Sites on Lake Okeechobee**
4.7.3 Methods and Analysis
Phytoplankton monitoring consists of collecting water from all but the bottom 0.5 m of the water column with an integrated sampling tube, on a quarterly basis as described in East and Sharfstein (2006). Water is collected for biomass determination (as chlorophyll \(a\)), community taxonomic composition and for laboratory bioassays which are used to determine whether light or nutrients are potentially limiting phytoplankton growth (East and Sharfstein, 2006). Additionally, P-I curves were generated using additional water samples. These P-I curves were used to evaluate how photosynthetic characteristics varied among sites located in ecologically distinct regions of LO (Phlips et al. 1993, Maki et al. 2004). Physical water quality data are also collected from a sonde and datalogger unit, while water chemistry is measured either by sonde or from surficial water grab samples.

Community Composition
Samples collected for phytoplankton community composition have been enumerated to species or lowest practicable level, and are reported as biovolumes (\(\mu m^3/mL\)). Two contract taxonomists have conducted phytoplankton identifications since 1994. Both contractors identified samples 1994-1996, and the current contractor has been identifying samples since 2000. Sampling frequency was reduced to quarterly in 2003 and has remained at that frequency. Therefore, all community composition analyses consist of quarterly samples collected from 1994-1995 and 2000 to present, with samples collected at four of the five sites (two nearshore, two pelagic). The fifth site was not included in these analyses because it was not monitored during 1994-1995. Differences in replication exist between the 1994-95 and the 2000-06 datasets. Ordinations should be considered exploratory at this time.

Biomass Determination
Chlorophyll \(a\) concentrations are determined spectrophotometrically following grinding of filtered water samples followed by extraction of the pigments in 90 percent acetone, following standard methods (APHA 1995). Total biovolumes are only reported in this section for 2000-2006 because these data have not yet been separated by taxonomist for 1994-1995. Therefore, only data for the current taxonomist were used. Data reported in this section are from the same nearshore and pelagic sites previously described.

Light and Nutrient Bioassays
Bioassays were conducted to measure phytoplankton photosynthesis and determine whether light or nutrient concentrations limited photosynthetic activity. These bioassays were conducted using five light levels as outlined in Maki et al. (2004). The bioassays were run within 24 hours of sample collection, at one of 20 irradiance levels ranging from 0 to \(~ 1000 \mu mol \text{ photons m}^2 \text{ s}^{-1}\) at ambient lake temperature, for one hour.

Diatom to Cyanobacteria Ratio
Diatom to cyanobacteria ratios were calculated from the percent total biovolumes for both Divisions.
Cyanotoxin
Cyanotoxin samples were collected from surface water grabs near three municipal water intake structures and four inflows to LO. All sites were located at nearshore locations in the north, west, and eastern part of LO (Figure 4-28). Microcystin, anatoxin and cylindrospermopsin concentrations were determined at a contract laboratory.

Results

Community Composition
This data set comprises quarterly data from one contractor. Split samples collected between 1994 and 1996 and analyzed by both taxonomists suggests that there are significant differences among both primarily in several of the cyanobacteria taxon identifications, as evaluated by the Analysis of Similarity (Anosim) test (ANOSIM, Global R = 0.73, p=0.001). Since one taxonomist identified all samples from 1996 through 1999, and identified a smaller set of samples, these samples have been excluded from this analysis.

Nonmetric multidimensional scaling (NMDS) ordination analysis of the community data suggests that year and then season were the two most significant factors. Among years (all sites combined), displayed the clearest separation between the phytoplankton communities (R<0.83, p=0.001, Figure 4-29). The group patterns suggest that while there was some differences in the community structure between 1994 and 1995 (R=0.52, p=0.001), there was relatively clear differences among the groups (R>0.7, p=0.001) between 1994, 1995 and each year from 2000-06. Some of the most significant (R>0.9, p=0.001) among-years differences occurred between 2000 and each of the subsequent years. During 2001 a lake recession and prolonged drought occurred and lake stage decreased by May of that year to roughly 1.7 m below the long-term seasonal average, which was, at that time, the lowest ever-recorded lake stage (since exceeded in June 2007). There was little difference between the communities in 2005 and 2006 (R=0.13, p<0.10).

The within-year phytoplankton communities had mean similarity percentages that ranged from a high of 45 percent (1994) and were <28 percent for each year between 2000 and 2006. These values represent mean taxon contribution to the community structural similarity among samples for each year and suggest that there was substantial within-year variability during 2000–06. Mean dissimilarity percentages between each yearly comparison ranged between 67 percent (1994 and 1995) and 98 percent (1994 and 2006). This among-year variability is illustrated in dendritic form in Figure 4-30. The taxa that were most dissimilar among 1994 and 2006 were the cyanobacteria taxa Lyngbya limnetica, Lyngbya contorta, Anabaena flos-aquae and Anabaena cicinalis. All of these taxa were abundant in 1994 (> 1.3 x 10^5 µm^3/mL) and with the exception of Anabaena circinalis (107 µm^3/mL), were not identified in the 2006 samples. The same taxa had the biggest contribution to the differences between the 1995 and 2006 assemblages, where the dissimilarity percentage between the two years was nearly as high (97 percent) as it was between 1994 and 2006.

In general, cyanobacteria taxa comprised three or four of the top five taxon that contributed most to the relative dissimilarity. Diatoms were much less important, although they did comprise one to two taxa which made significant contributions to the among-groups
dissimilarity values. In these cases, it was diatom taxa which were found primarily in 2001–2006. Among the 2000–2006 group comparisons, there existed a general mix of three diatom and one or two cyanobacteria taxa which contributed most significantly to the among-years dissimilarity values. These results suggest that the phytoplankton assemblage experienced an increase in diatom importance and variability after 2000. However, community variability also may have been due in part to variability in sample identifications (e.g., taxonomic drift).

Separation among the community on a seasonal basis was less clear (R<0.44, p=0.001, Figure 4-31). The largest separation, which was fairly significant, was between winter and fall (R=0.66, p=0.001) and the smallest separation, which was marginal, was between winter and spring (R=0.37, p=0.001). The same taxonomic pattern described for the among-year comparisons was observed for this data set, though there were typically one or two cyanobacteria taxa which contributed to the among-season differences than was observed in the among-years communities. It should be noted that the stress value associated with both the two dimensional among-years and among-seasons plots was sufficiently high to caution their use for anything beyond examination of general trends (per guidelines presented in Clarke and Warwick 2001).

There was very little difference among sites (R=0.11, p<0.01), whether examined on an among-years or among-seasons basis. The largest separation was between the communities at sites L005 and LZ40, but the amount of separation (R=0.32, p=0.001) was marginal. These comparisons suggest that temporal factors were more important than geographic location in influencing the community structure and that overall, there was little discernable separation and difference in the phytoplankton community structure among each site. Separating the data into years of lower lake stages (e.g., years <14 ft msl) and higher lake stages (e.g., years >16 msl) may have yielded better separation among sites, as photosynthetic behavior was shown to homogenous among sites during higher lake stages and heterogeneous under lower lake stages (Maki et al. 2004).

![Figure 4-29: Phytoplankton Community Ordination Plot by Year](image)
The distances from mean Bray-Curtis similarity coefficients on square root transformed biovolume data.

**Figure 4-30: Dendrogram Representation of Among-years Differences in the Phytoplankton Communities**

**Figure 4-31: Phytoplankton Community Ordination Plot by Season**

Attempts to correlate 12 years of water quality data to phytoplankton community structure in LO were not conclusive. Stepwise addition of water quality variables suggested a positive but weak relationship (Spearman $\rho=0.284$) between a combination of Secchi disc depth to
total depth (SD:TD), TSS, pH, mean wind speed, lake stage and the phytoplankton community composition. Similarly weak positive correlations between combinations of subsets of these variables also were observed.

**Biomass Determination**

Biomass defined as mean annual total biovolumes were variable among the nearshore and pelagic sites, and appears to be similar among site types for most years (*Figure 4-32*). Mean annual biovolumes appear to be significantly lower in 2006 relative to the other years and may be related to extremely low light levels in the water column since the passage of Hurricanes Frances and Jeanne in 2004 and Wilma in 2005. Mean annual biovolumes varied between 48,000 µm³/mL in 2006 (pelagic sites) to 1,900,000 µm³/mL in 2001 (nearshore sites).

Biomass as mean annual chlorophyll \(a\) concentrations were less variable and very similar among site types for all years (*Figure 4-33*). Mean annual chlorophyll \(a\) concentrations were generally between 10 and 20 µg/L. Algal bloom frequency, as previously defined (Havens et al. 1995) was infrequent during this period. Blooms were observed on average once a year (from quarterly samples) at either of the nearshore and pelagic sites. A large surficial bloom was observed in August, 2005, but these blooms occurred between the summer and fall quarterly sampling events.

![Figure 4-32: Annual Mean Phytoplankton Biomass in Total Biovolumes ± 1 S.D. at Both Nearshore and Pelagic Sites](image-url)
Lake Okeechobee Module

2007 System Status Report Final 4-51 November 2007

Figure 4-33: Annual Mean Phytoplankton Biomass as Chlorophyll a ± 1 S.D. at Both Nearshore and Pelagic Sites

**Light and Nutrient Bioassays**
Long-term (1997-2000) bioassay results indicate that light limited phytoplankton growth approximately 60 percent of the time, while N limited growth the remaining time (East and Sharfstein, 2006). While these bioassays continue to be conducted on a quarterly basis, the data analysis is on-going.

**Diatom to Cyanobacterial Ratio**
Diatom to cyanobacteria ratios have been < 1:1 since the mid 1990s (*Figure 4-34*). Since 2003, it appears that ratios have been increasing, at both the nearshore and pelagic sites, such that they have exceeded the PM since 2004. Since 2004, the diatom genera *Fragilaria*, *Aulacoseria* and *Cyclotella* have become increasingly important in both among-years biovolumes and how frequently they are found in each sample. This achievement of the PM target during a period of time when LO is in notably poor condition as a result of the hurricanes and high water levels, brings into question the validity of the PM. It may be that what is being measured is resuspended meroplankton rather than the diatom and cyanobacterial assemblage. Nevertheless, meeting restoration targets without restoration during extremely poor conditions suggests that either the PM should be modified to specify that the diatom species in question are typical pelagic organisms, or alternatively dropped altogether.
Cyanotoxin
Mean microcystin concentrations are generally low (e.g., <5µg/L), but were considerably higher during late summer (August-October) in 2005 (Figure 4-35).
4.7.4 Discussion

Phytoplankton has received considerable study on LO and past research has suggested that lake stage, nutrients, and light availability affect the phytoplankton (Philps et al. 1993, 1995). There also has been a shift in dominance from a diatom-dominated to a cyanobacteria-dominated assemblage that has coincided with cultural eutrophication of LO (Havens et al. 1996). Blooms have become more frequent since the 1980s (Havens et al. 1995) and conditions have become increasingly favorable for blooms to be comprised primarily of N-fixing cyanobacteria as the TN:TP ratio has declined (Smith et al. 1995).

The variability in the 1994-95 and 2000-2006 community composition data suggest changes that may be reflective of the dynamic climatic events experienced by LO over the past decade. Lake stage has fluctuated between a historical high of 18.5 feet msl during an extremely wet 1995 and a historical low of 8.97 feet msl following a lake recession and prolonged drought in 2001. The current prolonged drought has resulted in a minimum lake stage of 8.84 msl, recorded during June, 2007. Additionally, three hurricanes passed very near LO between 2004 and 2005, and turbidity levels became extremely high (e.g., over 100 ppm TSS) for up to six months. During 1994 and 1995, taxa which contributed most significantly to within-year similarity values were predominantly the cyanobacteria genus *Lyngbya*, *Anabaena*, *Oscillatoria* along with the diatom *Melosira* and the cryptomonad genera *Cryptomonas* and *Rodomonas*. While the cyanobacteria taxa *Lyngbya* and *Oscillatoria* continued to play the most significant part in within-group similarity for 2000-

Figure 4-35: Mean Microcystin Concentrations (µg/L)
2002, these similarities have been increasingly influenced by diatom genera such as *Fragilaria*, *Aulacoseria* and *Cyclotella*. Since 2004, at least four of the top five most similar within-year taxa for each have been diatoms, suggesting that they are more consistently being found in samples. Several of these taxa, such as *Thalassiosira proschikinae*, and species of the genera *Aulacoseria*, *Cyclotella* and *Stephanodiscus* are nutrient tolerant and indicative of eutrophic or hypereutrophic conditions (Yang et al. 2005).

Based on past research, it was surprising that there was very little difference among sites, whether evaluated on a yearly or seasonal (quarterly) basis. This contrasts with the oft-utilized heterogeneous characterizations of LO and subsequent development of the ecological zones concept delineating pelagic and nearshore regions of LO (Phlips et al. 1993), including phytoplankton spatial heterogeneity (Aldridge et al. 1995). The lack of significant separation among sites may be due to how the data were aggregated and it may be that examination at a finer scale would reveal differences among sites. Alternatively, these results suggest that phytoplankton may not be as spatially heterogeneous as they were during previous studies.

The weak correlations between water quality variables and community composition suggest that relationships are complex and community structure is likely dependent on dynamically varying individual or composites of water quality factors at different times and under different conditions. This may also suggest that unmeasured variables play an unexpected role, or that the frequency at which variables were measured was insufficient to define their sway on phytoplankton community structure (e.g., inability to appropriately lag data due to the coarseness of its periodicity). However, since phytoplankton generation times are often on the order of one day or less, the discontinuity between water quality data—most of which were collected the same day as phytoplankton samples—and which included light and nutrient concentration measurements was surprising. Still, it is anticipated that CERP projects will result in reduced nearshore and pelagic zone nutrient concentrations, which may facilitate a shift back to consistent diatom dominance, less frequent algal blooms and blooms comprised of a smaller portion of cyanobacteria than has been observed over the past 20 years.

### 4.8 Lake Okeechobee Hypothesis Cluster–Fish

#### 4.8.1 Abstract

Decreases in habitat and disruption of the food chain have resulted in decreases in the number and size of fish, as well as a shift to less desirable species. Efforts to resolve problems in water quality and volume (stage) will be reflected as improvements in fish habitat and quality and quantity of fish.

#### 4.8.2 Background Description

Biological integrity of a system may be defined as "maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981). Fish, besides being the most visible and sought after commodity in most water bodies, are at the trophic pinnacle among aquatic organisms, integrating the effects of both water management and basin development. Fish require a viable foodweb (thus reflecting the
status and health of the invertebrate community) and require suitable habitat to avoid predation and ensure reproductive success (thus reflecting the status and health of aquatic vegetation). A CEM (Figure 4-36) has been developed which relates the various stressors and drivers in LO to responses in the fish community.

Fish have been used for many years to indicate whether waters are clean or polluted, doing better or getting worse. LO has supported valuable commercial and recreational fisheries estimated at times in the hundreds of millions of dollars. Among important species taken from LO are white catfish (Ameiurus catus), bluegill (Lepomis macrochirus), largemouth bass (Micropterus salmoides), black crappie (Pomaxis nigromaculatus), and readear sunfish (L. microlophus).

4.8.3 Methods and Analysis

Fish populations in the littoral edge, interior marsh, and open water areas of LO were sampled to assess relative abundance, and acquire statistics for evaluation of length frequency and length/weight relationship determination. Fish populations in open water areas were sampled utilizing a trawl methodology at previously established sites and according to procedures from a previous study conducted in LO from 1987 to 1991 (Bull et al. 1995). Fish populations in the littoral edge and interior marsh were sampled utilizing electrofishing techniques at previously established areas and according to procedures developed for an ongoing evaluation of the largemouth bass (Micropterus salmoides) population in LO (Havens et al. 2005). Methods used allowed comparison to previous FWC surveys, some of which date back to the early 1990s. Locations of the sampling sites in 2005 are shown in Figure 4-37. Individual fish were identified, weighed and measured for length.

Future analyses to assess fish health in LO may rely more heavily on the 30+ years of existing creel survey data. A full analysis of this data will be pursued to acquire longer-term baseline information on the sport fishery in LO. These analyses may also improve current understanding of fish dynamics over time as a function of stage, SAV and other factors that may be related to fish health and abundance.
4.8.4 Discussion

A previous multi-year study (Bull et al. 1995) identified threadfin shad as the most abundant species sampled (Table 4-2) and black crappie as most abundant in terms of biomass Table 4-3. This relationship reflects the predator-prey relationship between the two species, namely that adult black crappie feed almost exclusively on threadfin shad. Although, threadfin shad remained a significant fraction of relative abundance in 2005 and 2006, overall counts of individual fish had dropped a hundred-fold. Since threadfin shad feed primarily on microscopic plant and animal life, phytoplankton and zooplankton, the reduction in their number can be arguably attributed to some combination of the 2004-2005 hurricanes, increased turbidities and stage which effectively reduced the shad’s food source and thus their population. As a consequence, black crappie biomass was reduced to around one percent of the overall fish population assemblage.
An additional important driving factor affecting LO’s fish population density and structure is the reduction in numbers of the chironomidae macroinvertebrates (Figure 4-38). Chironomid larvae comprise the primary food source of juvenile black crappie and the decline in the former is another causative factor, along with the decline in threadfin shad,
explaining the decline of the latter. Bluegill, also known as bream or brim, feed on very small fish and invertebrates. Bluegill abundance decreased in comparison to the 1987-91 data in 2005 and 2006 by 94 and 92 percent, respectively, which mirrors the decline in invertebrates as their direct prey and that of many of the smaller fish upon which they feed. However, concern regarding these precipitous declines in crappie population must be tempered by observing that 1986-90 was an unusually productive period (Figure 4-39), and that accordingly the 1987-91 dataset was biased high. Although the 2005-07 timeframe denotes the lowest catch rate on record, other periods of time have been similarly poor. Nevertheless, the preceding clearly illustrates the intertwined relationships among all the lake health attributes (e.g., SAV, water quality, lake stage, macroinvertebrates, and demonstrates the necessity to assess and manage LO from the widest holistic perspective of balanced ecosystem function).

![Average number of individuals (log10) of the order chironomidae sampled in each replicate sample by year by substrate type. Chironomidae are the main foodstuff for juvenile black crappie.]

**Figure 4-38: Average Number of Individuals of the Order Chironomidae Sampled in Each Replicate Sample by Year by Substrate Type**
A decline in other important species in LO is also apparent (Figure 4-40 and Figure 4-41). In comparison to the fish community structure of 1987-91, coarser fish appear to be becoming more dominant at the expense of more desirable species. Relative counts of Florida gar have risen approximately one percent in the older data to 16 and 11 percent of the total in 2005 and 2006, respectively. Florida gar, whose roe is toxic to mammals and birds, is a very tolerant species that can breathe by gills or a lung-like air bladder and is protected by scales that make respectable arrowheads. By weight, Florida gar are currently the most prevalent species, whereas in the previous dataset black crappie, a desirable recreational fish, was dominant.

Black bass fishing is the most popular type of fishing in the United States, with 44 percent of all freshwater anglers considering themselves to be bass anglers, and Florida ranks second behind Texas in number of bass anglers and number of bass fishing trips (USFWS 1996). LO is famed for its year-round bass fishing, and has yielded a large number of trophy bass. Although the data (Figure 4-40 and Figure 4-41) indicates that relative counts and weight of largemouth bass have remained stable, there is increasing concern that the last few years’ spawning cycles have not been fully realized, although the exact causes remain uncertain. Several possible reasons exist, among them are: 1) the bass successfully spawned but the juveniles did not survive due to a lack of food, 2) juveniles did not survive due to lack of SAV and could not avoid predation, or 3) simply the bass did not spawn. Since largemouth bass are such an important LO species portending ecological as well as financial consequence to recreational fisheries and their professional guides, the success of subsequent spawning cycles remains a concern. Black bass catch rate has shown precipitous declines which appear associated with extreme low lake stages (Figure 4-42); however, catch rate is a consequence of a complex set of factors among which are reproductive success and prey availability.
Table 4-2: Top Ten Species by Abundance by Year Sampled

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*from Bull et al. 1995


Table 4-3: Top Ten Species by Weight (kg) by Year Sampled

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Note: Key same as Table 4-2
Figure 4-40: Comparative Abundance (log_{10}) of Recent Sampling Efforts (2005 and 2006) to Historic Data (1987-91) of Selected Important Fish Species

Figure 4-41: Comparative Weights in Kilograms (log_{10}) of Recent Sampling Efforts (2005 and 2006) to Historic Data (1987-91) of Selected Important Fish Species
Variables are significantly correlated (Spearman rho=0.568, p=0.034) when catch rate is lagged one year. (Catch rate data courtesy FFWCC)

Figure 4-42: Largemouth Bass Catch Rate (Electrofishing, Fish/Minute) as Function of Stage (Feet MSL) by Year

Conclusion
The abundance and diversity of the native fish population in LO is dependent on a variety of interwoven factors. Most ostensible among these factors being SAV as habitat and the macroinvertebrate community as a basis of the foodweb. Water management and basin management directly affect lake stage and lake water quality, respectively, with consequence to SAV, algal blooms, sediment integrity, and so forth. The fish population evidences considerable variation year to year, with periodic very good years interspersed with years less so. Clear linkages between changes in the lake and changes in the fish community are not readily deducible from current datasets, presumably because ecological condition in the lake has evidenced diminished quality since fish monitoring started resulting in times when multiple stressors align to adversely affect the population. Recent downturns in fish community health are worrisome, but additional data will be necessary to determine whether these are cyclic events or an actual concern.

4.9 Lake Okeechobee Hypothesis Cluster Macro-invertebrates

4.9.1 Abstract
Macroinvertebrates in the pelagic zone of LO have been intermittently monitored since 1969 (Warren et al. 1995) and are currently being monitored at 18 synoptic sites located in the peat, mud and sand sediments of LO. These are the same sites in which monitoring occurred during 1969-1970, and 1987-1996 and these macroinvertebrate communities will provide pre-CERP implementation baseline data, which can be compared to post-CERP project completion community data. A five-year study assessing macroinvertebrate assemblages in three SAV and two emergent vegetation communities is also currently being conducted.
After CERP projects are on-line and nutrient and sediment loads to LO are reduced, the dominance by taxa tolerant to organic loading is anticipated to decrease, while numbers of intolerant taxa, species diversity, species richness and evenness of distribution are expected to increase.

### 4.9.2 Background Description

Macroinvertebrates have been used for the past century as indicators of water and habitat quality in lakes. Freshwater invertebrate communities are extremely sensitive to existing water quality conditions, and reflect a lake's trophic status because they are unable to escape perturbations (Warren et al. 2007) (Figure 4-43). Species composition, absolute abundance, relative abundance, diversity, species richness and evenness are metrics commonly used to evaluate the ecological condition in lakes. As the eutrophication process progresses, macroinvertebrate species richness and diversity are reduced, while the community composition shifts to one dominated by pollution-tolerant taxa. As a lake becomes increasingly eutrophic, macroinvertebrates which require higher levels of DO, such as many mussels (Pelecypoda), mayflies (Ephemeroptera), caddisflies (Trichoptera), dragonflies (Anisoptera), and damselflies (Zygoptera), are eliminated. The invertebrate communities then become dominated by groups of species physiologically adapted to withstand high degrees of organic loading and extended periods of low (<4.0 ppm) DO (Brinkhurst 1974, Warren 2007). If LO becomes hypereutrophic, all but the most tolerant segmented worm (Oligochaeta) species may be eliminated (Brinkhurst 1974, Wetzel 1983). Since macroinvertebrates are an important component of freshwater food webs, elimination of most of the macroinvertebrate taxa could have severe negative impacts on fish and other higher-trophic level organisms which utilize macroinvertebrates as a food source.

![Figure 4-43: Macroinvertebrate Conceptual Ecological Model](image-url)
4.9.3 Methods and Analysis

As a component of the MAP, pelagic zone and SAV/emergent vegetation macroinvertebrate communities are currently being monitored to establish pre-CERP implementation baseline conditions. The pelagic zone macroinvertebrate monitoring results also will be compared to those collected during a 1987-1996 ecosystem study (Warren et al. 1995), while the SAV/emergent vegetation monitoring results will be compared to those collected during 1986-87 (Rudolph and Strom 1990), thereby enhancing the pre-CERP implementation baseline data.

The LO synoptic pelagic zone monitoring is currently being conducted by the FWC, and will be compared to existing macroinvertebrate data from 1987 thru 1996. These benthic invertebrate community samples were collected from six sites within each of three aerially dominant habitat zones (mud, sand, peat) twice annually (Figure 4-44) using a petite ponar dredge, yielding a total of 54 samples per collection (see Warren et al. 2007 for complete details). Community structure metrics include taxonomic composition, taxa richness, absolute abundance, relative abundance, diversity (Shannon’s equation, as per Krebs 1999), and evenness (as per Pielou 1977).

The SAV/emergent vegetation monitoring is being conducted bi-annually, in triplicate SAV \( (\text{Hydrilla, Potamogeton, Vallisneria}) \) and emergent \( (\text{Scirpus, Typha}) \) sites located along the north, west and southern nearshore region of LO (Figure 4-44). This monitoring, as part of a larger trophic study involving fish, is being conducted by Malcolm-Pirnie, Inc., and is scheduled to continue through 2010. Results of the first SAV/emergent vegetation macroinvertebrate sampling event, which was conducted in October 2006, are still being analyzed.
Figure 4-44: Florida Fish and Wildlife Conservation Commission Sublittoral Zone Benthic Invertebrate Sampling Sites in Lake Okeechobee
4.9.4 Discussion

Overall Lake Community

Results from macroinvertebrate investigations conducted in the 1980s suggested that the communities reflected eutrophic conditions in LO’s nearshore SAV and emergent vegetation beds (Rudolph and Strom 1990) and the pelagic zone (Warren et al. 1995).

Results from the recent pelagic zone data indicated that a total of 48 individual aquatic invertebrate taxa representing 20 major taxonomic groups were collected from LO during the two sampling events (August 2005 and February 2006) conducted in study year one. Oligochaeta (segmented worms) numerically predominated the mud and sand habitat zones during both sampling events, and accounted for 64.3 percent (lakewide mean = 2,147 individuals m\(^{-2}\)) of the total number of organisms collected during the study year. Most abundant among the Oligochaeta were the tubificids *Limnodrilus hoffmeisteri* (974 m\(^{-2}\), 29.2%) and *Haber speciosus* (580 m\(^{-2}\), 17.3%).

*Aquatic Acari* (water mites) numerically predominated the peat zone of the southern lake region and accounted for 11.9 percent of all organisms collected (lakewide mean = 397 m\(^{-2}\)). The introduced Asian clam *Corbicula fluminea* was the fourth-most abundant taxon and accounted for 9.4 percent of all organisms collected (314 m\(^{-2}\)). No other individual taxon accounted for more than five percent of the total organisms. Chironomidae (non-biting midges), which usually account for a large percentage of the benthic fauna in the open water zones of lakes, accounted for only 2.8 percent of the total organisms collected from the sublittoral zone. The tubicolous detritivore *Chironomus crassicaudatus*, which has accounted for a substantial percentage of the sublittoral zone benthos in past collections (Warren et al. 1995), was present with a mean density of only one m\(^{-2}\) (<0.1% of total organisms). Other taxa notably important in past collections, but absent or present in low numbers in the 2005-06 collections, included the gastropods (snails) *Viviparus georgianus* and *Melanoides* sp., the amphipod crustaceans *Gammarus tigrinus* and *Hyalella azteca*, the isopod crustaceans *Cyathura polita* and *Cassidinidea ovalis*, and the chironomids *Cladotanytarsus* sp. and *Polypedilum halterale* (Warren 1995).

![Figure 4-45: Multidimensional Scaling Ordination of Combined Annual Macroinvertebrate Community Structure for Each Year Samples Were Collected](image)

The closeness of points to one another reflects the similarity of the macroinvertebrate assemblage, in this case from year to year.
It is clear that a distinct change in benthos community structure has occurred between 1996 and 2005 (Figure 4-45). Lower species diversity was evidenced in LO from 1988-1992, with a period of higher diversity observed during 1993-1996, followed by a large reduction in diversity occurring sometime between 1996 and 2005. Some factor likely associated with the hurricanes of 2004 and 2005 (e.g., perhaps excessive and prolonged high turbidity) may have resulted in decreased diversity and total number of organisms. This pattern is also apparent in the total number of organisms (Figure 4-46). As an alternative explanation, the unusually extreme low lake stage experienced during the 2001 dry season may have led to conditions which had negative impacts on the macroinvertebrate community. However, the DO regime did not reflect that lowered stages corresponded with low DO concentrations. Further analysis was unable to attribute reductions in diversity related to the 2001 dry season event to any stage or water level effects.

A small recovery in diversity and total number of organisms appears to have occurred in 2006 in comparison to 2005, which seems to substantiate a recent causative event and lends credence to the 2004-2005 hurricane hypothesis (Figure 4-46). However, these relationships also extend to the nutrient regime (Figure 4-47), so no absolute causative agent can be assumed.

![Figure 4-46: Diversity and Total Number of Organisms Combined Means by Year](image)

Significant relationships exist between mean annual diversity and trophic state indices for P ($R^2 = 72\%$, $P = 0.003$), and to a lesser extent chlorophyll $a$ ($R^2 = 43\%$, $P = 0.079$).

![Figure 4-47: Classic Species Diversity Index Response to Increasing Eutrophication](image)
Habitat and Seasonal Influences

Bottom substrate type is the primary determinant of invertebrate community structure in the LO sublittoral zone. Four primary benthic habitat regions characterize the sublittoral: mud, sand, peat, and limestone bedrock (Reddy 1993) (**Figure 4-48**). The mud region is distinguished by deep, fine-particle sized organic sediments that occupy the central and north-central areas of LO. The mud region accounts for more than 50 percent of the total bottom surface area of the sublittoral zone. The sand region zone is located at the periphery of the sublittoral zone in the northeastern, northern, and northwestern lake areas and, in the western lake area, extends lakeward for several miles along the entire length of Observation Shoal. The peat habitat region is located in the southern quarter of LO and is characterized by areas of both fine and coarse peat. The fourth habitat type is a limestone bedrock reef that separates the peat habitat region from the mud habitat region. For the purposes of this study, only the mud, sand, and peat habitat regions were sampled. The limestone reef was not sampled because of difficulties obtaining legitimate quantitative samples with the petite ponar dredge from the hard limestone substrate. A two-way ANOSIM (Clarke et al. 1993) suggests that separation among the macroinvertebrate communities was more significantly associated with the sediment type (Global R=0.64, p<0.01) than with variability among the summer sampling seasons. Mud and peat-associated macroinvertebrate communities had the clearest separation (R=0.83), while separation among the sand and mud communities was the less defined (R=0.48). The distribution of community types as a function of substrate type is depicted in **Figure 4-49**.

The global year-to-year differences, and in particular the differences in community structure between the 2005 and 2006 sample collection years is borne out by a similar pattern when each of the substrate types are examined independently (**Figure 4-50**). This indicates that the change that occurred between 1996 and 2005 affected all substrate types in a similar fashion. Examination of the non-2005/2006 sampling data (**Figure 4-51**) indicates a somewhat orderly progression of sample sets across the period of record in mud and peat; both of these communities are susceptible to oxygen stress since both substrate types are typically reducing environments. This may indicate that benthic oxygen stress may be increasing.

![Figure 4-48 Major Bottom-types of Lake Okeechobee, FL](https://example.com/figure4-48.png)
Multidimensional scaling ordination of species community structure as a function of substrate type, based on 162 replicate samples (6 sites of 3 replicates in each of 3 substrate types) collected in August 2005, February 2006 and August 2006 combined. Mud and peat benthic communities are the most dissimilar with sand communities intermediate.

**Figure 4-49: Multidimensional Scaling Ordination of Species Community Structure as a Function of Substrate Type**

Community structure in 2005 and 2006 differs substantially from all other years in all three major substrate types.

**Figure 4-50: Multidimensional Scaling Ordination of Species Community Structure as A Function of Ranked Mean Species by Each Substrate Type by Each Year**
Results from previous studies have shown that benthic invertebrate communities of the LO mud zone have displayed the lowest species richness and diversity of all sublittoral habitat type communities sampled (Warren et al.1995). The current study reflects these results. Mud sediment-associated community species richness were typically about half the species richness means from the other substrate types sampled except for the peat region in February 2006 which evidenced a sharp rebound from the 2005 low (Figure 4-51). Mud region species diversity was also lowest among habitat types in both sampling seasons, while mean values of evenness were nearly equivalent across all habitats and sample dates. Three individual segmented worm taxa (*Limnodrilus hoffmeisteri*, *Ilyodrilus templetoni*, and *Stephensoniana trivandrana*) numerically dominated the mud region and accounted for 77 percent of the total abundance. No other individual taxon accounted for more than four percent of the total abundance in the mud region. Mud region communities exhibited little seasonal variation in taxonomic composition.

Segmented worms also dominated the benthos of the sand habitat region. *Limnodrilus hoffmeisteri*, *Ilyodrilus templetoni*, and *Stephensoniana trivandrana* together accounted for 67 percent of all sand habitat organisms collected. The Asian clam *Corbicula fluminea* was the third most abundant invertebrate collected from the sand habitat, occurring with a mean density of 578 m⁻² and accounting for ten percent of all sand organisms. No other individual taxon accounted for more than five percent of sand total speciation. There were no substantial differences between seasonal means of species richness, evenness, or diversity within the sand habitat region.

The taxonomic composition of the peat habitat region invertebrate community differed substantially from the taxonomic compositions of mud and sand region communities,
however the pattern of extreme dominance by a few number of taxa exhibited in mud and sand-inhabiting communities was also reflected in the peat region. Aquatic Acari were, by far, the most abundant benthic invertebrates collected from peat, occurring with a mean density of 1,104 m\(^{-2}\) and accounting for 42 percent of all peat organisms. Other important dominants included *Corbicula fluminea* (364 m\(^{-2}\), 14 %), *Nematoda* (359 m\(^{-2}\), 14 %), the amphipod *Gammarus* *nr. tigrinus* (204 m\(^{2}\), 8 %), and the segmented worm *Stephensoniana trivandrana* (165 m\(^{2}\), 6 %).

Mean taxa richness in the peat region winter community (Feb. 2006) was less than half of the corresponding summer value. A remarkable result from the 2006 winter sampling event was that no Chironomidae were present in any peat region samples (see LO Fish chapter for further discussion). Chironomidae accounted for 26 percent of all organisms collected from the peat region during the 1987–1991 sampling period (Warren et al. 1995).

The plots are of the number of taxa represented by only one individual in the sample (class 1 on the x-axis), two to three individuals (class 2), four to seven (class 3), eight to 15 (class 4), and so forth.

**Figure 4-52: Geometric Abundance Class Plots for Each Summer**
In systems where a measure of balance exists between numbers of rare and common taxa, a geometric abundance class plot portrays a smooth curve. Where few rare taxa are represented, the higher geometric abundance classes are more strongly represented. Plots of the lake data (Figure 4-52 and Figure 4-53) indicate that rare taxa did not occur in LO during the 2005-2006 sampling events. Gray and Pearson (1982) have suggested that taxa in the three to five abundance classes are most sensitive to pollution-induced changes (a way to select indicator taxa). Class 3 through 5 were also absent from LO.

The taxonomic composition, species richness, evenness of distribution, and diversity of LO sublittoral zone benthic invertebrate communities during the two sample periods of the 2005-06 study year were overall indicative of very poor water quality. Extreme dominance of the mud and sand habitat regions by three species of pollution tolerant Oligochaeta represents a pattern echoing the findings of Warren et al. (1995). The 2005-06 absence of many taxa that were present during the 1987-91 study period may signal poorer habitat conditions in the sublittoral zone. However, complete analyses of the additional data acquired during the remaining two years of the present study are required for a comprehensive evaluation of lake status.

Expectations are that as LO nutrient levels decline, in part due to CERP implementation and in part due to the various complimentary efforts to control P runoff, the extreme numerical dominance of pelagic zone invertebrate communities by segmented worms (Tubificidae) as previously documented (Warren et al. 1995) should be supplanted by a more diverse, balanced and sundry community. Increases in the relative abundance of less pollution-tolerant taxa (e.g., snails, crustaceans, mayflies, caddisflies) will signal a return to a less eutrophic, pollution-tolerant and more natural condition.
Conclusion

The macroinvertebrate community in LO has continued to reflect the eutrophic conditions that preceded initiation of benthic sampling. The range of variation in the lake’s macroinvertebrate community has continued to swing somewhere between moderate and poor. The macroinvertebrate community monitoring reflects that variability, but also continues to be dominated by pollution-tolerant taxa, reflecting the poor water quality in LO. Against this backdrop, there exists a high probability that improving water quality conditions within LO will result in a demonstrably improving benthic community. Such improvements in the macroinvertebrate community will foment positive effects on fisheries and the ecological health of LO as a whole.

4.10 Lake Okeechobee Module Conclusion

Summary

Although historic biological data (prior to c.a. 1985) for LO is patchy and often anecdotal, most of the existing evidence suggests that the lake has undergone rapid eutrophication over the past 60 to 80 years. Recently collected paleolimnological nutrient and algal data supports this pattern of recent change and suggests that increased nutrient loading to LO can be attributed to post-1950s anthropogenic watershed alterations (Engstrom et al. 2006). Thus, it is rather certain that LO has changed from a mesotrophic or mildly eutrophic lake in the early 1900s, to one which is currently highly eutrophic or hypereutrophic.

Prior to development of the watershed, LO was underlain by sand and peat sediments and by many accounts contained a clear water column. This water clarity permitted adequate light penetration to occur to deeper depths than seen today, and as a result LO quite probably supported very extensive beds of native submerged and emergent vegetation. This widespread aquatic plant community in turn sustained thriving forage and sport fish populations, which likely explained the popularity of LO with the pre-modern settlement population. Following the development of LO’s basin and nearly complete hydrologic alteration, LO has accumulated a large flocculent mud sediment zone, and has developed elevated nutrient concentrations, high turbidity, and periodic algal blooms. The submerged and emergent plant and fish communities are highly variable and dependent on widely fluctuating conditions, and have been supplanted to varying degree by invasive and exotic species. These changes have resulted from a combination of factors including restricted outflow capacity resulting from the construction of the HHD, a large input of terrigenous materials from the surrounding highly agricultural watershed, and prolonged excessively high and low lake stages. These severe fluctuations in lake stage reflect the interaction of climactic variability and LO’s role as the key water supply and flood control storage structure in south Florida.

A number of CERP and related non-CERP projects are currently underway in the watershed, to reduce nutrient influxes to LO and to improve lake hydrology. These projects consist of aquifer storage recovery wells, stormwater treatment areas (STAs) and water storage reservoirs. Additional projects such as dredging and chemical inactivation of the sediments are being contemplated to reduce LO’s internal nutrient load as a means of accelerating ecological improvements to the system, since internal loading may delay the ecological restoration of LO on the order of many decades. In any discussion of LO restoration, it must
be kept clearly in mind that due to LO’s central location in the south Florida aquatic ecosystem, failure to resolve its nutrient and hydrologic problems jeopardizes the restoration of the NE and the entire southern half of the Everglades ecosystem.

Currently, routine monitoring is in place for lake water quality and hydrology, submerged and emergent aquatic vegetation, fish, macroinvertebrates and phytoplankton. In addition, the littoral portion of LO is included in system level monitoring for wading birds and their prey species, and for the Everglades snail kite. A number of other research studies are ongoing which aim to elucidate key ecological relationships between various ecosystem components. At present, research and monitoring efforts on LO are probably sufficient to detect significant changes expected to be brought about by restoration activities. However, only a small proportion of these monitoring and research activities are funded by CERP, while the balance are either funded through other mandated or non-mandated SFWMD programs or are done for permit compliance. In either case, the availability of this necessary data is outside the direct control of RECOVER.

Lessons Learned

The single most important lesson learned in assembling the LO SSR is the wide range of variability encountered in each parameter monitored. While some of this variability can be clearly associated with known natural and man made major physical perturbations, much of it cannot. As such, it is becoming increasingly clear that extensive, long duration monitoring will be required to clearly identify the impacts of restoration activities within the noise of normal environmental variability. Even with CERP watershed projects in place, there will continue to be good years and bad years and the ability to detect system wide improvement may depend on the ability to identify changes in the relative frequency or magnitude of these good and bad years.

A corollary to this lesson may be that certain monitoring parameters, such as SAV and macroinvertebrates, may prove more responsive to environmental restoration than others, and it will be these parameters in which long-term efforts need to be concentrated. Similarly, as ongoing research continues to elucidate relationships between key environmental components, it may become possible to monitor fewer parameters without sacrificing assurances that the entire ecosystem is benefiting from restoration activities.

4.11 Status of Monitoring in the Lake Okeechobee Module

The following table provides an abbreviated status of monitoring in the LO Module. The table includes a list of monitoring components, links them to the associated hypothesis cluster(s) and PMs, and provides a brief description of the monitoring itself as well as its status. The table is not meant to be exhaustively comprehensive and represents the most current information to date when the table was developed.
### Table 4-4: Status of monitoring in the LO Module

<table>
<thead>
<tr>
<th>Lake Okeechobee Hypothesis Cluster</th>
<th>Related Monitoring Components</th>
<th>Performanc Measure</th>
<th>Description of Monitoring/Research</th>
<th>Status of Monitoring and Research</th>
</tr>
</thead>
</table>
| SAV                              | stage, WQ                    | Lake Okeechobee Vegetative Matrix | Monthly/quarterly biomass transect monitoring  
Annual 1km2 grid cell presence/absence abundance estimation | Ongoing since 1999  
Ongoing since summer 2000 |
| Littoral Zone Emergent Vegetation | stage, WQ                    | Lake Okeechobee Vegetative Matrix | Scirpus (bulrush) stem count density monitoring at nearshore sites on a quarterly basis. | Ongoing since June 2005 |
| Phytoplankton                    | WQ                           | Lake Okeechobee Vegetative Matrix | Samples collected from 4 long-term (>12 years) monitoring sites on a quarterly basis, taxonomic identification in progress. Also collect samples for taxonomic identification at 7 nearshore sites and 2 near municipal water intakes | Ongoing since 1994 |
| Exotic Vegetation                | stage, WQ                    | Lake Okeechobee Stage | various treatment methods are currently being evaluated for Panicum repens (torpedo grass) and Typha (cattail) | Ongoing since 1994 |
| Macroinvertebrates               | WQ, sediment quality, SAV    | Lake Okeechobee Macroinvertebrates | Bi-annual benthic monitoring is in progress at 18 pelagic and nearshore sites (6 in mud, 6 in peat and 6 in sand sediments | Three year monitoring project commenced in 2005 |
| Fish                             | Pelagic Zone Fish SAV, Littoral Zone Emergent Vegetation, Stage, WQ | Lake Okeechobee Fish | Synoptic pelagic and nearshore fish communities are being monitored at long-term FFWCC sites. Sampling occurs annually (summer)  
Abundance and distribution of pelagic and littoral fish communities are being evaluated with regard to vegetation type, density and water depth. Sampling occurs annually. | Three year monitoring for annual sampling commenced in 2005.  
Five year monitoring for SAV and emergent – associated fish communities commenced in 2006 |
| N/A                              | Stage, Littoral and Emergent Vegetation | Lake Okeechobee Amphibians and Reptiles | Abundance and distribution is being evaluated with regard to vegetation type, density, seasonality and water depth. Sampling occurs 2 X per year. | Five year monitoring for emergent –associated communities commenced in 2006 |
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4.13 Acknowledgements

The AT gratefully acknowledges the work of the authors Bruce Sharfstein, Therese East, Kim O’Dell, Greg Graves, Tom James, and Andrew Rodusky, the data freely provided by the LO Division of the SFWMD and the helpful reviews provided by various LO Division Staff Members.
4.13.1 Appendix 4A–MAP Metadata

All maps appearing in this document meet the standards and guidelines as defined in the CERP GIS SOP Manual. These maps are NOT to be used as Stand Alone Documents. To utilize a map as a stand alone hand out, please contact the map creator for additional map elements.

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Lake Okeechobee Landscape Units Boundaries
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  Map Created: March 26, 2007
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      CERP SDE; GISLIB.MIAMIDADE_BDJUR_MUNICIPAL

Lake Okeechobee Fish Collection Stations
  Map Author: Laura Biddison, CERP GIS Map Technician
  Map Updated: May 31, 2007
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      LO_FISH_COLLECT_05_06
    SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Lake Okeechobee Invertebrate Monitoring Stations
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SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Lake Okeechobee Phytoplankon and Cyanotoxin Monitoring Stations.
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: June 4, 2007
Map Location:
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LO_PHYTOPLANKTON
Cyanotoxin Monitoring Sites–CERP SDE; GISLIB.RECOVER_MONITORING;
LO_CYANOTOXIN
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Lake Okeechobee SAV Monitoring Stations
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: May 22, 2007
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LO_SAV_Transsect_Rodusky
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD
5.0 NORTHERN ESTUARIES MODULE

5.1 Brief Description, Background Information, and Figure for the Northern Estuaries Module

The NE module team is responsible for waters on both Florida coasts with the Caloosahatchee River and Estuary (CRE), San Carlos Bay and Estero Bay on the west coast and the St. Lucie Estuary (SLE), the Southern Indian River Lagoon (SIRL), the Loxahatchee River Estuary (LRE) and Lake Worth Lagoon (LWL) on the east coast (Figure 5-1). Detailed descriptions of these individual water bodies can be found in the 2006 SSR. Historically, natural freshwater discharges into these water bodies sustained an ecologically appropriate range of salinity conditions to facilitate the presence of healthy floral and faunal communities. The recent urbanization of Florida’s coastal regions and the ensuing increased demand for water and flood control has led to frequent high and low salinity extremes within the coastal water bodies. Managing for these demands has subsequently resulted in a shift in the ecological components that historically defined the coastal water bodies to communities that have been deemed less desirable. Current management goals under the CERP and other restoration activities are to develop strategies that will mitigate the impacts of historical water management practices by developing more realistic scenarios for controlling: 1) water levels for flood management, 2) the frequency and duration of water releases and consequent rapid salinity shifts, and 3) the introduction of the point and non-point pollutants. Implementation of projects to reach these goals will require a comprehensive approach of both CERP and non-CERP constructed storage and water quality features as well as restoration of natural wetlands and both urban and agricultural best management practices. Removal of anthropogenically produced mucky sediments in the water bodies will also be needed to achieve the water quality and clarity goals. These goals, if achieved, should curtail current habitat loss and allow the recovery of more desirable communities.
5.2 Northern Estuaries Hypothesis Cluster-Submerged Aquatic Vegetation

5.2.1 Abstract
Freshwater discharge influences SAV presence/absence, community structure, aerial extent and productivity by: (1) the timing of releases; (2) the quantity of water released; and (3) the quality of the water released. Alterations to freshwater flow into estuaries may have dramatic affects on SAV (Figure 5-2) over weeks, months, years and decades. Flows that are altered beyond historic conditions have negatively impacted SAV in the NE. For example, freshwater SAV such as *Vallisneria americana*, which was historically found in upper estuaries have been diminished or extirpated because of their inability to survive prolonged periods of elevated salinity that often results from diminished freshwater flow. Similarly, marine SAV species such as *Thalassia testudinum* and *Syringodium filiforme* are harmed by excessively low salinities and highly variable salinity regimes.

![Figure 5-2: A Simplified CEM Used to Illustrate the Complexity of the Relationship Between Freshwater Releases and the Response by SAV](image)

5.2.2 Background Description
The relationship between freshwater dynamics and SAV is complicated (Figure 5-3) with outcomes dependent upon the timing, quantity and quality of freshwater releases coupled with the salinity requirements of individual SAV species and their associated communities. Thus in addition to our primary hypothesis (see below), a series of sub-hypotheses have been developed for use in understanding the synergistic nature of water delivery and SAV populations, these can be found in the 2006 Assessment Strategy for the MAP (RECOVER, 2006a).

H1: Freshwater discharge rates affect SAV distribution and function
**Figure 5-3: CEM Used to Illustrate the Interactions Among Factors that May Be Controlled by Freshwater Releases and the Response to the Releases by SAV**

**Interim Goals:** The NE Module Interim Goal for SAV can be stated using three metrics:
1. Increase the areal extent of SAV where it has been lost
2. Improve the functionality of SAV
3. Restore the natural temporal and spatial dynamic of SAV

The strategy includes both predictions in SAV response to restoration activities and the corresponding monitoring and assessment of the SAV to evaluate the actual response of the SAV communities. This team will: (1) develop target conditions for SAV for each NE in five-year increments based on the most up to date restoration implementation schedule; (2) develop a predictive tool(s) with which to forecast changes in SAV distribution across a suite of spatial and temporal scales to both natural and anthropogenic stressors; (3) examine how SAV data and ancillary data are being collected across the NE; (4) develop a strategy to standardize the methodology currently being used (including temporal and spatial scales); (5) develop a standardized strategy for analyzing data; and (6) continue data collection and assessment under the obligation of these new criteria.
5.2.3 Methods and Analysis

Within each NE, an effort is underway to evaluate the dynamics of SAV over a large (landscape) scale. These efforts include the acquisition of aerial photographs that are photo-interpreted, ground-truthed and used to develop spatially explicit maps depicting SAV within each individual estuary. The common goal of these efforts is to identify areas of change (loss or gain) and those that are stable over time to gain a better understanding of dynamics at an estuarine scale.

In the CRE image acquisition is being conducted every two to five years (Figure 5-4). Because of the tannin color of the water in the river above its mouth, identifying SAV from aerial images in this area is not possible. To overcome this logistic difficulty, SFWMD began to collect scientific quality hydroacoustic data, which could be used to detect and monitor (i.e., percent cover, mean canopy height and edge of bed location) *Vallisneria americana* in the upper river and seagrasses in the lower region of the estuary. This effort was originally begun under contract with the Corps in 1996 and continued through 2004. These data continue to be collected tri-annually by SFWMD.

![SAV Areal Extent and Distribution in Charlotte Harbor](image)

**Figure 5-4:** SAV Areal Extent and Distribution in Charlotte Harbor as Delineated from 2006 Aerial Photographs
In both the SIRL and the lower SLE (downstream of the Roosevelt Bridge) aerial extent delineations from aerial photographs are available on a two to three year basis from 1986 to 2006 (Figure 5-5); 2006 data are currently being processed.

Figure 5-5: SAV Areal Extent and Distribution in the Southern Indian River Lagoon

A detailed SAV survey (based on intensive ground-truthing) of the SLE (Figure 5-6) was initially conducted in 1997 and another is planned for the summer of 2007. These data will be used to conduct a change analysis of SLE SAV over the period of record. A change analysis (1986 to 1999) has been completed for the SIRL and an initial review of the seagrass mapping data from 1999-2006 has been conducted for the section of the lagoon between the Stuart Causeway and St. Lucie Inlet (an area influenced by St. Lucie River discharges) (Table 5-1). Seagrass acreage in this section of the lagoon remained fairly stable from 1999 through 2003 (Figure 5-7). However, following the hurricanes of 2004 there was a decline in dense, continuous seagrass coverage and a slight increase in patchy seagrass coverage. Following Hurricane Wilma in 2005 (and associated LO discharges), the pattern continued. Consequently, from 2003 to 2006, there was a dramatic decline in the acreage of dense, continuous seagrass in this portion of the lagoon (Figure 5-7). Some of this acreage loss can be accounted for by a shift from dense to patchy seagrass.

Figure 5-6: 1997 SAV Groundtruth Stations in the St Lucie Estuary
Table 5-1: Southern Indian River Lagoon Seagrass Estimates by Year (1986–1999)  
(and Lagoon segment along with Target Acreage [Figure 5-8])

<table>
<thead>
<tr>
<th>Lagoon Segment Number</th>
<th>Total Seagrass Acreage Per Mapping Year</th>
<th>Target Acreage</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>2471</td>
<td>2435</td>
</tr>
<tr>
<td>23</td>
<td>3916</td>
<td>4815</td>
</tr>
<tr>
<td>24</td>
<td>1806</td>
<td>1279</td>
</tr>
<tr>
<td>25</td>
<td>Not Mapped</td>
<td>Not Mapped</td>
</tr>
<tr>
<td>26</td>
<td>Not Mapped</td>
<td>Not Mapped</td>
</tr>
<tr>
<td>TOTAL</td>
<td>8193</td>
<td>8529</td>
</tr>
</tbody>
</table>

Figure 5-7: Acreage of Seagrass for the Section of the Southern Indian River Lagoon Between the Stuart Causeway and St. Lucie Inlet (1999-2006)
While the maps created from aerial photographs are not species specific, field inspections indicate that many of the “no change” areas are dominated by shoal grass (*Halodule wrightii*). At least some of the areas of significant loss are known to have been dominated by manatee grass (*Syringodium filiforme*). Shoal grass is more tolerant of low salinities and salinity variation than manatee grass (Irlandi 2006), which helps explain its persistence.

To better help understand the observed seagrass acreage and distribution change, the SFWMD is planning to conduct a species specific mapping project in this area in the summer of 2007. Additionally, efforts will continue to complete a 1999-2006 seagrass change analysis for the entire SIRL.

SAV distribution, as interpreted from aerial photographs for LRE, is available for numerous years from 1981–2004 with a general change analysis having been conducted over these dates. The next mapping event is scheduled for summer 2007.
A similar LWL SAV mapping effort began in 2001 with a second set of photographs acquired in 2003. Following this, a schedule was developed to acquire aerial photographs every three to five years. The scheduled 2006 flight was postponed until 2007 because of weather factors. Following the acquisition of these images, a change analysis (2001 to 2007) will be conducted and coverage variability and targets will be refined. A seagrass target methodology has been developed for LWL and preliminary targets have been identified (Braun 2006). Seagrass distribution data from 2001 was evaluated by segment with the use of a digital elevation model. Substrate characteristics were modeled based on early sediment surveys (1970s) in conjunction with a muck sediment survey performed in 2003. As photosynthetically active radiation (PAR) distribution is mapped, the targets will be revised.

In situ SAV monitoring is estuary specific with dependent variables sampled (Table 5-2), spatial and temporal scales (Table 5-3), and methodologies (e.g., transects vs. random quadrats) differing among estuaries as well as among monitoring projects. However, each estuary has stations that are minimally sampled biannually (winter and summer) with the exceptions being SLE (stations monitored monthly) and LWL which is monitored annually.
Table 5-2: Data Used for the Assessment of the SAV Hypothesis Cluster

<table>
<thead>
<tr>
<th>Variables</th>
<th>Upper CRE</th>
<th>Lower CRE and San Carlos Bay</th>
<th>SLE</th>
<th>SIRL</th>
<th>LRE</th>
<th>LWL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAV spp presence/absence</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>SAV spp percent cover</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>SAV blade length</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canopy Height</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epiphyte Cover</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below ground biomass</td>
<td>x</td>
<td>x</td>
<td>.</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Shoot counts (field)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoot counts (lab)</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blade counts</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAV blade width</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Areal extent</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Epiphyte species</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep edge of bed</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio chl a:chl b</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tertiary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drift algae presence/absence</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drift algae percent cover</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Macroalgae spp presence/absence</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Macroalgae spp percent cover</td>
<td></td>
<td>x</td>
<td>x</td>
<td>(Caulerpa)</td>
<td>x (Caulerpa)</td>
<td>x</td>
</tr>
</tbody>
</table>

(Note: In the SLE and SIRL (x’) Caulerpa spp. are sampled.)
Table 5-3: Spatial (S) and Temporal (T) Sampling Scales for SAV Monitoring in the NE

<table>
<thead>
<tr>
<th>Variables</th>
<th>Upper CRE</th>
<th>Lower CRE</th>
<th>SLE</th>
<th>SIRL</th>
<th>LRE</th>
<th>LWL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>T</td>
<td>S</td>
<td>T</td>
<td>S</td>
<td>T</td>
</tr>
<tr>
<td>SAV spp presence/absence</td>
<td>3 sites</td>
<td>9 sites</td>
<td>Monthly</td>
<td>6 weeks</td>
<td>9 sites</td>
<td>5/6 weeks</td>
</tr>
<tr>
<td>SAV spp percent cover</td>
<td>3 sites</td>
<td>9 sites</td>
<td>Monthly</td>
<td>6 weeks</td>
<td>4 sites</td>
<td>9 sites</td>
</tr>
<tr>
<td>SAV blade length</td>
<td>3 sites</td>
<td>9 sites</td>
<td>Monthly</td>
<td>6 weeks</td>
<td>4 sites</td>
<td>9 sites</td>
</tr>
<tr>
<td>Canopy Height</td>
<td>3 sites</td>
<td>9 sites</td>
<td>Monthly</td>
<td>6 weeks</td>
<td>4 sites</td>
<td>9 sites</td>
</tr>
<tr>
<td>Epiphyte Cover</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below ground biomass</td>
<td>3 sites</td>
<td>9 sites</td>
<td>biannual</td>
<td>5/6 weeks</td>
<td>9 sites</td>
<td>5/6 weeks</td>
</tr>
<tr>
<td>Shoot counts (field)</td>
<td>3 sites</td>
<td>9 sites</td>
<td>Monthly</td>
<td>6 weeks</td>
<td>4 sites</td>
<td>9 sites</td>
</tr>
<tr>
<td>Shoot counts (lab)</td>
<td>3 sites</td>
<td></td>
<td>biannual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blade counts</td>
<td>3 sites</td>
<td>9 sites</td>
<td>Monthly</td>
<td>6 weeks</td>
<td>4 sites</td>
<td>9 sites</td>
</tr>
<tr>
<td>SAV blade width</td>
<td>3 sites</td>
<td></td>
<td>Monthly</td>
<td>4 sites</td>
<td>bimonthly</td>
<td></td>
</tr>
<tr>
<td>Areal extent</td>
<td></td>
<td></td>
<td>Estuary</td>
<td>2 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epiphyte species</td>
<td>Deep edge of bed</td>
<td>Ratio chl a:chl b</td>
<td>Tertiary</td>
<td>Drift algae presence/absence</td>
<td>Drift algae percent cover</td>
<td>Macroalgae spp presence/absence</td>
</tr>
<tr>
<td>------------------</td>
<td>------------------</td>
<td>------------------</td>
<td>----------</td>
<td>-----------------------------</td>
<td>---------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>Semi-annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>3 beds</td>
<td>Monthly</td>
<td>Annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>Semi-annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>3 beds</td>
<td>Monthly</td>
<td>Annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>Semi-annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>3 beds</td>
<td>Monthly</td>
<td>Annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>Semi-annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>3 beds</td>
<td>Monthly</td>
<td>Annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>Monthly</td>
<td>Semi-annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
<tr>
<td></td>
<td>3 beds</td>
<td>Monthly</td>
<td>Annual</td>
<td>3 beds</td>
<td>Monthly</td>
<td>Monthly</td>
</tr>
</tbody>
</table>
Biomass samples have been collected by Sanibel-Captiva Conservation Foundation (SCCF) since 2004 from the upper river sites, beginning in the fall of 2005 biomass samples were also collected from down river sites. Mote Marine Laboratory (MML) who also collects biomass samples, take no more than ten *V. americana* rosettes per up river site while using a 15.25 square centimeters (cm$^2$) core to a depth of approximately 25 centimeters for the collection of SAV biomass from the seagrass sites. In addition to SAV characteristics, all programs also collect data for a suite of independent variables (*Table 5-4*) and MML also samples a subset of their sites (n = 5) for fish and invertebrates (epibenthic and infaunal) with special interest in *Callinectes sapidus* (blue crab) and *Rangia cuneata* (common clam).

### Table 5-4: Independent Variables Being Sampled Within Each of the NE

<table>
<thead>
<tr>
<th>Variables</th>
<th>Upper CRE</th>
<th>Lower CRE and San Carlos Bay</th>
<th>SLE</th>
<th>SIRL</th>
<th>LRE</th>
<th>LWL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Temperature</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductivity</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DO</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secchi depth</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAR</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light spectra</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Transparency</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color (CDOM)</td>
<td>x</td>
<td>X</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
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<td></td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbicides/Pesticides</td>
<td>X</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>X</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>X</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH$_4$</td>
<td>X</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO$_4$</td>
<td>X</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For all NE descriptive summaries of dependent and independent variables using standard statistical techniques (e.g., multiple linear and/or stepwise regression analysis; *Table 5-5*) by species, by month, by season and by year will be carried out for future reports. Time series analyses examining annual time lags to optimize correlations of dependent variables in
relation to year for each independent variable will be conducted. Multivariate analyses (i.e., Principal Component Analysis (PCA), MDS, cluster analyses) of transformed and standardized dependent variables will be carried out using Bray-Curtis indices against transformed and standardized independent variables using Euclidean distance indices. Multiple Linear and Stepwise Regression models built to predict each dependent variable from all independent variables will be used. Data analysis will seek to determine sources of variation across spatial and temporal scales of measure. Also, analyses will seek to elucidate cause and effect relationships between dependent and independent variables (e.g., excessive salinity variation and declining seagrass biomass).
Table 5-5: Statistical Analysis Being Conducted on SAV Data Within Each of the NE

<table>
<thead>
<tr>
<th>Statistical Analysis</th>
<th>Statistic</th>
<th>CRE</th>
<th>SLE</th>
<th>SIRL</th>
<th>LRE</th>
<th>LWL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive</strong>&lt;br&gt;(dependent and independent variables by species, month, season and year)</td>
<td>Mean</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
</tr>
<tr>
<td><strong>Descriptive</strong>&lt;br&gt;(dependent and independent variables by species, month, season and year)</td>
<td>Range</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
</tr>
<tr>
<td><strong>Descriptive</strong>&lt;br&gt;(dependent and independent variables by species, month, season and year)</td>
<td>SD</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
</tr>
<tr>
<td><strong>Descriptive</strong>&lt;br&gt;(dependent and independent variables by species, month, season and year)</td>
<td>N</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>X</td>
</tr>
<tr>
<td><strong>Time Series Analysis</strong>&lt;br&gt;(optimize correlations of dependent variables in relation to year for each independent variable)</td>
<td>Annual Time Lags</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multivariate Analysis</strong>&lt;br&gt;(transformed and standardized dependent variables using Bray-Curtis indices against transformed and standardized independent variables using Euclidean distance indices)</td>
<td>Principle Component Analysis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multivariate Analysis</strong>&lt;br&gt;(transformed and standardized dependent variables using Bray-Curtis indices against transformed and standardized independent variables using Euclidean distance indices)</td>
<td>Multi-Dimensional Scaling</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Multivariate Analysis</strong>&lt;br&gt;(transformed and standardized dependent variables using Bray-Curtis indices against transformed and standardized independent variables using Euclidean distance indices)</td>
<td>Cluster Analysis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Regression Models</strong>&lt;br&gt;(built to predict each dependent variable from all independent variables)</td>
<td>Multiple Linear Regressions</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Regression Models</strong>&lt;br&gt;(built to predict each dependent variable from all independent variables)</td>
<td>Stepwise Regressions</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Correlation Analysis</strong>&lt;br&gt;(water quality, PAR and “healthy seagrasses”)</td>
<td>Spearman’s Rank Correlation</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Correlation Analysis</strong>&lt;br&gt;(water quality, PAR and “healthy seagrasses”)</td>
<td>Pearson’s Correlation</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Correlation Analysis</strong>&lt;br&gt;(water quality, PAR and “healthy seagrasses”)</td>
<td>Kendal’s Tau</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Analysis of Variance</strong>&lt;br&gt;(differences between sampling events)</td>
<td>One-Way ANOVA</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Analysis of Variance</strong>&lt;br&gt;(differences between sampling events)</td>
<td>Two-Way ANOVA</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>GIS Spatial Analysis</strong></td>
<td>SAV Distribution Change Analysis</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
5.2.4 Discussion

Historic reference conditions of NE SAV, either individually or as a unit, are difficult to assess because of the paucity of knowledge of these estuaries prior to the team’s sampling efforts. SAV distributions for some estuaries can be estimated, with appropriate caveats because of no groundtruthing, based on historical photographs if adequate aerial photographs are available. Alternatively, historic conditions may be estimated by developing distribution estimates based on data from other estuaries coupled with available historical environmental data. These data are being examined and where appropriate pooled, to establish natural SAV targets for a generic estuary. To achieve the requisite site-specific targets, the data pool needs to be based on a minimum of three years (generic life span of seagrass species in NE) of data from a specific estuary. Adequate substrate characterization and mapping of PAR distribution will be necessary to set targets. Pre-CERP reference conditions are based on the existing period of record of actual mapping and monitoring that has occurred prior to the implementation of CERP and is therefore different from both historic (pre-development) conditions and restoration targets. The pre-CERP reference is the reference from which positive change can be measured post CERP implementation.

Each of the NE includes mapping SAV through the acquisition of aerial photographs. These mapping exercises will be coupled with historical maps interpreted from aerial photographs. For example, SAV mapping efforts within the CRE include surveys conducted in 1945, 1982, 1999, 2004 and 2006 (Figure 5-4). From these efforts a SAV distribution target (i.e., the greatest value of a segment’s mean maximum depths) for the CRE has been set (based in part on data summarized by Corbett et al. 2005). This study included assessments of long-term trends in SAV distributions (northern Charlotte Harbor SAV is stable, while SAV in at least some parts of the CRE are in decline) based on the interpretation of aerial photographs.

Historical maps of SAV distribution in the SLE were compiled by Woodward Clyde (1999) but are limited to generalized estimates and cannot be construed as definitive. Compared to 1997 data (Woodward Clyde 1999) that documented sparse coverage of H. wrightii, Halophila johnsonii and H. engelmannii in the lower estuary (downstream of the A1A Bridge) with very sparse areas of Ruppia maritima, Vallisneria americana and Najas guadalupensis present in the South Fork, these historic accounts indicate that SAV beds were present in the North Fork, mid and lower estuary; with very sparse SAV present in the South Fork. Once CERP restoration efforts are implemented, expansion of SAV is expected. A preliminary depth target of one meter has been established for recovery of SAV in the SLE (URS Greiner Woodward Clyde, 1999). H. wrightii and R. maritima are the most likely species to recruit suitable substrate once CERP restoration projects are in place.

Evaluation of SIRL map data (1986 to 1999) suggests that <50% of the southern Indian River Lagoon’s potential seagrass habitat (< 1.7 m deep–based on seagrass light requirements and water quality parameters in SIRL; SWIM Plan) was covered by seagrass in any year (Robbins and Conrad, 2001), therefore it was posited that there was potential to increase seagrass areal extent within the SIRL. Of particular interest to CERP are the findings that: (1) the SLE had the greatest potential seagrass area available; (2) the evaluation of seagrass distribution data, as developed from the aerial photographs needs to be conducted by segment
(i.e., areas of relatively homogeneous water quality); and (3) significant changes in seagrass distribution can occur without net changes in seagrass areal extent—thus areal extent (acres or hectares) alone is not an appropriate target for CERP interests.

CERP targets for SAV need to be based on long-term monitoring data collected at a spatial and temporal scale that will allow a better understanding of SAV natural variability in the NE. Of particular interest is the influence of extreme weather events (e.g., hurricanes) on seagrass distribution. For example, prior to the 2004 and 2005 hurricane seasons, pre-CERP monitoring data led to an erroneous understanding of the effects of excessive freshwater discharges into the LRE on SAV. The impacts of three hurricanes (Jeanne, Frances, and Wilma) and one tropical storm (Ivan) during this time period altered the understanding of excessive freshwater discharges and it is expected that a new, more realistic conceptual model of SAV dynamics will be developed as the assessment of extreme events is taken into account.

The earliest seagrass survey for LWL was performed in 1940 (PBCERM and FDEP 1998) and determined that 4,271 acres of seagrass were present. In 1975, a resource inventory was performed and determined that only 161 acres of seagrass remained in LWL, representing a substantial loss of seagrass from 1940. The loss of seagrass was hypothesized to be linked to sewage disposal outfalls that directly discharged to Lake Wwotl Lagoon as well as degraded water quality. During the 1950s, an estimated ten million gallons per day (MGD) of raw sewage was discharged resulting in extensive bacterial and nutrient pollution. By 1970, seven major waste water treatment plants had been constructed, discharging 18.49 MGD of secondarily treated sewage effluent. The volume was reduced to 2.98 MGD by 1984, largely as a result of the NPDES program administered by the EPA (Palm Beach County Environmental Resources Management (PBCERM) and FDEP 1998). In 1990, a natural resource inventory was performed on LWL (PBCERM 1990) and included detailed in-water surveys which provided the most complete information to date. The survey indicated that there were 2,110 acres of seagrass; approximately half were lost when compared to the extent of seagrass in 1940. However, there was an increase of 1,945 acres when compared to results of the 1975 survey.

In 2001, true color aerial photographs were interpreted to determine the seagrass coverage in LWL. While this did not include extensive in situ ground truthing, the goal was to develop a methodology from which a baseline for future studies could be constructed. The north segment was determined to have the majority of seagrass, 1,134 acres followed by the south segment with 300 acres; and the central segment with 192 acres of seagrass. The total coverage was determined to be 1,626 acres of seagrass. Although the methods of analysis were markedly different for the 1990 and 2001 surveys, there appears to be a loss of seagrass coverage over an 11-year period. One possible explanation for the loss during the 1990s is that development increased rapidly in the watershed causing upland disturbance and increased stormwater discharge. This development led to increased eutrophication and release of sediments into the LWL which supported by water quality data for the time period.

Preliminary SAV targets (Table 5-6) based on the depth distribution of SAV and modeled substrate characteristics have been set for LWL and will be refined as improved substrate
characterization data as well as PAR data are collected and analyzed. While the north segment is not anticipated to be impacted by CERP, increases in cover of SAV beds is expected to areas that are less than 5.0 feet NGVD in the central segment and 4.0 feet NGVD in the south segment. The central segment has 729 acres of suitable habitat, of which only 192 is colonized by SAV. The south segment has 536 acres of suitable habitat, of which only 300 is colonized by SAV.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Target depth (NGVD)</th>
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</thead>
<tbody>
<tr>
<td>North</td>
<td>1.8  -6</td>
</tr>
<tr>
<td>Central</td>
<td>1.5  -5</td>
</tr>
<tr>
<td>South</td>
<td>1.2  -4</td>
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</tbody>
</table>

Large-scale (estuary-wide) SAV dynamics are being evaluated via the creation of temporal isopachs (change maps) within a GIS. For example, in the CRE a change analysis has been conducted between 2003 and 2004, and 2004 and 2006 to examine the dynamics of SAV distribution. Table 5-7 details percent change in SAV areal extent. The long term intent is to understand differences in areas that display change (loss and/or gain) in SAV and those that remain static through time so that management decisions can be more efficiently tailored to specific areas within an estuary. The example presented here indicates that the change that has occurred in these regions of Charlotte Harbor over the mapping interval is typically positive with the addition of SAV areal extent. Note that because of the dark color that typifies the water in the Caloosahatchee River, no SAV was detected during any mapping year (2003–2006); similarly, the change seen in the Caloosahatchee Estuary is also probably biased because of water color. The 43 percent increase in SAV within Estero Bay between 2003 and 2004 is also thought to be the result of water clarity differences between mapping years rather than actual improving SAV distribution. Understanding SAV dynamics at the spatial and temporal scales that SAV are mapped (i.e., SAV areal extent delineated through the interpretation of aerial photographs) will also allow the role of episodic (drought) and/or extreme (hurricanes) events to be more effectively studied and understood.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Estero Bay</td>
<td>43</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>Caloosahatchee River</td>
<td>-15</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>Matlacha Pass</td>
<td>9</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Pine Island Sound</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>San Carlos Bay</td>
<td>3</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Caloosahatchee Estuary</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Total &lt; Estero Bay</td>
<td>5</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

(includes Estero Bay)
Long-term NE SAV distribution dynamics are most likely driven by episodic events such as hurricanes and subsequently as with any large scale driving factor (e.g., CERP), sampling strategies must allow the appropriate spatial and temporal scales to be sampled. Preliminary data showed a negative impact to the 2004 hurricanes in the SIRL \((\text{Figure 5-7})\), the LRE \((\text{Figure 5-9})\), and LWL. Specifically, dramatic decreases (~24%) were seen in seagrass percent cover within the LRE following the 2004 hurricane season \((\text{Table 5-8})\); interestingly, the same response was not seen in the CRE \((\text{Table 5-7})\). Throughout the next 12 months of post-hurricane monitoring of \(S.\, filiforme\) in the LRE no appreciable recovery in occurrence was seen; however, during this same period the occurrence of \(Halophila\, johnsonii\), increased from <10 percent (immediately following the hurricanes) to > 60 percent (12 months post-hurricanes; Ridler et al., 2006).

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\hline
1 & 20.7 & 60.3 & 32.0 & 2.3 & 44.0 & 23.7 \\
2 & 30.0 & 9.3 & 22.0 & 7.0 & 23.7 & 13.0 \\
3 & 43.3 & 19.3 & 12.0 & 70.3 & 40.3 & 0.0 \\
4 & 14.0 & 20.3 & 60.7 & 25.0 & 46.0 & 0.0 \\
5 & 38.7 & 73.7 & 75.3 & 60.3 & 71.3 & 43.0 \\
6 & nd & 2.0 & 62.0 & 10.7 & 0.7 & 0.0 \\
8 & nd & 41.3 & 24.3 & 26.3 & 22.0 & 0.0 \\
9 & nd & 6.3 & 54.3 & 22.3 & 18.7 & 0.0 \\
10 & nd & 18.7 & 18.3 & 2.3 & 29.3 & 1.0 \\
\hline
Change & 7.3 & 12.2 & -14.9 & 7.7 & -23.9 & \\
\hline
\end{tabular}
\caption{Mean Percent Cover by Station in Lake Worth Lagoon from 2000–2005}
\end{table}

The last row reflects the percent change between mean percent cover values between successive years. Note the change between 2000 and 2001 does not include Stations 6–10, which were not sampled in 2000.
Monthly seagrass sampling show impacts following the hurricanes (dotted line) and associated excessive freshwater flows of September 2004. These data provide a fresh understanding of SAV resilience following a large, natural disturbance.

Additionally, a habitat suitability index (HSI) for *V. americana* (Mazzotti et al. 2006b) and seagrasses (Mazzotti et al. 2006a) has been developed for the CRE by University of Florida Institute of Food and Agricultural Sciences (IFAS) in cooperation with SFWMD, that may serve as a framework to evaluate long-term projections, based on changes to the current system. Other tools have been developed include a *Vallisneria* numerical model developed by SFWMD personnel (Hunt and Doering 2005), which was used in the development of a minimum flow level (MFL) in the CRE and a *Halodule* numerical growth model currently being developed (Hunt pers. comm.).
Conclusions and Key Findings
In addition to the team’s need to better understand the causal mechanisms that control SAV growth, is the need for CERP to understand the affect that the timing (duration and time of occurrence) of a freshwater discharge may have on SAV; specifically, changes in water quality must be accounted for with regard to controlling freshwater discharge in the NE. As stated previously, light attenuation and its influence on seagrasses have been well-studied; however, there is limited information available that shows how the timing of decreased water clarity (e.g., elevated turbidity events) might affect SAV health. For example, *Zostera marina*, a temperate SAV species, may or may not be negatively affect by decreased light availability depending on the timing of that event (Moore et al. 1997). Specifically, turbidity events that occurred during the early spring severely curtailed growth of *Z. marina* for the entire growing season. Light also appears to be a major factor controlling the depth distribution of seagrasses in the NE with turbidity and color (two major light attenuators) significantly affecting seagrass distributions. For example, elevated freshwater discharges into the SIRL from the SLE result in increased color and turbidity (hence increased light attenuation), which inhibits seagrass coverage especially at the deep edge of a bed (Crean et al. 2007). Managing the frequency and duration of freshwater discharges with relation to the species-specific physiological requirements of seagrasses should reduce light attenuation through a reduction in turbidity and color and thus relax this stressor on seagrass growth. Research examining this question is sorely needed if CERP is to minimize the affect of freshwater discharges on SAV. Research studies need to be designed and implemented to better understand the linkage between light attenuation, timing and SAV growth.

SAV salinity tolerances are also important environmental constraints for CERP to consider especially when setting desired flow levels in the NE. While many studies have been conducted with regard to SAV salinity tolerances their results are in many cases not definitive. For example, several studies have been designed and conducted to assess the salinity tolerances of *V. americana*. Unfortunately, conflicting results impede rather than increase the understanding of the relationship between this SAV species and salinity. Also, there is a paucity of information available as to whether and how other factors (e.g., light attenuation) might modify salinity tolerance. The timing of a salinity change is also an unknown quantity. However, a third factor regarding timing (duration and time of occurrence) needs to be addressed. Specifically, while current research may provide insight as to the range of salinities that SAV species may tolerate, little data are available that describes the response of SAV to rapid salinity changes, as might be the case when controlling freshwater discharges in the NE. Studies addressing this question need to be designed and implemented.

More research is also needed to better understand species-specific growth responses to the dynamics of freshwater discharge rates and timing, especially on different stages of plant development. For example, development of SAV growth models for additional species in the outer SLE, SIRL, LRE and LWL should be pursued. Specifically, *H. wrightii* and *Halophila johnsonii* near the mouth of the SLE are expected to expand if salinity and clarity conditions improve (i.e., less variable, fewer occurrences of fresh or near fresh water in that area). A model for *H. wrightii* is being developed for the SE and could potentially be expanded to fit the needs of the NE, which would assist in the further exploration of this possibility. The
other dominant seagrass that is expected to show improvements due to CERP implementation, especially projects that will decrease the size and frequency of large discharges is *S. filiforme*. Additional mesocosm and species-specific mapping, as well as increased monitoring for this species north and south of the St. Lucie River mouth in the SIRL would be needed in order to develop a predictive tool for *S. filiforme* expansion. The watershed, hydrodynamic salinity and the *Vallisneria* models need to be integrated. The watershed runoff model needs to be run at five-year intervals that will correspond to the South Florida Water Management Model (SFWMM) runs. Flows from the watershed can then be used in conjunction with S-7 flows supplied by the SFWMM in order to predict salinities at different locations in the river and estuary at five-year intervals. It is anticipated that data from the mass-based model will eventually be extrapolated to predict spatial coverage using GIS applications. Ultimately, the SAV model and GIS applications will be linked to hydrodynamic water quality models to refine predictions. Establishing linkages between water quality/quantity and SAV requires real-time *in situ* monitoring of key water quality parameters. A network of sampling units within the NE will be necessary in order to relate assessments to goals and targets.

**A thorough discussion of water quality issues in the NE can be found in Appendix 5A.**

5.3 Northern Estuaries Hypothesis Cluster—Oysters

5.3.1 Abstract

The Eastern Oyster is ecologically important because it improves water quality by filtering particles from the water. An individual oyster can filter 4-34 liters of water per hour, removing phytoplankton, particulate organic carbon, sediments, pollutants and microorganisms from the water column. Oyster bars provide habitat for numerous organisms and several studies have demonstrated the species richness of oyster bars (Wells 1961, Bahr and Lanier 1981). Oysters serve as an excellent indicator species because salinity conditions suitable for oysters also produce optimal conditions for a suite of other desirable estuarine organisms. In addition, given their sedentary nature, it is easy to make cause and effect relationships between the water quality and health of the organisms (hence their use in the International Mussel Watch Program and National Oceanic and Atmospheric Administration [NOAA] Status and Trends Program). Due to limited funding for monitoring, the oyster therefore makes an ideal candidate for a PM that can be used in all phases of AM. The oyster has been used by CERP project planners to help select the best alternative plan and it provides an interim goal by which restoration progress can be predicated and then monitored. The monitoring and assessment process can then feed back into operational decisions.

5.3.2 Background Description

Restoration of more natural freshwater inflows (retention in reservoirs and STAs, 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.
The working hypotheses for oysters in the NE are discussed in detail in the 2006 Assessment Strategy for the MAP (MAP, Part 2) (RECOVER, 2006a) and the 2006 SSR and are a result of a conceptual model (Figure 5-10) of stressors that impact oysters and thus oyster reef and secondary habitat. Predictions of oyster reef development following implementation of CERP are made by using a HSI model described in Volety et al. (2005).

### Data Used for Assessment

The main objective of this effort is to implement a long-term monitoring program for *Crassostrea virginica* in south Florida estuaries. Five aspects of oyster ecology are being monitored including spatial and size distribution patterns of adult oysters, reproduction and recruitment, juvenile oyster growth and survival, physiological condition (as measured by condition index [CI]) and the distribution and frequency patterns of the oyster diseases *Perkinsus marinus* (dermo) and (on the east coast only) *Haplosporidium nelsoni* (MSX).

![Figure 5-10: Conceptual Model of Stressors and/or Factors that Influence Oysters](image)

Boxes with dashed lines are not currently being measured. However, depending on the need and the model output, these factors may be included in the monitoring.

**Figure 5-10: Conceptual Model of Stressors and/or Factors that Influence Oysters**

### Adult Density

Density of living oysters appear to be higher among the west coast locations compared to the east coast locations (Figure 5-11). Results from all the estuaries suggest that while minor differences in living oyster density are apparent between winter and summer (Figure 5-11), the average density of living oysters is relatively constant (note smaller standard error bars).
The higher living densities during the dry season are a result of high recruitment of oyster spat (juveniles) at the end of the spawning season. However, during the subsequent months the juveniles and new recruits encounter mortality due to a combination of predation and salinity. Intra-annual variation in oyster abundance within each of the east coast study estuaries is relatively minor compared to among site and among year variations (Figure 5-11). In most cases, oyster abundance is higher at the end of the dry season than at the end of the wet season due to the abundance of first year animals during the fall survey period. It is expected that many of those small oysters will not survive to achieve maturity and contribute to future populations, so the dry season survey provides the best estimate of population status. Oyster abundance within each site, determined as an average of all sampling data, illustrates the large variation in oyster population density among study sites (Figure 5-11), but these data should be interpreted with caution because populations in the Sebastian and St. Lucie estuaries have rebounded strongly in response to reduced fresh water flows during 2006 and 2007 relative to 2005. As a result, oyster density in those estuaries is approaching that observed in the LRE and LWL.

![Graph showing adult oyster (Crassostrea virginica) densities within various South Florida Estuaries.](Figure 5-11: Adult Oyster (Crassostrea virginica) Densities (mean number m$^{-2}$ ± standard error [S.E.]) Within Various South Florida Estuaries)
The top figure compares average annual densities among the various study sites, the middle figure compares those densities between the wet and dry seasons, and the bottom figure compares the overall annual means between the east coast and west coast sites (note that east coast sampling was initiated in spring 2005) (Figure 5-11). All CR sites are within the Caloosahatchee River, with subsites IC = Iona Cove, CD = Cattle Dock, BI = Bird Island, KK = Kitchel Key, and TRB = Tarpon Bay. For the remaining sites, TB = Tampa Bay, ML = Mosquito Lagoon, SR = Sebastian River, SL-N = St. Lucie River North Fork, SL-C = St. Lucie River Central Estuary, SL-S = St. Lucie River South Fork, LS-N = Loxahatchee River Northwest Fork, LX-S = Loxahatchee River South Fork, LW = Lake Worth Lagoon, and BB = Biscayne Bay.

Reproduction, Reproductive Potential, and Recruitment

Histological analysis was used to examine gonadal state and reproductive potential of oysters from different sites during the study period. Gametogenic stage was identified under a microscope according to Fisher et al. (1996) and the International Mussel Watch Program (1980).

Although oysters at the upstream locations in the CRE had slightly higher gonadal indices, overall gonadal index values were relatively constant between sampling locations (Figure 5-12). Oysters in the CRE showed peak reproductive activity (as evidenced by higher gonadal index values) between May and October (Figure 5-12). These results corroborate the spat recruitment observed between June and November. Gonadal index values were relatively stable between sampling years (Figure 5-12), although it should be cautioned that the data for 2007 are incomplete. Data on gonadal development patterns of oysters from Tampa Bay and the east coast sites are not yet available.

Oyster spat recruitment varied between sampling locations, sampling months and sampling years in all the estuaries (P < 0.001). Recruitment was higher on the west coast estuaries compared to the east coast estuaries (Figure 5-13) and in higher salinity locations and estuaries. Recruitment rate within each estuary reflects adult abundance patterns; sites with relatively high adult densities receive similarly high numbers of recruits. That pattern may reflect the greater substrate availability provided by healthy oyster reefs coupled with the physical flushing effect of freshwater flows into the estuaries during the summer/fall months when oysters are spawning. However, it is not clear whether recruitment patterns are due to water quality conditions that support both adults and recruits or if it reflects a direct relationship between spawner abundance and availability of recruits. This distinction is important and can be better evaluated upon acquisition of a temporally lengthier data set. Spat recruitment in all the estuaries occurred between March–November, with peak recruitment occurring between June–November (Figure 5-13). Spat recruitment varied between years, possibly as a result of previous environmental history (e.g., fresh water release regime) with average values ranging from two-to-ten spat/shell/month at most sites (Figure 5-13).

Note that 2007 mean recruitment rates are derived from incomplete data that do not include the primary months of recruitment, so the reported values are biased downward.
Site abbreviations are as in Figure 5-11. Line colors correspond to the bars in the top figure. Data for Tampa Bay and east coast sites are not yet available.

**Figure 5-12**: Mean (± S.E.) Gonadal Index Averaged by Site (top), by Month (middle), and by Year (bottom) for Oysters (*Crassostrea virginica*) Sampled from the Caloosahatchee River.
Site abbreviations are as in Figure 5-11. Data are presented as the overall mean (± S.E.) within each site (top), as the mean (± S.E.) for each month averaged over all years (middle), and as the mean (± S.E.) within each year averaged over all months (bottom). Line colors correspond to the bars in the top figure.

Figure 5-13: Mean Recruitment to Artificial Collectors for Oysters (*Crassostrea virginica*) Sampled from Various South Florida Estuaries
Juvenile Growth Monitoring

Juvenile oysters were planted at all stations to monitor growth and mortality. The juveniles were cultured from parent broodstock collected from the local estuary, or collected from natural stock in the wild. At the east coast sites during 2005 and in the CRE, offspring were raised to a size of 10-20 mm, and then transported to their respective field sites for planting. Juvenile oysters were not available for planting at the Sebastian River site during 2005, and all juvenile oysters planted at the SLE site during 2005 quickly died. At the east coast sites during 2006, juvenile oysters were planted at a size of 2-5 mm in an effort to obtain a better understanding of growth and survival patterns for the smallest possible size class.

Juvenile growth and mortality data are being analyzed using a nested multi-factorial model. For the growth rate analysis, the 30-50 individual size measurements are nested within cage treatment (open or closed), which is nested within station and analyzed by site and year. For the survival data, there is only a single data point (rather than 30 replicates) within the cage treatment, but the statistical approach is otherwise the same. Obviously, statistical power will be considerably less for the mortality than the growth study, but logistical constraints prevent the application of multiple replicate cages at each station.

In the CRE, oysters were deployed at the sampling locations during each study year. Results clearly indicated that juvenile oyster growth responds directly to freshwater releases and resultant salinity prevailing at each location. A representative growth profile of juvenile oysters is presented for elucidating general trends (Figure 5-14). Typically, due to watershed runoff and freshwater releases from LO, low salinities (< 10 parts per thousand [ppt]) prevail in the upper portion of the estuarine region in the CRE during the late summer/fall months. When juvenile oysters were deployed post-freshwater releases/watershed flows, oysters at the upstream portions where estuarine salinities prevail showed the highest growth rate compared to other downstream locations. Most downstream locations, despite receiving the highest spat recruitment, showed poor survival and growth due to higher salinities (> 35 ppt) and diseases and predators that dominate those high salinity regions.

Growth of juvenile oysters varied substantially among the Tampa Bay and east coast sites. During 2005, juvenile oysters grew most rapidly in the south fork of the LRE and most slowly in LWL. A similar pattern was observed during 2006, except that the fastest growing oysters were recorded from the Sebastian River and St. Lucie South sites, neither of which were planted during the 2005 study. Overall, growth rates were remarkably rapid and most juvenile oysters planted achieved a shell height of at least 45 mm within a year.
Figure 5-14: Shell Height of Juvenile Oysters Deployed Within Cages at Various Sampling Locations

Shell height (mean ± S.E.) of juvenile oysters deployed within cages at various sampling locations (top) on the east coast during 2005-2006, (middle) on the east coast during 2006-2007, and (bottom) along a salinity gradient in the CRE during 2006-2007. Results are the means of 50 randomly selected oysters from each location every month.
Condition Index
CI, a ratio of meat weight to shell weight, significantly varied between sampling locations, sampling months and sampling years in all the estuaries and sampling locations (Figure 5-15). For all estuaries, the overall mean CI ranged between 2.5 and 4 (Figure 5-15). The decrease in CI in oysters during March–June is probably a result of spawning activity, where shedding of gametes results in loss of tissue and hence a decrease in CI. Oysters start to accumulate energy reserves and tissue mass during the cooler winter months, and thus increase in the cooler winter months (Figure 5-15). Variation in CI between years is a result of environmental history (salinity, flow changes, hurricanes) during the year (Figure 5-15).

Disease Monitoring
Oysters were collected monthly for the analysis of gonadal condition and for the prevalence and intensity of the oyster diseases Perkinsus marinus (Dermo) and Haplosporidium nelsoni (MSX). Note that MSX has only recently been described from Gulf of Mexico waters (Ulrich et al. 2007) so monitoring for that parasite at west Florida sites is not included in the present sampling regime.

Disease intensity (scale 0–5; Figure 5-16) and prevalence (percent infected oysters; 0-100 percent; Figure 5-17) of Perkinsus marinus varied significantly between sampling stations, sampling months and sampling years (P < 0.001) in all the estuaries. Overall, disease intensity and prevalence were higher in higher salinity areas and also higher on the west coast of Florida sites compared to the east coast locations (Figure 5-16 and Figure 5-17). Higher salinities and temperatures favor parasite development and proliferation. Given the interaction of temperature and salinity cycles in southwest and southeast Florida estuaries, no distinct seasonal patterns of disease prevalence and intensity were discernable (Figure 5-16 and Figure 5-17). Although mean prevalence at all the sampling locations ranged between 0–90 percent, mean intensity at all sampling locations averaged was between 0 and 1.5 percent, an overall light infection. The antagonistic effects of high temperatures and low salinities in warmer months and of high salinities and lower temperatures during winter months keep disease intensity and prevalence of P. marinus in oysters at low levels in southwest and southeast Florida estuaries (Volety et al. 2003). Perkinsus marinus intensity and prevalence appear to be increasing over the past five years (Figure 5-16 and Figure 5-17), however it should be cautioned that the overall level of infection remains relatively low (< 1.5 percent).

As noted above, the oyster disease MSX has only recently been recorded from oysters inhabiting Gulf of Mexico estuaries (Ulrich et al. 2007) but a monitoring program has not been initiated. Data for MSX in east coast estuaries is not yet available, although preliminary analyses suggest that this disease will be rare in oysters collected from all Florida estuaries.
Site abbreviations are as in Figure 5-11. Data are presented as the overall mean (+ S.E.) within each site (top), as the mean (+ S.E.) for each month averaged over all years (middle), and as the mean (+ S.E.) within each year averaged over all months (bottom). Line colors correspond to the bars in the top figure.

Figure 5-15: Mean Condition Index for Oysters (Crassostrea virginica) Sampled From Various South Florida Estuaries
Site abbreviations are as in Figure 5-11. Data are presented as the overall mean (± S.E.) within each site (top), as the mean (± S.E.) for each month averaged over all years (middle), and as the mean (± S.E.) within each year averaged over all months (bottom). Line colors correspond to the bars in the top figure.

**Figure 5-16: Mean Intensity of Perkinsus marinus (“dermo”) for Oysters (Crassostrea virginica) Sampled from Various South Florida Estuaries**
Site abbreviations are as in Figure 5-11. Data are presented as the overall mean (± S.E.) within each site (top), as the mean (± S.E.) for each month averaged over all years (middle), and as the mean (± S.E.) within each year averaged over all months (bottom). Line colors correspond to the bars in the top figure.

Figure 5-17: Mean Prevalence of *Perkinsus marinus* (“dermo”) for Oysters (*Crassostrea virginica*) Sampled from Various South Florida Estuaries
Water Quality Monitoring
Monthly water quality sampling was conducted in conjunction with field sampling at each study site. Parameters monitored included temperature, salinity, conductivity, pH and DO. Typically, salinities are lower due to rainfall and/or releases from LO and watershed runoff during the summer months when the water temperatures tend to be higher. In the winter months when water temperatures are lower, salinities are higher (results not shown). Since freshwater inflow and salinity data were available in the CRE from 2000–2007, the relationship between freshwater inflows and salinities in that estuary were determined using logarithmic regression. Results indicated a significant relation between flows and salinity at various points along the estuarine axis (53-74 percent; Figure 5-18).

Figure 5-18: Relationship between Freshwater inflows from S-79 Lake and Dam into the CRE and Salinities at Various Locations Along the Estuarine Axis

Flows below 3,500 cfs will result in salinities > 10 ppt at all locations. Abbreviations are as in Figure 5-11, with IC being the most upstream and TRB the most downstream of the sites.

A baseline for oysters in each estuary is being established by mapping the existing distribution of reefs and the mean density of living oysters on each bed. Historical distributions, where available, are being used to assist in identifying areas that may have suitable habitat conditions for reestablishment, given predicted changes in the salinity regime. At five-year intervals during CERP implementation, a map of oyster reefs within the various study sites and including size distribution, density of living oysters, and height of the oyster reef (when possible) will be prepared.

**A thorough discussion of water quality issues in the NE can be found in Appendix 5A.**
5.3.3 Methods and Analysis
For comparisons among sites, a multivariate analysis of variance was employed. In the CRE, given the longer period of data collection, a three-way analysis of variance is used to determine the differences in disease intensity, condition index, spat recruitment due to main effects—sampling site, sampling month and sampling year. Given the sample size (see above for detailed information) and sampling frequency (once a month), the design will detect a change in mean oyster abundance that is +/- 1–1.5 sd. For example, that sampling intensity will allow the detection of a true change in the density of oysters that is one and a half times the standard deviation of oyster density at that site, with a 95 percent probability of detecting a true change when that change occurs (equivalent to a five percent likelihood of a Type I error). Of equal or greater importance (Underwood and Chapman, 2003), the probability of making a Type II error (no change in density is detected when one has actually occurred) will be less than 20 percent for a change that is one and a half times the standard deviation and will be less than five percent for a change that is two times the standard deviation. Thus, if a substantial change in oyster density occurs at any of these sites, ostensibly in response to CERP water management activities, there will be a very high likelihood of detecting that change. Replicate reefs/sampling locations will be nested within each site and recruit density will be compared among sites and among months. At the level of site and month, this will provide nine replicate estimates of recruit density each month for each of ten sites, equivalent to a statistical power exceeding 0.80 when analyzing at an alpha of 0.05. However, since the data set used in the current analyses is only for baseline determination of spatial and temporal variation of oyster responses, no changes due to CERP are being analyzed at this point in time.

5.3.4 Discussion
Current State of Oyster Reefs
Surveys performed in 2004 and 2005 indicate that there are 18 acres of live oyster bars in the CRE (Figure 5-19), 117 acres in the SLE (Figure 5-20), ten acres in the LRE (Figure 5-21), approximately 18 acres in LWL (Figure 5-22), and no oyster reefs in Biscayne Bay. A detailed description of oyster locations is provided in Table 5-9.
### Table 5-9: Current Location of Oyster Habitat in the Northern Estuaries

<table>
<thead>
<tr>
<th>Estuary</th>
<th>Existing Oyster Acres</th>
<th>Restoration Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLE</td>
<td>208 (1997) 117 (2003)</td>
<td>834 acres live oyster habitat with SIRL plan; includes, reservoirs, wetland rehydration, STAs, muck removal, and addition of artificial substrate + LO improvements and aquifer storage and recovery (ASR)</td>
</tr>
<tr>
<td>CRE</td>
<td>18 (2004)</td>
<td>100 acres of live oyster habitat with C-43 Reservoir, LO improvements + ASR 500 acres of live oyster habitat with the above + addition of artificial substrate</td>
</tr>
<tr>
<td>LRE</td>
<td>10 (2003)</td>
<td>No degradation of existing total acreage to be achieved by addition of substrate to move oyster habitat zone to mitigate for potential losses that are predicted to occur under restorative flow scenarios</td>
</tr>
<tr>
<td>LWL</td>
<td>18 (2005)</td>
<td>Under development</td>
</tr>
<tr>
<td>Biscayne Bay</td>
<td>0 (2005)</td>
<td>Under development</td>
</tr>
</tbody>
</table>
Figure 5-19: Existing Oyster Habitat in the CRE

Potential habitat may be realized upon adjusting freshwater inflows.

Figure 5-20: Current and Potential Oyster Habitat in the SLE
Figure 5-21: Existing Oyster Habitat in the LRE
Figure 5-22: Existing Oyster Habitat in LWL
Description of Analyses Framework for Assessing Change

Since the current data is only from pre-CERP conditions, this data set only provides a baseline value of oyster heath and abundance. These results will be used in the analyses to detect the change in direction and magnitude of change when post-CERP related responses are available. Based on statistical analyses of current data, any change > mean +/- 1.5 SD can be accurately measured. Trends that would be of interest include: increase in the density of living oysters m\(^{-2}\) compared to existing conditions; increase in CI, juvenile growth, extent of oyster reef coverage, spat recruitment and decrease or maintenance of disease prevalence and intensity of *Perkinsus marinus* (Figure 5-16 and Figure 5-17). These changes will be correlated to changes in water management due to CERP implementation. Changes in volume, timing and location of flows and their relationship to estuarine salinity conditions will be the key driver/indicator relationship analyzed. Other water quality parameters will be taken into consideration as ancillary data. If over time it is determined that food may be a limiting factor further phytoplankton monitoring may need to be added to the program. In future years more real-time water quality monitoring will be used in the NE to complement the biological monitoring and provide a more meaningful temporal data set to complement the biological indicators being monitored. In addition, a HSI model that has been developed for the CRE will be used as a framework for both predicting and assessing change over time. New monitoring data can be used to develop and calibrate similar HSI models for the other estuarine water bodies.

Measuring Change from the Pre-CERP Condition

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 reestablishment of healthy oyster beds.

**Caloosahatchee River Estuary**

With changes in freshwater inflows (500-3,500 cfs) into the CRE resulting from the construction of the CERP, it is anticipated that salinities in the riverine portion (north of Shell Point) of the CRE would increase. This would result in estuarine salinities > 10 ppt that are suitable for the growth and enhancement of oyster reefs in areas north of Shell Point. Given the shift in the estuarine locus in the estuary, it is expected that the epicenter of oyster reef development in the CRE would shift from south to north of Shell Point. It is anticipated that there will be a five-fold increase (~100 acres) in oyster reef coverage in the next ten to 15 years, with an annual increase of ~10 to 20 percent. It is expected that ~40 acres of reefs will develop north of Shell Point while 60 acres of oyster reefs will develop in San Carlos Bay.

The CRE lacks hard substrate suitable for larval settlement and hence growth of oyster reefs. With the placement of shell substrate and creation of reef material equaling 100–150 acres in strategic places, reef growth is expected to accelerate, forming ~400 to 500 acres of oyster reefs in about 15 years. Of these reefs, it is anticipated that ~200 to 300 acres will be north of Shell Point while 150 to 200 acres of oyster reefs will be in San Carlos Bay (south of Shell Point).
St. Lucie Estuary
Based on the analyses of the SLE approximately 890 acres of oysters are predicted to occur once the proposed flow regime of 350 to 2000 cfs is established. Oysters are predicted to occur in the middle estuary from the Roosevelt Bridge downstream to the A1A Bridge (Figure 5-20).

Oyster sampling in the North and South Forks of the SLE indicates significant changes in oyster bed growth and composition since the initial 1997 assessment. Results reported in URS Greiner Woodward Clyde (1999) indicate the average density of live oysters in the upper estuary to be approximately one oyster per m of substrate. Although the density was low, the beds were live and functioning. Field work for the 2003 study produced no sign of live oysters in either the North or South Forks of the estuary. While live aerial coverage in these areas fell from one to five percent in 1997 to zero (0) percent in 2003, the size of relic oyster shell in the beds increased from less than five centimeters in 1997 to an average of five to ten centimeters and some larger than ten centimeters in 2003. Dead oyster density in these reaches also increased in some beds to more than twice the amount of live coverage that was lost. Total acreage of functioning oyster beds in the North and South Forks fell from the reported 1997 figures despite the discovery of new beds and increased shell density.

The presence of new beds and larger oyster shell size in the North and South Forks indicates successful productivity for the oysters at some time between the 1997 study and 2003 (URS Greiner Woodward Clyde, 1999). Reproduction and death of oysters in beds ultimately results in changes in bed area (acreage). When comparing the 1997 and 2003 studies, the difference in bed sizes of an acre or more may be attributed to loss of oysters. However, minor size changes of less than an acre in some beds may be a result of difficulties determining the exact limits of each bed. Poor water clarity in the SLE prevents visual confirmation of the bed boundaries. Most importantly, the acreage of live beds in the estuary contributes to the ecological function of oysters in the estuary system. Results from the 1997 study reflect only one small dead oyster bed located in the southern reach of the estuary. Loss of live beds since 1997 has resulted in an overwhelming loss of functioning oyster bed acreage (Table 5-10).

<table>
<thead>
<tr>
<th>SLE Reach</th>
<th>#Live Beds 1997</th>
<th>#Live Beds 2003</th>
<th>Acreage Beds 1997*</th>
<th>Live Beds 2003</th>
<th>Acreage Loss (ac.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle</td>
<td>11</td>
<td>11 of 13</td>
<td>149.7</td>
<td>116.9</td>
<td>-32.8</td>
</tr>
<tr>
<td>North</td>
<td>7</td>
<td>0 of 9</td>
<td>34.4</td>
<td>0</td>
<td>-34.4</td>
</tr>
<tr>
<td>South</td>
<td>10</td>
<td>0 of 10</td>
<td>23.4</td>
<td>0</td>
<td>-23.4</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>11</td>
<td>207.5</td>
<td>116.9</td>
<td>-90.6</td>
</tr>
</tbody>
</table>

* Acreages obtained from URS Greiner Woodward Clyde 1999 page 5-5.
Loxahatchee River Estuary
LRE oyster reefs grow mostly in intertidal and shallow subtidal areas (Figure 5-21). Oysters also grow on rip-rap, seawalls and bridge piers. Islands upstream of the Northwest Fork River delta (river mile [RM] 4) are fringed with oysters growing on red mangrove roots. Reefs grow as point bars, usually on the downstream ends of the mangrove islands. In 1990, reefs were present in the southwest and northwest Forks but were rare in the North Fork. Reefs in the central embayment are small, contain mostly relict shells, and are associated with shoals, point-bars and mangrove islands (Law Environmental, Inc. 1991).

Field observations in the LRE (Law Environmental, Inc. 1991) revealed oysters were smallest at upstream and downstream locations and largest in the central part of their range (Figure 5-21). In the Northwest Fork, the largest living oysters (standard length 80 to 90 millimeters) occurred between RMs 4.0 and 6.0, where average high tide surface salinities were between 7 and 22 ppt, and ranged from about 2 to 28 ppt. The river delta (S-Bar) located at approximately RM 4.5, played a controlling role in upriver salinities and was the most active oyster ground (Law Environmental, Inc. 1991).

The base case for oyster populations was documented in a mapping effort by the Loxahatchee River District under contract with the SFWMD in 2003 (WildPine Ecological Laboratory, 2004). The live oyster reefs were defined as areas having at least five live oysters m$^{-2}$. The area of concern for that document was between RM 4.0 to RM 6.0, and 9.6 acres of oysters were mapped. The density of live and recently dead oysters as well as their length was determined from four sample locations in the northwest fork. The majority of oysters (76 percent) were <5 centimeters in length, 23 percent were between five and ten centimeters and only two percent were greater than ten centimeters. The highest density and largest area of reefs occurred at RM 4.5. Density decreased upstream.

As part of the Loxahatchee Restoration Plan (SFWMD and FDEP, 2006) the distribution and abundance of oysters in relation to salinity was determined for the northwest Fork under different restoration flow scenarios. The oyster model predicted that under the preferred restoration flow scenario, the suitable salinity environment would move downstream with a minimum impact on the majority of the existing oyster beds. However, mitigation for oyster beds lost in the most upstream locations (~ RM 5.4–6.0) could be addressed by providing additional substrate in downstream locations predicted to have the most conducive salinity ranges under a restoration flow.

Lake Worth Lagoon
A 1990 survey of LWL found oyster bars in the vicinity of John D. MacArthur State Park, near the Bingham Islands and at the north end of Hypoluxo Island.

However in 2004, the majority of oysters were encrusting in dock pilings and seawalls (Ben Harkanson, PBDERM, electronic mail, August 18, 2004). They were found in a very defined and narrow band of about a foot and a half (vertical distance) on these surfaces. This band begins about one foot below the high tide line and extends to roughly the low tide line. Oysters were found encrusting in this manner from approximately Southern Boulevard south to the Boynton Inlet, with the densest concentrations centered around the mouth of the C-51
Canal. Outside of this area, in areas of increased salinity, oysters are gradually displaced by barnacles as encrusting organisms. North of Southern Boulevard, oysters were almost completely absent from dock pilings and seawalls. Oysters found within this zone of the central lagoon tend to have dark, discolored shells and exhibit high mortality (about one live oyster for every ten shells).

North of the Palm Beach inlet, unattached clusters of oysters were found in the shallows around Munyon Island. These specimens are quite different from those found further south in the lagoon. The oysters examined from the upper lagoon tend to have white and pink/purple shells with much higher vitality (close to ten live oysters for every ten shells examined).

It is anticipated that with CERP-related salinity and water quality changes, spat recruitment, growth of juvenile oysters, living densities and CI should increase and disease intensity will remain at the same levels or slightly increase. This however can be mitigated by releasing freshwater during times of higher temperatures. With the sampling design and protocols in place, it is anticipated that accurate determination of the direction and magnitude of change in the PM metrics will be available. Depending on the frequency and magnitude of episodic events such as hurricanes, and higher than anticipated freshwater releases from LO, the living densities and oyster responses may decrease to unfavorable levels in the short term, but is unlikely since the half-life of such low salinity waters is expected to be in days, not weeks which would be detrimental to sedentary benthic organisms such as oysters.

Key Findings and Conclusions
A significant relationship exists between freshwater inflows and salinities at various points in the CRE. Flows below 3,500 cfs into the estuary from S-79 will result in salinity regime that will enable oysters to survive and grow. Disease prevalence was lower at upstream locations and increased with distance downstream, suggesting that higher salinities result in increased disease incidence. Limited freshwater releases for durations of less than two weeks will result in lower disease prevalence and intensity of oysters and higher survival. Oysters in the CRE appear to spawn actively between May–October, a period that coincides with freshwater releases and or watershed runoff. While downstream locations attract higher spat recruitment due to higher substrate availability and estuarine conditions during high flow summer-fall months, growth and survival of juveniles is poor. Limiting freshwater releases to < 3,500 cfs during these months will limit flushing of oyster larvae to downstream locations and create a favorable salinity regime for spat recruitment and survival. Low disease incidence, high CI, sufficient spat recruitment and high growth rate at the upstream locations (e.g., Iona Cove) suggest that with the provision of suitable substrate and limiting freshwater flows during the spawning season, oyster reefs will survive and grow at the upstream locations. With the implementation of CERP projects and reduction in the freshwater flows, it is anticipated that the focus of oyster reef development will be shifted upstream compared to current locations. In the coming years with continued monitoring of oyster responses from other estuaries, similar conclusions can be drawn.

Some refinements in the monitoring program, development of predictive tools and further knowledge of all factors effecting the reestablishment, health and long-term survival of the
oyster communities are needed. Major conclusions and recommendations are discussed below. There appears to be no need at this time to revise any of the oyster hypotheses, but some gaps in knowledge, such as the affect of contaminants on oysters, need to be studied.

While the existing sampling design and sampling frequency can adequately assess the direction and magnitude of change in the PMs, the sampling protocol may be adjusted to better capture the spatial variation of responses. Since the second full year of sampling has only recently been completed for the east coast estuaries, seasonal trends will need to be examined before any adjustments are made. For example, if the salinity regime in two stations is too close, the location of the stations may be adjusted to capture the range of salinities that would influence the oyster responses.

Analyses of reproduction are currently performed using histological techniques. Such techniques are time-consuming, expensive and require specific expertise limiting the number of samples that can be analyzed. Newer techniques such as enzyme linked immunosorbant assays that use antibodies against egg protein of eastern oysters are now being developed. These techniques will greatly enhance the sample processing and increase the sample size.

While the water quality (i.e., temperature, salinity, and DO) are being measured at the sampling site during each sampling event (once a month), a more frequent sampling is required to capture episodic events. An attempt is being made to assess the predation pressure in the east coast estuaries, but this parameter is not being assessed in the CRE. Given that predation pressure is significant in some locations, such information is necessary and will enhance the HSI model by strengthening the predictability of potential suitable habitat.

The PM for living oyster densities is being assessed, but a plan to map the extent of oyster reef development (spatial coverage in acres) needs to be developed and implemented. Extent of oyster coverage is described as an interim goal, thus oyster mapping should be conducted on a five-year schedule that corresponds to the interim goal schedule.

Oyster reefs occupying the various estuaries in southeast Florida are not isolated entities but are instead linked to one another via exchange of larvae. Each reef is linked to other reefs to a greater or lesser degree depending upon distance, hydrodynamics and environmental factors that promote or defeat the survival and growth of the larvae. Previous studies (Hare and Avise, 1996) clearly indicate that, based upon variations in genetic structure among southeast Florida oyster populations, larval exchange is spatially structured. It is probable that temporal variation in larval exchange also characterizes these populations. An understanding of larval exchange is a necessary precursor to the proper management of oyster reefs in Florida because that information will reveal those oyster reefs that act as larval sources and are therefore fundamental to the long-term survival of oyster populations in Florida waters. At present, the needed genetic and hydrodynamic information to define those linkages is not available.
5.4 **Northern Estuaries Hypothesis Cluster–Benthic Macroinvertebrates**

### 5.4.1 Abstract

The benthic infauna has been quantitatively monitored quarterly since February 2005 at 13 sites in the SLE and the SIRL following EPA and International Council for the Exploration of the Sea (ICES) standards. Measurements of a number of environmental variables have also been made; including sediment, water content, organic content, color, type, structure, and firmness, oxygen profiles, surface and bottom water temperature, salinity, oxygen, pH, surface water turbidity (NTU) and Secchi depth.

The short term monitoring data indicate that primarily the SLE is ecologically degraded. Especially serious conditions exist in the South Fork, and also in the middle St. Lucie Estuary basin, which receives the frequent freshwater discharges from the C-44 canal. The data also indicate that the narrow Hell’s gate may be designated as a transition zone, and the conditions beyond here improve dramatically. The data do not indicate that the C-25 canal (Taylor Creek) has any significant negative impact on the adjacent SIRL system.

In spite of the short monitoring period, it is obvious that the benthic communities respond quickly to environmental changes and that they reflect changes in discrete zones within the monitored areas in the SLE and SIRL.

### 5.4.2 Background Description

Benthic fauna are important indicators of water quality and are used in a variety of monitoring programs to assess overall estuarine health and to follow long-term trends in estuarine communities related to anthropogenic impacts. From a monitoring perspective, the infaunal communities in the SLE and SIRL offer several positive attributes: they are relatively sedentary and long-lived, they occupy an important intermediate trophic position, and they respond differently to varying environmental conditions. By examining shifts in the benthic community over time, it is possible to obtain an understanding of the major environmental processes affecting the local biota. Moreover, the benthic monitoring program in the SLE and in the SIRL is able to capture discrete zones within these estuarine systems and rapidly identify and predict responses to environmental changes.

Data collected between 2005 and 2007, as well as previous studies (Haunert and Startzman 1985; Rudolph 1990; Schropp 1994; Graves and Strom 1995; Graves et al. 2002), indicate that large areas of the SLE display low diversity and high numbers of pollution tolerant, opportunistic taxa (r-strategists). This current, or worsening, state is driven by three major stressors. These stressors are illustrated in the benthic macroinvertebrate CEM (*Figure 5-23*).

1. Irregular and extreme shifts in salinity in the SLE. These shifts prevent the establishment of a natural healthy estuarine community.
2. The anthropogenically exacerbated accumulation of soft, unconsolidated and strongly reducing sediments. This change from a natural substrate inhibits the establishment of infaunal species resulting in an impoverished community characterized by low
diversity and abundance. Moreover, re-suspension of fine sediments in the SLE severely impacts certain infaunal species, important for the ecosystem stability.

3. Excessive nutrients dramatically alter the trophic status of the water column, contributing to processes of eutrophication, accelerating phytoplankton production and biomass accumulation, which lead to periodic hypoxia and anoxia.

**Figure 5-23: Benthic Macroinvertebrate CEM for the Northern Estuaries**

**Data Used for Assessment of Hypothesis Cluster**
Data used for analysis and assessment of this macroinvertebrate hypothesis cluster were collected between February 2005 and January 2007. Data collection is ongoing on a quarterly basis. See Section 5.4.3 for details.

**Interim Goals**
Although benthic invertebrates are not currently being used as an interim goal indicator, their health, abundance and species diversity are directly affected by flows from the watershed and LO.

The water quality and living resources of an estuary are closely linked to the volume of freshwater inflow. Benthic species composition and abundance vary with salinity changes along a gradient. The water diversions and improvements in basin storage capacity in SLE
and SIRL due to restoration activities are expected to result in significant improvements which will be rapidly reflected as significant changes in the benthic community.

The benthic monitoring program will provide predictions and assessments of salinity pattern ecological effects in the discrete zones of the estuaries. Expectations are that salinity in the riverine segment of the North Fork of the SLE, north of the confluence with the C-24 canal, will experience a significantly lower and more stable salinity regime. As a result, the benthic community will undergo significant structural changes in community type that are more indicative of freshwater riverine systems. This should result in an increase in abundance of taxa such as mayfly (Ephemeroptera) and caddisfly (Trichoptera) species. Midge (Diptera:Chironominae) and certain freshwater oligochaete taxa should continue to persist while marine/estuarine taxa (Isopoda, Decapoda, Polychaeta) currently present at these sites will inevitably be excluded. These changes will reliably document the desired ecological response to change in salinity regime. As a consequence of diverting water currently discharged from the C-24 and C-23 canals northward, the salinity regime in the central embayment of the SLE west of the US Highway 1 Bridge will experience higher and more stable salinity. In response to these changes, the infaunal population will become more evenly distributed, with a decrease in relative dominance and an increase in species richness and diversity. The opportunistic (r-strategist) taxa (such as the polychaetes Streblospio benedicti, Mediomastus sp., Heteromastus sp., Capitella sp.), which now dominate large parts of the North Fork and middle SLE, will decrease from current levels of 15-50 percent to less than five to ten percent, and some of these taxa will disappear completely. The South Fork of the SLE is currently dominated by taxa that are tolerant of high organic enrichment and low (and fluctuating) salinities. Freshwater diversion of the C-23 canal and storage and treatment in the C-44 watershed along with improvements in LO regulation schedules and additional storage north of LO will all combine to improve flows from canal 44 into the South Fork of the estuary. These changes will considerably limit the success of these organisms (currently at 50-75 percent relative abundance). Estuarine organisms most common at salinities of 5-18 ppt and euryhaline marine organisms will become established in the SLE.

5.4.3 Methods and Analyses

Sampling Methods

Quantitative macroinvertebrate sampling and sediment core sampling are performed quarterly at thirteen sites according to guidelines/recommendation from EPA and ICES (Figure 5-24). On each sampling occasion, temperature, salinity, DO, pH (surface and bottom), turbidity, secchi depth, presence of hydrogen sulfide (H2S), current direction and speed, wind direction and speed, air temperature and percent cloud cover are recorded. Separate sediment cores for granulometric (grain size) analysis are collected at every site once per year. Sediment profiles of oxygen and sulfide concentrations are made using ultra-sensitive microelectrodes interfaced with a computer for analysis. In the laboratory, faunal samples are identified to the lowest possible taxon and enumerated. The quarterly sediment samples are analyzed for percent water content and percent organic content (loss on ignition [LOI]) at each site.
Data Analysis
A customized web-based database was created in 2005 specifically for the macrobenthic project by Per Karlsson and Lisen Runsten, University of Goteborg, Sweden. Data are analyzed using several different software packages including: Sigmastat 3.5, Sigmaplot 10, Statecol, Systat 11, Corel Draw 10 and PRIMER 6 (Plymouth Routines in Multivariate Ecological Research). Many different components within PRIMER 6 (Clarke & Warwick 2001) are used for data analysis including: cluster analysis, two-way indicator species analysis (Hill 1979), principal component analysis (PCA), correspondence analysis (CA), canonical correspondence analysis (CCA), MDS (Kruskal and Wish 1978), Anosim and Similarity Percentage Analysis (Simper). Of these, the main components used are Cluster analysis, MDS, Simper and Anosim to analyze differences between sites and to examine the contribution of individual species to the similarity/dissimilarity between sites and replicates. Several statistics are calculated using the above listed software packages, including, arithmetic means with variances and standard error for abundance of taxa and/or sites, Shannon-Wiener index and Hill’s diversity numbers N1 and N2 for diversity, Hill’s modified ratio E5 for evenness, and Mann-Whitney U tests and Wilcoxon Matched Pairs tests for temporal changes. The project procedures are described in detail in the 2004-2005 Annual Report (Tunberg 2006a) and the 2006 SSR (Tunberg 2006b). Bachelet et al. (1994) have also in detail described how to analyze similar datasets using multivariate approaches.

Quality Assurance
The following guidelines are being used for the field and laboratory procedures: FDEP-SOP-001/01 (FDEP SOP for Field Activities), FDEP-SOP-002/01 (FDEP SOP for Laboratory Activities) and FDEP-QA-001/01 (New and Alternative Analytical Laboratory Methods). CERP Quality Assurance Systems Requirements (QASR) Plan will be incorporated when that guidance is made available. In those cases where national guidelines may be missing, the international standards established by ICES and Boyd (2002) will be followed.
Figure 5-24: Quantitative Macroinvertebrate Sampling and Sediment Core Sampling Sites
Section 5
Northern Estuaries Module

5.4.4 Discussion

Reference Conditions
Prior to the anthropogenic changes of the last century, water entered the SLE after flowing through an extensive marsh watershed. These marshes stored vast amounts of water in the wet season causing increased evapotranspiration and allowed for a slow and more evenly distributed flow of water into the estuary. The natural watershed allowed sediments and contaminants associated with the sediments to settle out within the marsh rather than entering the estuary and nutrients to be absorbed and used by the wetland vegetation. Cleaner water reached the estuary at a slower, more naturally seasonal rate. Under such conditions the macroinvertebrate community could be expected to reach high diversity and productivity.

However, long-term benthic monitoring in the SLE and the SIRL has unfortunately never been performed and no quantitative data for the macroinvertebrate community exists under undisturbed conditions. However, short term studies have been performed recently (Section 5.4.2). This leaves managers without a quantitative historic condition, but gives a picture of the Pre-CERP reference state of the impacted water body.

Lessons Learned
To be able to develop an accurate picture of long term changes, and to be able to distinguish natural changes, successions and oscillations from anthropogenic impacts it is necessary for a monitoring program to continue uninterrupted for a long time period (e.g., Day et al. 1989; Bachelet and Castel 1997; Tunberg and Nelson 1998; Hagberg and Tunberg 2000; Hagberg et al. 2004). This is especially important in a shallow (sub-tropical) estuary where severe, naturally occurring weather conditions may in some extreme years overshadow the effects of restoration efforts.

Results
The mean Shannon-Wiener diversity at all the sampling sites throughout the two-year study period is presented on the map showing the sampling sites (Figure 5-24) and the mean number of taxa and individuals from all the replicates at each site is presented in Figure 5-25. Low values for all these parameters were recorded at sites M3-M6, situated in the middle of SLE. Slightly higher values were recorded from the North Fork River (M1 and M2) and significantly higher values were recorded south of Hell’s Gate (M7 and M8) and north in the SIRL (M9-M13).
As presented in Figure 5-26, the large freshwater discharge in July 2005 had a negative impact on both bottom oxygen levels and the number of taxa in the SLE. Figure 5-27 shows that the organic content (loss on ignition) of the sediment in the middle SLE Basin was high, while lower values were recorded in the North Fork River (M1-M2) and beyond Hell’s Gate.
(M7-M13). The relationships between substrate type and diversity and taxa are presented in Figure 5-28. This graph shows that there is a significant negative correlation (cross correlation analysis) between the sediment organic content and the health of the infaunal communities. The two layers (0-2 centimeters and 2-5 centimeters) at sites M3-M6 also differed more than at the other sites. The sediment water content at these sites was also high (not presented here).

![C-44 DISCHARGE](image)

**Figure 5-26: Freshwater Discharges from C-44 in July 2005**

Large freshwater discharge from C-44 in July 2005 had a negative impact on both bottom oxygen levels and the number of taxa in the SLE.
Figure 5-27: Organic Content (loss on ignition) of the Sediment in the Middle SLE Basin

Figure 5-28: Relationships Between Substrate Type and Diversity and Taxa

Figure 5-29, Figure 5-30, Figure 5-31 and Figure 5-32 present the relationships between taxa, individuals and salinity at combined sites. In Figure 5-29, the monthly salinity measurements from SFWMD (DBHydro database) have been used for the analyses, but in Figure 5-30, Figure 5-31 and Figure 5-32, the data collected within this project have been used for the analyses. In the future, the data from the DBHydro database will be used for all sites when available. M7 and M9 have been excluded from these analyses because they had to be relocated at an early stage. The data have been standardized (standard deviates) according to the procedure described in Sokal and Rohlf (1981). This approach has also been
used successfully by Tunberg and Nelson (1998) on North Sea benthos data sets. Best fit polynomial regressions were used to elucidate the temporal changes and correlation between the variables. No statistical comparisons have been performed concerning the relationships between the variables because of the present short monitoring period. An increase in salinity from low to no water discharge at M1 and M2 (**Figure 5-29**) in late 2006 initially decreased the number of taxa and individuals, but the prolonged higher salinity has most likely allowed for estuarine species to invade this area, accounting for the high increase in taxa in January 2007.  **Figure 5-30** shows the negative impact from the freshwater release in July 2005, but also the improvement later during the study period, most likely natural and seasonal, but the short study period makes it hard to evaluate if this is the case. The data from the study site M8 at Peck’s Lake (**Figure 5-31**) indicates that taxa and individuals were negatively impacted by the low salinities in July 2005, but high salinities later during the study period seemed to have a positive effect (increases) on both taxa and general abundance. The SIRL (sites M10-M13) experienced the least impact from the large freshwater discharge in July 2005 (**Figure 5-32**). The salinity variations were also comparatively limited here during this monitoring period. MDS, Cluster, and Similarity Percentage analyses have been performed for each site to evaluate which taxa had the largest impact on observed changes.

![Figure 5-29: Relationships Between Taxa, Individuals and Salinity at Sites M1 and M2](image-url)
Figure 5-30: Relationships Between Taxa, Individuals and Salinity at Sites M3-M6

Figure 5-31: Relationships between taxa, individuals and salinity at site M-8
The results from these analyses are currently being evaluated and will provide important information on which taxa should receive special attention in the future. One representative MDS plot is presented in Figure 5-33. It shows the similarity among replicates and that the sites beyond Hell’s Gate (M7-M13) differ from the ones in the middle SLE basin (M3-M6). This was confirmed by the cluster analysis (not presented here). Figure 5-34 shows an example of a bubble plot where the relative abundance of the opportunistic polychaete *Streblospio benedicti* has been superimposed on the MDS plot for October 2005 (mean values for each site). It occurred in high abundances in the main SLE Basin (M3-M5), but also in much lower densities at sites M7 and M9 beyond Hell’s Gate. Anosim will be performed on the data sets to elucidate the temporal differences between the sampling occasions at each site.
The sites beyond Hell’s Gate (M7-M13) differ from the ones in the middle St. Lucie Estuary Basin (M3-M6).

**Figure 5-33: MDS Plot Illustrating the Similarity Among Replicates**
Illustrates an example of a bubble plot where the relative abundance of the opportunistic polychaete *Streblospio benedicti* has been superimposed on the MDS plot for October 2005 (mean values for each site). It occurred in high abundances in the main SLE Basin M3-M5, but also in much lower densities at sites M7 and M9 beyond Hell’s Gate.

**Figure 5-34: Example of a Bubble Plot Where the Relative Abundance of the Opportunistic Polychaete *Streblospio benedicti* Has Been Superimposed on the MDS Plot**

**Findings**

At this early monitoring stage it is not possible to elucidate with any certainty the reasons behind the observed temporal changes. In order to distinguish natural changes, successions and oscillations from anthropogenic disturbances it is necessary to generate long term data series (e.g., Bachelet and Castel 1997). Additionally the study areas were heavily disturbed by the large freshwater release in July 2005 and (to a lesser extent) by hurricane Wilma in October 2005. The large freshwater releases in 2005 (*Figure 5-26*) turned the SLE system (from surface to bottom) into a near limnic or oligohaline body of water, which eliminated the natural stratification in the water column. As a result of the large nutrient loads and salinity decrease from these releases, the SLE experienced a severe bloom of the bluegreen algae *Microcystis aeruginosa*. This species releases toxins when it sinks to the bottom, which most likely decreased the number of benthic taxa and abundance throughout the SLE.

Additionally, later in the study period (2006), the increase in salinity caused by low (or no) freshwater release caused mesohaline conditions further into the SLE, increasing the number of taxa and individuals by the end of this monitoring period. These trends further confirm the quick responsiveness of the infaunal communities to hydrologic changes and their utility providing feedback to water managers. Substrate conditions are also important controlling
factors on benthic community structure. Sediment transport is a natural part of a healthy undisturbed estuary, while accelerated deposition as a result of anthropogenic activities may have severe impacts. Sites where significant differences in organic content and water content were recorded between the upper (0-2 cm) and the lower layers (2-5 cm) indicated that a higher rate of deposition occurs here. These areas had the poorest infaunal communities, dominated by a few opportunistic (r-strategists) and other pollution tolerant taxa. Often the sediments here smelled strongly of hydrogen sulfide. This is a clear indication of severe ecological problems (e.g., Buzzelli et al. 2002). It is noteworthy that large numbers of empty shells belonging to estuarine bivalves have been collected in the samples. At M2, in the North Fork, large numbers of *Rangia cuneata* were often obtained in the samples. At several sites in the middle SLE Basin and also in the SIRL, *Mulinia lateralis* shells were often obtained in large numbers, which may be caused by larger than normal fluctuations in salinity.

Once a larger dataset is available, it will be possible to divide and analyze the infaunal communities as functional ecological groups. The SFWMD nutrient measurements will also be included in the future statistical analyses.

**A thorough discussion of water quality issues in the NE can be found in Appendix 5A.**

## Conclusion

The infaunal monitoring indicates that the SLE and SIRL display gradients of disturbance. The most disturbed areas occur in the South and North Forks and the middle SLE Basin, which periodically receives high freshwater releases (and nutrients) from the C-23, C-24 and C-44 canals. The North Fork is in better ecological condition with a mixture of limnic and estuarine taxa. However, the large number of dead *Rangia cuneata* shells found at site M2 is disturbing. The data indicate that the narrow Hell’s Gate may be designated as a transition zone and the conditions beyond here improve dramatically. The monitoring sites are euryhaline and most likely benefit from the decreased sediment deposition and tidal influence and its proximity to the St. Lucie Inlet. The data from sites M12 and M13 do not indicate that the C-25 canal (Taylor Creek) has any significant negative impact on the adjacent SIRL system. The discharge from this canal is most likely diffused by the strong tidal currents from the Fort Pierce Inlet. In spite of the short monitoring period it is obvious that the benthic communities respond quickly to environmental changes and that they reflect changes in discrete zones within the monitored areas in the SLE and SIRL.

### 5.5 Northern Estuaries Hypothesis Cluster-Fish

#### 5.5.1 Abstract

The NE Fish Sub-team recommended that monitoring of fish populations in the NE begin immediately in order to establish baseline conditions prior to CERP-related changes. In the past and currently, monitoring has been accomplished using standard techniques (e.g. seines and trawls). Over the past two years, a variety of alternative techniques have been implemented to assess their ability to aid in producing a fish MAP. Fish larval and juvenile ontogenetic stages are targeted for assessment due to their vulnerability to marginal ambient environmental conditions, predation, food limitations and habitat destruction. Classical capture techniques were utilized including plankton, seine and trawl nets of various sizes and
configuration. Shock boats were used in habitats where seine and trawl nets could not be used and where salinities were low enough to permit the use of this technique. Spawning and migratory behavior of adult fish were also targeted for PMs as technologies now allow these behaviors to be readily monitored continuously and remotely using passive acoustic systems.

A combination of methodologies allows quantitative data to be captured revealing spatial and temporal dynamics of fish populations and species assemblages. These data are complemented with historical quantitative information on fish assemblages using classical techniques, seine and trawl nets. When sufficient spatial and temporal information is available on fish population dynamics and assemblage biology, indices of biological integrity and PMs can be produced that allow quantitative measure of fish population/assemblage response to various activities involved with the CERP.

Water management scenarios should consider three primary PMs to determine CERP impacts on fish assemblages. These are: (1) fish spawning intensity monitored continuously with passive acoustic technologies; (2) fish larval abundance and diversity monitored routinely relative to the physical/chemical frontal boundaries associated with freshwater flows; (3) distribution, abundance, size-frequency, species composition and general health of juvenile and small adult fish be monitored in a variety of habitats such as seagrass beds.

### 5.5.2 Background Description

From 2005 to present the members of the NE Fish Sub-team have evaluated and examined the potential for fish communities to provide adequate information to RECOVER program ecosystem managers. A primary objective was to determine how relevant and timely PMs based on fish communities can be integrated into the CERP MAP. During this same time period a collaborative effort by state and federal agencies and private entities have utilized and tested a wide variety of fish assessment and monitoring techniques and technologies. The NE Fish Sub-team came to a consensus that a variety of techniques should be implemented to target critical life history stages of regional fish populations that are most likely to be impacted by RECOVER activities. Abundant small, primarily resident species and early developmental stages of larger, primarily transient species are known to be most vulnerable to water quality, predation, and habitat loss. Therefore, these smaller fishes and the early life history stages of larger species were of particular concern.

Since 1998 a variety of fish assessment techniques have been implemented in the NE, including the Gulf coastal Caloosahatchee River/Charlotte Harbor and the Atlantic coastal St. Lucie River/IRL estuaries (Error! Reference source not found.).
Figure 5-35A
Figure 5-35B

Figure 5-35: Map of Fish Monitoring Boundaries of the West Coast (A) and East Coast (B) Northern Estuaries
Periodically some of these techniques were used to determine their efficacy in monitoring fish community response for the RECOVER program. However, most RECOVER directed fish assessment in the NE has been conducted from 2003 to present. Routine monitoring and experimental techniques included 15.5 and 21.3 m, 3.2 mm mesh center bag seines, 6.1 m, 3.2 mm mesh cod end trawls, 183 m, 37.5 mm mesh haul seines, 0.5 m, 500 micron mesh plankton nets, electro-shock boats, high resolution sonars (DIDSON, Blue View), passive acoustic transects, stationary passive acoustic observatories and fish tagging with acoustic tags (VEMCO) and acoustic sensor arrays (VR2s). Technique trials have included collaborative work with the FWC, FDEP, USGS, NOAA/National Ocean Survey and the Florida Oceanographic Society.

Though information may be lacking for the NE relative to other Florida estuaries, historic information on fish populations/communities, species composition and relative abundance in various estuaries throughout Florida is substantial, giving some insight into the potential behavior of the NE fish community under a variety of environmental conditions. The Fisheries Independent Monitoring (FIM) program has been monitoring fishes in tributaries to Tampa Bay, Charlotte Harbor and the northern IRL (N of 27° 30’ N) simultaneously since 1989. FIM uses a variety of techniques in an effort to determine fish community dynamics relative to a variety of environmental parameters including freshwater inflows, nutrient dynamics, microhabitat selection and habitat change (Matheson et al. 1999, 2004, 2005; Peebles et al. 2005; Greenwood et al. 2004, 2006; Stevens, et al. 2006; Switzer et al. 2006). This work has shown promise in defining associations between freshwater inflow and the distribution and abundance of fishes.

Small fishes and early fish developmental stages of larger species suffer the highest mortality rates and are often more sensitive to adverse environmental conditions, than are adults of larger species. Small resident fishes and transient juvenile developmental stages have been emphasized in historic estuarine studies throughout Florida (Springer 1960; Tabb and Manning 1961; Livingston 1997; Livingston et al. 1997; Sogard, 1987, 1989a,b). NE juvenile fish studies include the Loxahatchee-Jupiter Inlet estuaries (Christensen 1965; Snyder 1984), St. Lucie/Indian River Lagoon estuaries (Gilmore et al. 1983, 1985; Gilmore1988; Haunert and Starzman 1980, 1985) and Caloosahatchee/Charlotte Harbor estuaries (Wang and Raney 1970; Poulakis et al. 2004). Preliminary work and studies of fish egg/larval dynamics relative to freshwater flows in the NE have been conducted in tributaries to Charlotte Harbor (Peebles et al. 2005), the Loxahatchee River (Gilmore and Haunert 2004) and reveal that planktonic larval fish abundance is directly associated with salinity frontal boundaries where their principal prey may aggregate. These frontal boundaries are influenced directly by dynamic freshwater flow patterns. Therefore, if larval fish populations can be monitored on a transect through various estuarine salinity environments, their preferred location relative to salinity frontal boundaries may be determined.

Since at least 400 fish species will be directly impacted by CERP activities, there is great variation in the spatial temporal scale in life history stages I-IV (Figure 5-36) and susceptibility to physical/chemical environmental dynamics physiological stress, predation and disease. Typically the larval stage, (II in Figure 5-36) is most vulnerable to physical/chemical conditions in the water column, while juveniles (III in Figure 5-36) are
most vulnerable to changes in critical habitat necessary to protect them from predation and present adequate food resources for rapid growth and maturation. Adult mortalities are far lower and may be greatest when they gather to spawn.

Fish life cycle illustrating key components used for addressing fish populations impacted by the CERP. A range of spatial temporal scales are presented relative to life history stage. White arrows depict significant differences in mortality rates between life history stages.

**Figure 5-36: Fish Life Cycle**

The NE Fish Sub-team used both experience with historical use of various quantitative fish assessment-monitoring technologies and tested a variety of new techniques/technologies to come to the conclusion that egg/larval, juvenile and adult life history stages should be an integral part of the Fish Community assessment model. Since this perspective was not adequately presented in earlier NE fish CEM diagrams, the ecological model has been modified to represent the emphasis of recommended RECOVER MAP priorities (**Figure 5-37**). The life history stages are listed in **Table 5-11** along with the technologies used to monitor them.
Table 5-11: History Stages of Fish with Monitoring Technologies

<table>
<thead>
<tr>
<th>Life Stage</th>
<th>Monitoring Techniques</th>
<th>Techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg-Larvae</td>
<td>Plankton Net</td>
<td>Plankton Pump</td>
</tr>
<tr>
<td>Juvenile</td>
<td>15.4 m and 21.3 m/3.2 mm mesh Seine</td>
<td>6.1 m Trawl</td>
</tr>
<tr>
<td>Adult-Spawning</td>
<td>Hydrophone observatory and transects</td>
<td></td>
</tr>
<tr>
<td>Adult-Migration</td>
<td>VR2 receivers/acoustic tags</td>
<td>183 m Haul net</td>
</tr>
<tr>
<td>Adult-Feeding</td>
<td>183 m/37.5 mm Haul net</td>
<td>Shock boat</td>
</tr>
</tbody>
</table>

Interim Goals
Fish are currently not being used as an IG indicator in the NE.

Interim goals should be based on the following PMs recommended from 2004-2006 fish evaluation and assessment in the NE:

1. Fish spawning intensity should be monitored continuously with passive acoustic technologies.
2. Fish larval abundance and diversity should be monitored routinely relative to the physical/chemical frontal boundaries associated with freshwater flows.
3. Distribution, abundance, size-frequency, species composition and general health of juvenile and small fish should be monitored in habitats such as seagrass beds affected by restoration activities.
5.5.3 Methods and Analysis

From the 800+ fish species occurring in the CERP NE, the NE Fish Sub-team has estimated that 128 species are most likely to produce quantitative data that is valuable in determining the success of CERP in restoring indigenous fish assemblages to historical levels in relative abundance, function and diversity. These species include numerous planktivores, substrate associated predators/detritivours and top carnivores. At least 36 of these species are of direct economic importance.

The following methodologies are being used or examined for their ability to give accurate, cost effective and timely information on critical life history stages of fish populations/assemblages.

**Sampling Methods**

Thirteen different fish assessment and monitoring systems have been used from 2005 to 2006 allowing a detailed comparison of relative cost, effectiveness and practicality of various fish assessment and monitoring techniques and technologies. All techniques were used in an attempt to produce quantitative information on all fish life history stages considered of importance in developing RECOVER PMs (Table 5-12, Table 5-13 and Table 5-14).

**Table 5-12: Technology Targets for Fish Assessment in the RECOVER Fish Module**

<table>
<thead>
<tr>
<th>TARGET ORGANISMS</th>
<th>ZOOPLANKTON</th>
<th>JUVENILE FISH</th>
<th>ADULT FISH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IDENTIFICATION</td>
<td>DENSITY/BIOMASS</td>
<td>PERIODICITY</td>
</tr>
<tr>
<td></td>
<td>IDENTIFICATION</td>
<td>DENSITY/BIOMASS</td>
<td>PERIODICITY</td>
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<td></td>
<td>IDENTIFICATION</td>
<td>DENSITY/BIOMASS</td>
<td>PERIODICITY</td>
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<tr>
<td></td>
<td>IDENTIFICATION</td>
<td>DENSITY/BIOMASS</td>
<td>PERIODICITY</td>
</tr>
<tr>
<td>CLASSICAL TECHNOLOGIES</td>
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<td></td>
</tr>
<tr>
<td>Plankton net (505 um)</td>
<td>X X X</td>
<td></td>
<td></td>
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<tr>
<td>3.3 m, 3.2 mm mesh Seine</td>
<td>X X X X</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>21.3 m Seine</td>
<td>X X X X</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>67 m, 3.2 mm mesh Seine</td>
<td>X X X X</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>1 sq m, 3.2 mm mesh throw net</td>
<td>X X X X</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>Electro-shock, to 15ppt</td>
<td>X X X X</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>INNOVATIVE TECHNOLOGIES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive Acoustic Array, ECOS</td>
<td></td>
<td></td>
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<tr>
<td>Passive Acoustic Network, VR2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biosonics Sonar, Long range (1.0 km)</td>
<td>X X X X</td>
<td>X X X X</td>
<td></td>
</tr>
<tr>
<td>DIDSON Sonar, Short range, &lt;30 m</td>
<td>X X X X</td>
<td>X X X X</td>
<td></td>
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<tr>
<td>BLUE VIEW Sonar, Short range, &lt; 30 m</td>
<td>X X X X</td>
<td>X X X X</td>
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<tr>
<td>Telemetry/Communication Station</td>
<td>Disseminates data continuously real time to processing and data analyses centers</td>
<td></td>
<td></td>
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<tr>
<td>Web Site</td>
<td>Disseminates data continuously real time to processing and data analyses centers</td>
<td></td>
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</tbody>
</table>
Table 5-13: Fish Module Data PMs for RECOVER MAP

<table>
<thead>
<tr>
<th>Life Stage and Technique</th>
<th>Diversity(^1)</th>
<th>Population Dynamics</th>
<th>Biomass</th>
<th>Preferred Habitat</th>
<th>Preferred Ecological &amp; Physiological Parameters</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(No. Species)</td>
<td>(No. per m(^2), m(^3))</td>
<td>(No. per unit time)</td>
<td>(Wt. per m(^2), m(^3))</td>
<td>(Mean salinity range)</td>
<td>(Mean temperature range)</td>
</tr>
<tr>
<td>EGG-LARVAE</td>
<td>X X X X X X X X</td>
<td></td>
<td>X X X X X X X X</td>
<td>X X X X X X X X</td>
<td>Capture Pt. Meter Meter Meter</td>
<td></td>
</tr>
<tr>
<td>Plankton net, plankton pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Capture Pt. Meter Meter Meter</td>
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<tr>
<td>JUVENILE</td>
<td>X X X X X X X X</td>
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<td>X X X X X X X X</td>
<td>X X X X X X X X</td>
<td>Capture Pt. Meter Meter Meter</td>
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<tr>
<td>15.4 m and 21.3m/ 3.2mm mesh seine, 6.1 m trawl</td>
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<tr>
<td>ADULT</td>
<td>X X X X X X X X</td>
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<td>X X X X X X X X</td>
<td>X X X X X X X X</td>
<td>Hydrophone observatory and transects</td>
<td></td>
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<tr>
<td>Spawning</td>
<td>X X X X X X X X</td>
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<td>X X X X X X X X</td>
<td>X X X X X X X X</td>
<td>Migration</td>
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<tr>
<td>VR2 receivers/acoustic tags, 183m haul net, Shock boat</td>
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<tr>
<td>Feeding</td>
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<td>X X X X X X X X</td>
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<td>Feeding</td>
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<tr>
<td>183 m /37.5mm mesh haul net, Shock boat</td>
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</table>

\(^1\)Species richness, diversity and relative abundance may be divided for study and monitoring of representative guilds of value, such as based on variation in sensitivity to physical parameters, trophic conditions, habitat loss and predation.
Table 5-14: Technology Habitat Targets for Assessment by the RECOVER Fish Module

<table>
<thead>
<tr>
<th>TARGET HABITAT/ECOSYSTEM</th>
<th>CLASSICAL TECHNOLOGIES</th>
<th>INNOVATIVE TECHNOLOGIES</th>
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<tr>
<td></td>
<td>CANALS-C-44,C-23,C-24</td>
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<td>FLOOD GATES, SPILLWAYS</td>
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<td></td>
<td>RIVER OXBOWS, CREEKS</td>
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<tr>
<td></td>
<td>BACKWATERS</td>
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<tr>
<td></td>
<td>MAIN RIVER BANKS</td>
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<td></td>
<td>MAIN RIVER CHANNEL</td>
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<td></td>
<td>WATER COLUMN</td>
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<td></td>
<td>MAIN RIVER BOTTOM</td>
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<td></td>
<td>ESTUARINE MEADOWS</td>
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<td></td>
<td>ESTUARINE FORMATION</td>
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<td></td>
<td>ESTUARINE CHANNEL, 2-3</td>
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<td>M DEEP DEPRESSIONS</td>
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<td>OCEAN INLET</td>
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<td>OCEAN REEF FORMATION</td>
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<td>OCEAN WATER COLUMN</td>
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<thead>
<tr>
<th>MONITORING TECHNOLOGIES</th>
<th>Plankton net (505 um)</th>
<th>3.3 m, 3.2 mm mesh Seine</th>
<th>21.3 m Seine</th>
<th>67 m, 3.2 mm mesh Seine</th>
<th>1 sq m, 3.2 mm mesh throw net</th>
<th>Electro-shock, to 15ppt</th>
<th>Passive Acoustic Array, ECOS</th>
<th>Passive Acoustic Network, VR2</th>
<th>Biosonics Sonar, Long range (1.0 km)</th>
<th>DIDSON Sonar, Short range, &lt;30 m</th>
<th>BLUE VIEW Sonar, Short range, &lt;30 m</th>
<th>Telemetry/Communication Station</th>
<th>Web Site</th>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>Disseminates data continuously</td>
<td>Disseminates data continuously</td>
</tr>
</tbody>
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5.5.4 Adult Spawning–Fish Egg/Larval Abundance

Methodology-Spawning Site Isolation and Monitoring Using Passive Acoustics

At least 64 fish species occurring in the NE are sound producers, particularly during social and reproductive displays. It is now well documented that fish spawning activity is associated with a particular suite of environmental variables that dictate larval survival and dispersal. Spawning calls produced by estuarine fishes are associated with these environmental parameters. The techniques used for monitoring biological sounds relative to environmental conditions followed those that were conducted using passive acoustic methods, egg-larval plankton collections and adult fecundity studies in the Indian River Lagoon, Mosquito and Banana River lagoons (Gilmore and Mok 1983; Gilmore 1994, 1996, 2001, 2003; Rountree et al. 2006). The intensity and ubiquity of spawning fish calls provide another metric to measure the success of spawning as there is a direct correlation between fish egg/larval abundance at the spawning site and sound intensity, duration and periodicity in chorality produced by species that form large leks, or calling aggregations.

In May 2006 a permanent passive acoustic monitoring station was installed on a spawning site for sand seatrout, silver perch, spotted seatrout, gafftopsail and hardhead catfish and Atlantic toadfish at Hell’s Gate in the St. Lucie River. A variety of acoustic, computer and telemetry hardware was used to determine the most robust systems to monitor in situ fish spawning activities continuously under all weather and oceanographic/hydrological conditions. For more details on this project see (Gilmore 2007final report).

Figure 5-38 depicts the graphical representation of data obtained at the Hell’s Gate site. The spectral analysis calculates several parameters used to quantify the sound segment under study (Figure 5-39 and Figure 5-40). These are:

1. Peak Frequency: strongest spectral component in the entire period of the sound segment under study
2. Peak Amplitude: amplitude of the strongest spectral component in the entire period of the sound segment under study
3. Total Power: calculates the total RMS power level for the entire spectrum
4. Total Harmonic Distortion (THD): the ratio of the harmonic power to the fundamental power by searching the entire spectrum to find the peak frequency and then calculating the total power in the harmonic frequencies
5. Signal to Noise Ratio (SNR): measures the signal power over background noise for the entire period of the sound segment under study;
6. Overall Decibel Level: the total sound decibel (dB) for the entire period of the sound segment under study

The hydrophone observatory recorded ambient sound for three to five hours and four to five intervals were used for sound analyses from these three to five hour evening recordings, beginning at 2000 hour (during four hour periods), or 1900 hours on five hour periods. All signals were used until midnight, 2400 hours, as a comparative standard for activity that evening. The parameters recorded from these periods are:

1. species producing the sound
2. species call period (SCP): duration of species specific chorlial activity (hr.m.s)
3. total choral period (TCA): duration of total choral activity for all species combined (hr.m.s)
4. start time (ST): time of commencement of choral activity (0000 hrs)
5. stop time (SPT): time of cease of choral activity (0000 hrs).

Figure 5-38: Graphic Representation of Data Obtained for Quantitative Analyses of Bio-acoustical Signals

Graphic representation of data obtained for quantitative analyses of bio-acoustic signals taken from a four hour time series segment on 11 September 2006 at the Hell’s Gate Observatory (HGO). SpectraPro software automatically generates acoustic statistics on any sound sample, in this case the loudest sound produced that evening at 2356.35.213 hours. Also shown below is a comparison of sound energy produced by spotted seatrout before (early evening, left below) and during a spawning chorus (late evening on right, below).
THD for bio-acoustic signals at Hells Gate during September 2006 relative to lunar phase expressed as percent full moon (PFM–solid red line).

**Figure 5-39: THD for Bio-acoustic Signals at Hells Gate**

Figure 5-40: Examples of Daily Variation in Overall Spawning Call Intensity, Total Power (PWR), THD, Total SNR and Peak

**Methodology-Egg and Larval Fish Distribution, Plankton Sampling**

Fish egg and larval sampling at the spawning site began May 2007 as part of the documentation of egg-larval abundance in association with fish spawning call intensity. Classical plankton net sampling with a 500 micron mesh, 0.5 m diameter net on five minute
tows at the spawning site were carried out nightly for two weeks during peak spawning periods, spring.

5.5.4.1 Juvenile–Adult fish Captures

Methodology–Fish and Wildlife Commission Fisheries Independent Monitoring
FIM monitoring of the SLE system has been underway since 1998 and presently consists of 144 annual randomly selected samples in the SLE and the Indian River Lagoon Estuary using a 183 m haul seine. The CRE and lower Charlotte Harbor Estuary has been sampled since 2003 with 852 randomly selected annual samples using three gear types, a 21.3 m-3.2 mm mesh seine, 183 m haul seine, and a 6.3 m trawl with a 3.2 mm mesh cod end net.

Methodology-Indian River Lagoon Seagrass Fish Populations Impacted by Freshwater Release, Bessie Cove
From July to November 2006 juvenile fishes were captured monthly with a 15.4 m 3.2 mm mesh seine associated with seagrass sites monitored by the SFWMD, at Boy Scout Island in the Indian River Lagoon, proximate to the mouth of the St. Lucie River. Since detailed seagrass meadow structure and density was being monitored at these sites by the SFWMD these fish collections gave some indication of the habitat fish relationship along with other water quality conditions, salinity, temperature and DO.

Seagrass monitoring was carried out for several reasons. Seagrass botanical assessment (part of the RECOVER CERP) and a seagrass MAP was being developed for this ecosystem. Seagrass is included in CERP as it supports the most diverse aquatic communities in Florida estuaries and is sensitive to water quality related to freshwater runoff. Seagrass fish communities in the St. Lucie Inlet and IRL within a mile or two of the mouth of the St. Lucie River supports the most diverse aquatic estuarine faunas in the United States. Seagrass ecosystems in this region of the IRL were largely responsible in documenting the unique United States aquatic fauna of this region and thus the designation of the IRL as an Estuary of National Significance by EPA.

Since historical fish collections had been made in Bessie Cove from 1962 to 1997 and detailed quantitative collections from 1974 to 1975, new fish collections allow comparisons with the old faunas if same, or similar, techniques and locations could be revisited. This historical perspective could give considerable depth to the assessment of fish populations over time, in this case three decades based on the 1974–1975 quantitative collections. If significant water release did take place during the study its influence on seagrass communities relative to historical studies may be assessed.

Methodology-North Fork St. Lucie River Adult Fish Habitat, Electro Shock Captures
The fish population at North Fork St. Lucie River sites was sampled by electrofishing to compare with DIDSON sonar images and to determine the effectiveness of electroshock techniques in captured specific species of interest such as the smaller, rare species of snook and various gobioid fishes. Sampling was done on two occasions, September 2005 and April 2006 and centered on areas around the mouth of the North Fork and an oxbow, or old river
channel system adjacent to the FWC long term sampling sites for fish, a region of the river with the most fish collection data

Methodology—Sonar Experiments in Fish Assessment
A variety of sonar systems were experimentally deployed at the HGO. Sonars in two modes were used; stationary moored and mobile transects. The sonars used were the DIDSON system, a new prototype Blue View sonar, not yet on the market; a Biosonics 120 kHz split beam digital echo sounder sonar, and side scan sonar. The Biosonics sonar was best deployed in a vertical look down mobile transect mode, while DIDSON was best deployed in a stationary mode allowing it to resolve the most detail in fish morphology and swimming behavior. Further experiments were performed by mating a portable passive acoustic monitoring system (PAMS) with DIDSON and a high resolution low light underwater camera in a fish pond with 7-15 m visibility focusing on twelve species of estuarine and marine fish of various sizes. The results of this experiment are still in preparation, but it appears that DIDSON can be important in identifying fish, size, number and fish behaviors under zero visibility conditions. However, DIDSON should not be used as a mobile system unless surveying microhabitat structure is the objective, geometric objects are easily monitored and recorded, but mobile fish are more difficult to identify in this mode. The Blue View sonar could not resolve fish very well and was dismissed as a tool for future studies. The Biosonics sonar can resolve planktonic and fish mass in the water column, but cannot identify this mass to phyla or species. However, it could determine the amount of material in the water column if its identity is known. A combination of passive and active acoustic sampling and visual imagery, organism collection or remote examination (shadowed image particle profiler and evaluation recorder [SIPPER]) would be optimum in maintaining accurate identification of organisms and determining their numbers, size and behavior at an observatory site.

Methodology-Adult Fish Migration
Fish migration was to be studied using 18 VEMCO VR2 passive acoustic receivers and 40 VEMCO acoustic tags in the Estuarine, Coastal and Ocean Science, Inc. (ECOS) inventory in collaboration with FWC scientists. This program has been delayed, but will commence in 2007. The receivers will cover the St. Lucie River ecosystem from the ocean inlet to the locks at LO. Fish movements will be monitored by downloading data from the receivers every two weeks for one year, possibly longer. Various snook species have been targeted for tagging.

5.5.5 Discussion
Florida East Coast Northern Estuaries
Historical reference conditions are limited to the quantitative seagrass fish assemblage studies in the IRL adjacent to the St. Lucie Inlet and river mouth conducted 1974-1975 (Gilmore 1988), the Haunert Starzman (1980, 1985) multi-gear studies of fishes within the St. Lucie River and the FIM 183 m haul seine collections made in the SLE and IRL. These studies have produced fish species lists that are comprehensive for each NE with an accurate assessment of their relative abundance. However, fish assemblage dynamics in association with changes in a variety of environmental and biological parameters has to be determined over several annual cycles to allow a reference condition to be determined. The faunal
biodiversity and composition has been defined. Particular critical habitat sites such as seagrass in Bessie Cove, spawning sites at Hell’s Gate and old river channel sites in the North Fork have been consistent in giving vital information on fish activity and relative abundance.

**Florida West Coast Northern Estuaries**
The FIM work on the Florida west coast has isolated several fish faunal habitat associations that may be predictable based on data collected to date. Habitat suitability models developed from FIM sampling have been created for the Charlotte Harbor estuarine system (Rubec et al. 1999; Whaley et al. 2007). These studies seek to define optimal fish habitats and present the data spatially as maps to support decision making for management of essential fish habitat (EFH). Whaley et al. (2007) found that spatial patterns of fish community composition were highly correlated with distance to the nearest pass and area of continuous seagrass habitat. Spatial patterns were generated specifically for juveniles of several recreationally-important sport fishes: red drum, gray snapper, lane snapper, sand seatrout and spotted seatrout. These exercises suggest that incorporating measures of habitat area (over multiple scales) and spatial position into models of fish distribution can be useful in conservation and management planning. Species-specific studies providing detailed descriptions of habitat use in Charlotte Harbor have been published for juvenile permit, gag and common snook (Adams and Blewett 2004; Casey et al. 2007; Stevens et al. 2007).

**Biodiversity Reference Conditions**
Historic data on fish communities associated with the NE demonstrate that they contain the richest estuarine fish faunas within the United States (Gilmore 1977, 1981, 1995, 2000; Poulakis et al. 2004). The St. Lucie River and St. Lucie Inlet portion of the IRL system contains the epicenter of estuarine fish diversity. Over 500 fish species are known to have been captured within three miles of the mouth of the St. Lucie River, in the IRL, St. Lucie Inlet and the St. Lucie River proper. If species from the Caloosahatchee and Charlotte Harbor estuarine ecosystems are combined, more than 525 fish species that occur in these ecosystems could be impacted by CERP activities. The richest estuarine fish fauna in the NE is associated with seagrass meadow habitats near ocean/gulf inlets. This great biodiversity, along with relatively high fish abundance, has enhanced recreational and commercial fisheries in the NE forming a major economic benefit to the region.

**Index of Biological Integrity**
An Index of Biological Integrity (IBI) should be considered using the data collected to date on fish populations in the NE (Hughes and Noss 1992). The complete species list could be used to isolate groups of species and guilds that are defined on eco-physiologies (euryhaline versus stenohaline), habitat reliance (euryoecious versus stenoecious), biogeographic affinity (tropical versus temperate), trophic habits (carnivore, omnivore, herbivore, primary or tertiary consumers) and relationship to other quantifiable behavioral (estuarine spawning) or life history/environmental characters.

**Acoustic Background and Species Spawning Activity**
Species recognition/classification and relative intensity of spawning calls has now been studied in the Indian River Lagoon since 1979. A large bio-acoustic library of these
background and species specific sounds has been stored on analog and digital media for nearly 30 years. However, the St. Lucie and Indian River Lagoon fish spawning sites were being monitored continuously for the first time during 2006-2007. Over 2,000 hours of data were recorded including a wide variety of new biological and mechanical sounds. For this reason great care must be made to accurately identify the sound producers.

It is anticipated that the completion of call source recognition using captive specimens over the next two years will give a good baseline of acoustic conditions and call source libraries will allow future acoustic source identification in these systems. A similar effort should address the CRE fish spawning sites that would allow reference acoustic conditions to be defined quantitatively. These acoustic data can then be recorded continuously and monitored simultaneously with physical-chemical data taken at critical fish spawning sites within the estuaries producing a large reference data base for a variety of environmental conditions.

5.5.5.1 Results/Discussion-Adult Spawning–Fish Egg/Larval Abundance

Acoustic parameters associated with spawning activity of eight fish species can easily be monitored continuously in real time and data sent to remote sites hundreds (Clearwater, Florida routine downloads), or thousands of miles (Oahu, Hawaii, monitored St. Lucie River, February 2007) away via web site technologies. Results are preliminary, so no detailed analyses and conclusions have been made other than this technology and technique works well in monitoring spawning activities within the estuary relative to ambient environmental conditions, however, the 2007 data will allow conclusions to be made.

Acoustic data is analyzed for: (1) species identification (*Figure 5-38*, and *Figure 5-41*); (2) species call intensity in dB for ten minutes on each hour of a five hour period nightly beginning at 1700 hours and ending at 2000 hours (*Figure 5-42*); (3) and percent occurrence of diagnostic species calls on each hour of each evening in which sounds are recorded. The time series for each five hour period is also stored as a bitmap and PowerPoint image for daily comparison of choral temporal dynamics.

Initial species call recognition were carried out by comparing diagnostic calls catalogued in the ECOS acoustic library that contains over 10,000 hours of Indian River Lagoon estuarine biological sounds recorded over a 30 year period, 1976 to 2006. At least 40 fish species have been documented in this proprietary acoustic data bank and classified based on time series, spectral and sonographic analyses, fish capture and fish spawning in the wild and captivity. Historical fish classification work conducted by ECOS has developed a signal recognition system used to train a neural network. The diagnostic call parameters developed during historical work were used to perform signal analyses and signal processing developments.
Diagnostic spectra of the calls of the spotted seatrout and the time series details from HGO 21 September 2006 1900 hours.

Figure 5-41: Diagnostic Spectra of the Calls of the Spotted Seatrout

Figure 5-42: Diel Variation in Spotted Seatrout Spawning Call Intensity
Top to bottom, time series, spectra, and sonogram of early evening calls (left side) and intense late evening chorus (right side) in which a higher frequency simultaneous caller, the silver perch has joined the trout chorus.

5.5.5.2 Results/Discussion-Juvenile–Adult Fish Communities

Fisheries Independent Monitoring staff have undertaken a number of recent studies to aid determination of minimum flows and levels for the Southwest Florida Water Management District (SWFWMD) (Greenwood et al., 2004; Matheson et al., 2005a; Matheson et al., 2005b; Greenwood et al., 2006; MacDonald et al., 2006; Peebles et al., 2006a; Peebles et al., 2006b). In these studies, it is apparent that fish often respond dynamically to changes in freshwater inflow. Short-term responses to decreased flow often include dynamic distribution changes; increases in relative abundance of species that would normally occur near the lower limit of the tidal river, or decreases in relative abundance of low-salinity species that normally occur near the upstream limit of salt penetration. Analyses have demonstrated unimodal responses to flow in some species where relative abundance is greatest at intermediate flow levels and declines at high or low flows. This pattern probably represents a combination of processes. At low flows, relative abundance may be low because the input of nutrients and prey to the system is low or because the chemical signature attracting new recruits to the system is weak. At high flows, physical displacement from the system may occur or changes in food supply/physicochemical characteristics may be unsuitable for fishes or the chemical signal attracting nekton to the estuary may be diluted.

Analyses similar to those described above are planned for data collected for the SFWMD. Expansion of this holistic, multi-gear, long-term monitoring program into southern Charlotte Harbor, and subsequent analyses will provide south Florida resource managers with valuable information on fish communities that may be useful when gauging the effects of natural and anthropogenic disturbances, restoration projects affecting fish habitat and changes in water quality and quantity. Based on CEMs, the effect of salinity fluctuation on estuarine fish communities is an important question to be addressed, as is the effects of salinity fluctuation on seagrasses (Sime 2005). Thus, it will be of interest to closely examine if the seagrass-associated species in southern Charlotte Harbor respond to freshwater discharge. Also, of interest are the effects of mangrove loss on estuarine fish communities. Although much of the Charlotte Harbor estuarine system is protected by Aquatic Buffer Preserves, mangrove losses in the Caloosahatchee River, from the confluence of the Orange River tributary downstream to the mouth, have been dramatic; over 50 percent of the shoreline has been hardened with seawall and rip-rap. Much of the remaining mangrove habitat in the Caloosahatchee River is restricted to its backwaters (embayments, oxbows, and tributaries). It is hypothesized that freshwater and estuarine fish assemblages, and species-specific juvenile habitat, likely differ between the mainstem and backwaters of the river. Such differences may be relevant when analyzing data to determine the effects of freshwater inflow. Thus, a basic comparison of mainstem and backwater fish assemblages of the Caloosahatchee River seems necessary.
FIM: Southern Charlotte Harbor, Caloosahatchee River, and Estero Bay
The FIM program uses a stratified-random sampling design. For southern Charlotte Harbor and the Caloosahatchee River, the study area was divided into six bay zones (A-E and G) and three riverine zones (H, M, and P; Figure 5-43). Funding by the SFWMD allowed the expansion of sampling into Zones E, G, and H. Zones E and G encompass the southern portion of Charlotte Harbor, including parts of Matlacha Pass, Pine Island Sound and San Carlos Bay. Zone H extends from the mouth of the Caloosahatchee River upstream approximately 23 nautical miles (nm) to the Franklin Lock. A total of 71 samples were collected each month as part of the FIM expansion into lower Charlotte Harbor and the Caloosahatchee Estuary. For Estero Bay, the study area was divided into a bay zone (Estero Bay proper) and five riverine zones.

All sampling zones were divided into 1-nm² grids that were randomly selected for sampling each month. Sampling grids were stratified by habitat and depth, thereby identifying the gear types that could be used in those areas. A multi-gear approach was used to collect data on fishes and select invertebrates from a wide range of habitats and life history stages (Table 5-15). A 21.3-m center bag seine was used to collect small-bodied species and juveniles of large bodied species and in shallow areas (≤1.8 m), a 6.1-m otter trawl was used to collect juveniles to adults of various species and adult fish in deep water (1.0-7.6 m) and a 183-m haul seine was used to collect sub-adult and adult fish in shallow water (≤2.5 m) along shorelines.

Map of FIM designated sampling areas within the Charlotte Harbor and Caloosahatchee River region of the CERP NE.

Figure 5-43: FIM Map with Designated Sampling Areas
Table 5-15: Description of Monthly Monitoring Sampling Gear Used in 2005

<table>
<thead>
<tr>
<th>Gear</th>
<th>Deployment</th>
<th>MESH SIZE (mm)</th>
<th>Area Sampled</th>
<th>Description of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.3-m Seine (center bag)</td>
<td>Bay</td>
<td>3.2</td>
<td>140 m²</td>
<td>used in shallow (≤1.5 m) nearshore and shoreline areas</td>
</tr>
<tr>
<td></td>
<td>River</td>
<td>3.2</td>
<td>68 m²</td>
<td>used along river shorelines ≤1.8 m</td>
</tr>
<tr>
<td>183-m Haul Seine (center bag)</td>
<td>Boat</td>
<td>38.1</td>
<td>4,120 m²</td>
<td>used along shorelines and exposed sandbars (≤2.5 m)</td>
</tr>
<tr>
<td>6.1-m Otter Trawl</td>
<td>Bay/River</td>
<td>38.1 (3.2-mm liner)</td>
<td>1,130 m²-2,259 m²</td>
<td>used in areas from 1.8 m to 7.6 m deep</td>
</tr>
</tbody>
</table>

A more detailed description of each gear can be found in the FIM program’s Procedure Manual.

Environmental data consisting of water chemistry, habitat characteristics and physical parameters such as tidal conditions were recorded for each sample. The sample work-up technique was similar for all collected samples regardless of gear type or sampling regime. All fishes and select invertebrates captured in net collections were identified to the lowest practical taxonomic level, counted and measured (standard length for teleosts, precaudal length for sharks, disc width for rays, carapace width for crabs, and post-orbital head length for shrimp). All fishes and invertebrates were then released except for representative samples of each taxon (for laboratory confirmation of field identifications) and samples required for specific research projects. A detailed explanation of the standard sample work-up for data collection is described in the FIM program’s Procedure Manual.

Indian River Lagoon Seagrass Fish Populations Impacted by Freshwater Release, Bessie Cove
From July to November 2006 juvenile fishes were captured monthly with a 15.4 m 3.2 mm mesh seine associated with seagrass sites monitored by the SFWMD, at Boy Scout Island (Figure 5-44) in the Indian River Lagoon, one and a half kilometers from the mouth of the St. Lucie River. Since detailed seagrass meadow structure and density was being monitored these fish collections gave some indication of the habitat fish relationship along with other water quality conditions, salinity, temperature, and DO.

Historical Comparisons
The fish species captured in Bessie Cove seagrass meadows during 1974 were similar but not identical to those captured in 2006. Sixty-seven total species were recorded during the August to November period for both 1974 and 2006. During this late summer, fall period 17 species were captured in 1974 that were not captured in 2006, representing 25 percent of the total species recorded. 20 species were captured August to November in 2006 that were not captured during this same period in 1974, representing 30 percent of the total May-November
Bessie Cove fauna. The most notable differences were in the schooling planktivores, certain reef species and cryptic species such as gobiids, as both were lower in numbers and species in 2006 than in 1974.

In the CRE, the most abundant taxa were bay anchovy (*Anchoa mitchilli*), silversides (*Menidia* spp.), eastern mosquito fish (*Gambusia holbrooki*), mojarras (*Eucinostomus* spp.) and striped mullet (*Mugil cephalus*). The most abundant species of direct economic value were striped mullet, menhaden, (*Brevoortia* spp.), red drum (*Sciaenops ocellatus*), blue crab (*Callinectes sapidus*), and bluegill (*Leopomis macrochirus*). These lists of abundant and economically valuable species include a mixture of marine/estuarine and low-salinity/freshwater species, indicating the transition from estuarine to freshwater conditions within this system. The list of economically valuable species also includes several species for which the system is a valuable nursery area. A report providing additional details regarding the results of FIM sampling in this system has been prepared by the FIM program and is available upon request.

![Figure 5-44: 2003 versus 2006 Comparison of Boy Scout Island Seagrass Fish Monitoring Site, Indian River Lagoon](image)

The families whose species were present in 1974 collections, but not well represented in 2006 collections were the anchovies, snook, grouper, grunts, drums (*Sciaenidae*), wrasses and parrotfishes. Families better represented in 2006 were the sardines/herrings, mojarras,
filefish and boxfishes. Snapper, pipefish, jack, porgy, goby, blenny, puffer and burrfish representation was not very different between the years. Unusually prolonged snapper spawning activity in the adjacent Atlantic Ocean (FWC observations, Craig Faunce, personal communication) correlated well with late season recruitment in lane, mutton and gray snapper young of the year to both Boy Scout Island and Jensen Causeway seagrass meadows.

A qualitative analysis comparing species numbers and relative abundance exclusive of unit effort and relative fish density estimates, the 1974 and the 2006 collections separate in a Bray-Curtis similarity plot (Figure 5-45 and Figure 5-46). Significant total differences in captures between the years 2006 and 1974 in stenohaline reef species were observed in the great barracuda, 16 versus 44; grunts in the genus Haemulon, 19 versus 135; and wrasses and parrotfish, 0 versus 25. For some reason the species of mojarra that is the most abundant species in historical FWC collections in the St. Lucie River (Winner et al. 2005), the silver mojarra, Diapterus auratus, was much reduced in numbers in recent 2006 collections, with 26 (2006) versus 1,108 (1974) specimens captured.

![Bray-Curtis similarity plot for all species captured at Boy Scout Island in 2006 and historic collections in Bessie Cove in 1974, August to November including those fish species that do not associate with seagrass meadows as nursery habitat.](image)

**Figure 5-45: Bray-Curtis, Bessie Cove and Boy Scout Island-All species 2974 Versus 2006**
Bray-Curtis similarity plot for all species captured at Boy Scout Island in 2006 and historic collections in Bessie Cover in 1974, August to November including only fish species that associate with seagrass meadows as nursery habitat.

**Figure 5-46: Bessie Cove and Boy Scout Island Seagrass Species Only**

PCA and MDS plots, analyses and regression analyses indicated that historical seagrass collections in Bessie Cove were similar to those taken in 2006 for the same season of the year, August through November. Although they do consistently separate in MDS projections, they overlap in PCA plots with only August 1974 and September 2006 separating significantly (**Figure 5-47**).
Seagrass Fish Productivity–Densities

Fish densities are calculated based on the area covered by the seine transect (detailed species lists are available in the principle investigators annual reports). In comparing these numbers it must be kept in mind that the area sampled in 2006 (3,693 m²) is roughly three times that sampled monthly in 1974 (1,160 m²). Mean fish density in the 2006 collections was 81.87 fish per acre, only 5.35 percent of the 1974 average or 1,531.81 fish per acre. The three species with highest densities in collections made in 1974 are all open water planktivores, such as anchovies, while the 2006 collections top three included benthic predators, two mojarras, one of which is known to associate with seagrass meadows, the silver jenny, *Eucinostomous gula*. The pinfish, *Lagodon rhomboides* ranked high in both historical and recent collections although their densities were over three times higher in 1974 collections. Overall fish densities were 18.6 times higher in 1974 than they were in 2006.

These density estimates allow for the calculation of the approximate number of fish that may have been extirpated by the loss of seagrass in the St. Lucie Inlet area for the period August through November. If the snappers alone are examined, the lane snapper having a density of 108 fish per acre of seagrass in 1974 would have had a hypothetical population of 148,176 lane snapper in the 1,372 acres lost in the St. Lucie Inlet area 2004-2006. Mutton snapper would have had 61,740 additional fish, gray snapper, 9,604, red grouper 1,372, and 23,873 common snook. Therefore, these five species could have lost habitat for a quarter of a million individuals, 244,765 fish in the Bessie Cove, St. Lucie Inlet area alone.

If the average density of 1974 seagrass fish populations in Bessie Cove is taken as a conservative estimate, 1,532 fish per acre from August to November, then it can be estimated that 2,346,669 fish were lost due to seagrass meadow extirpation during this period of the year. Since this estimate includes planktivorous fishes such as anchovies this is undoubtedly an underestimate as single collections in seagrass samples of 1,160 m² have contained 150,000 individuals, including anchovies. That equates to 523,319 fish per acre during one instant in time, and the gear used, a 67 m, 3.2 mm mesh bag seine, is not totally efficient. Some abundant fish escaped capture, particularly mullet and diminutive gobies.

Overall these data indicate that even with the return of small amounts of seagrass in three species on Boy Scout Island Transect No. 2, there is utilization by primary seagrass associates especially newly recruited ocean spawners such as the snappers. This is extremely important as not only do snappers play a substantial ecological role as abundant predators, they also support regional commercial and sport fisheries and thus have great economic value. Since several snapper species are stenothermic tropicales, particularly the mutton and yellowtail snappers, the St. Lucie Inlet represents one of the only east coast ocean inlets north of Palm Beach County (others being Jupiter, Fort Pierce and Sebastian inlets) that can allow snapper recruitment to the IRL. This area may support more juvenile snapper populations than the Jupiter/Loxahatchee system simply due to its greater area, thus it would be of greater importance to producing young adults that recruit to continental shelf populations. The loss of seagrass in the vicinity of the St. Lucie Inlet has the potential to have substantial negative impacts on continental shelf fisheries, particularly the snapper fisheries based on these data.
Seagrass fish assemblages not only harbor the most diverse NE fish fauna, they are also contain fish that are more sensitive to water quality, salinity and other environmental perturbations that could inform freshwater ecosystem managers of potential deleterious CERP impacts. Seagrass fish assemblages can also reveal very positive measures that are taking place upstream. The 2006 fish collections in the Bessie Cove area demonstrated that even though there was limited seagrass compared to historical records, it was coming back at Boy Scout Island and the principal associated seagrass fish were returning as well, to the point that statistical comparisons indicated a resemblance with 1974 collections.

St. Lucie River–DIDSON Sonar and Shock Boat Field Observations
The initial DIDSON survey indicated that schools of adult mullet, 12 individuals were easily counted (Figure 5-48), as well as slow moving larger fish appeared to associate with bank vegetation and tree roots. The DIDSON sonar also indicated that it would be valuable in imaging bank vegetation and habitat complexity below the water’s surface. Observations revealed that the best operational mode for DIDSON was in a stationary monitoring position, panning the sonar image 360 degrees around a vertical post. This format would give the greatest image resolution. DIDSON use while in a drifting or mobile mode indicated that it was difficult to discern diagnostic morphological details on fish targets. DIDSON could be effectively used to monitor fish size, numbers and movements into and out of a choke point, such as the entrance to an oxbow or old river channel. Since its power requirements are minor, a field deployment of a unit with autonomous 24 volt battery power could allow remote monitoring for more than a day (Figure 5-48).

The shock boat collections captured 26 species, 206 individuals with common snook being the most abundant in collections. Next in abundance were striped mullet and tidewater mojarras. Fish numbers and species were more abundant in oxbows or old river channels than in dredged river channels, based on catch per unit effort. The three exotic species captured were all captured in the dredged river channel, while the four valuable tropical peripheral species were captured in the natural oxbow/old river channel habitats. This indicates that shock boat operations should concentrate on old river channels to capture the most indigenous fish species and numbers of individuals.

The sonar shocker comparison indicated that both techniques were complementary, the shock system allowing verification of sonar target. If the sonar was positioned in a stationary mode near a constriction in the river channel, it is apparent that all the fish moving by the sonar would at least be counted and measured, if not identified to species. It was also apparent that habitat complexity could be determined and potentially quantified using the DIDSON sonar image.
DIDSON image of a mullet school, old river channel, North Fork of St. Lucie River, 27 April 2006. From digital camera image of the laptop monitor screen.

**Figure 5-48: DIDSON Image of a Mullet School**

St. Lucie River–Autonomous Vehicle and Automated Water and Plankton Sampling Sea Trials

In August 2000, ten engineers from the University of South Florida (USF) Marine Science program gave a public briefing and demonstration of their prototype technologies and instrumentation designed to monitor various physical, chemical and biological parameters in remote aquatic settings. The demonstrations occurred in the IRL at Jensen Beach and in the North Fork of the St. Lucie River at White City. A new technology for capturing quantitative data on larval fish and other zooplankton, the SIPPER was examined with field trials during the fall 2006. This work indicated that SIPPER may be able to identify and quantify zooplankton in the NE provided its software processing can handle the particulate loads typical of estuaries.

Measuring Change/Confidence Uncertainty/Key Findings

Many investigators have used IBI to evaluate the health of freshwater ecosystems (Karr, 1981, Karr et al. 1994; Hughes 1995, Hughes et al. 1998). Fish assemblage, richness-diversity and species/population classification compared to sensitivity to environmental perturbation, nativity, economic and ecological value have been used to quantify indices allowing ecosystem managers to model fish assemblage dynamics relative to human activities.
Historical measurements of fish assemblage and population dynamics have often been made with classical fish capture equipment such as seine nets and trawls. This gear can be effective under certain circumstances, but typically require direct contact with the fish, extensive manpower, time and support equipment to capture and process the samples. Shock boat operations sample without removal, though it also requires contact with the fish and is limited by climate, personnel commitment, water salinity and fish size. These attributes do not permit shock boats to adequately sample small juvenile fish nor to work in higher salinities within the estuary. Remote observational techniques have used sonar and passive acoustic means to detect fish presence, estimate number and determine behavior such as spawning. These techniques require less manpower and can be set up to remotely transmit data to a central data depository, but are limited in identifying the target fish species, particularly in the case of sonar. Additional biological information on fish such as age, genetics and stomach contents can be carried out with fish capture techniques, but not with passive acoustics.

*Table 5-16* compares the positive and negative attributes of the various fish assessment systems utilized in this initial CERP Fish Module effort. *Table 5-17* attempts to place some subjective quantitative value on the various techniques in obtaining data on the specific life history stages that are presented in the Fish Module General Model for CERP. Emphasis should be placed on larval and juvenile fish assessment. This means that spawning activity should be monitored via passive acoustics; larval fish should be monitored with plankton nets or new technologies such as SIPPER; juveniles sampled with small mesh nets (seines or trawls) in critical habitats (seagrass), or shock boats, where possible, in difficult and complex freshwater habitats. Undoubtedly the major problem experienced by earlier investigators is the immense storage acoustic data requires. Without major computer systems associated with the observation posts, these early systems were destined to be impractical in the long run. Now that revolutionary data storage and transmittance systems are available, as well as software that automates data analyses, a continuous *in situ* passive acoustic observatory can be constructed and maintained on a relatively low budget, yet produce very powerful data sets.

With available resources, the FWC FIM program has been able to amass a huge data set on fish assemblages throughout Florida and correlate these data with environmental parameters over nearly two decades. This valuable program targets many of the most vulnerable life history stages, the larvae and juveniles, and should be considered for expansion in the CERP NE. It is recommended that both site specific sampling with relatively small 3.2 mm mesh seines and random sampling both be considered in this new effort. The use of these techniques should take into account the rich and voluminous data that has already been gathered by FIM to determine the most conservative and effective use of personnel, gear and time, yet yield the best data possible on the fish populations and assemblages determined to be most valuable to the CERP MAP effort.
### Table 5-16: Comparison of Fish Net Capture Data with Acoustic Data

<table>
<thead>
<tr>
<th>NET CAPTURE DATA</th>
<th>ACOUSTIC DATA (PASSIVE &amp; ACTIVE)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QUALITATIVE DATA</strong></td>
<td></td>
</tr>
<tr>
<td>SPECIES IDENTIFICATION</td>
<td>SPECIES IDENTIFICATION</td>
</tr>
<tr>
<td>NUMBER OF SPECIES</td>
<td>NUMBER OF SPECIES</td>
</tr>
<tr>
<td><strong>QUANTITATIVE DATA</strong></td>
<td></td>
</tr>
<tr>
<td>% FREQUENCY OCCURRENCE</td>
<td>% FREQUENCY OCCURRENCE</td>
</tr>
<tr>
<td>NUMBER OF INDIVIDUALS</td>
<td>NUMBER OF INDIVIDUALS (W. SOURCE LEVEL, MULTIPLE HYDROPHONES)</td>
</tr>
<tr>
<td>RELATIVE ABUNDANCE CATEGORY</td>
<td>RELATIVE ABUNDANCE CATEGORY</td>
</tr>
<tr>
<td>INDIVIDUAL WGT/SPECIES</td>
<td>MEAN CALL ENERGY LEVEL BY SPECIES (dB)</td>
</tr>
<tr>
<td>MEAN SPECIES WGT.</td>
<td>MEAN CHORAL ENERGY LEVEL, (dB) (SINGLE SPECIES or MIXED CHORUS)</td>
</tr>
<tr>
<td>INDIVIDUAL LENGTH</td>
<td>INDIVIDUAL LENGTH (DIDSON SONAR)</td>
</tr>
<tr>
<td>MEAN INDIVIDUAL LENGTH</td>
<td></td>
</tr>
<tr>
<td><strong>ADVANTAGES</strong></td>
<td></td>
</tr>
<tr>
<td>COMBINATION OF GEAR TYPES</td>
<td>UNOBTRUSIVELY DETERMINES SPAWNING INTENSITY, LOCATION, AND TIME PERIOD, GIVES INDIRECT DATA ON RELATIVE ABUNDANCE OF EGG/LARVAE, UNDER VARIOUS ENVIRON. CONDITIONS</td>
</tr>
<tr>
<td>NEEDED TO CAPTURE ALL LIFE STAGES</td>
<td>CAN DETERMINE AGE AND GROWTH PASSIVE, DOES NOT INTERFERE WITH FISH BEHAVIOR</td>
</tr>
<tr>
<td>CAN DETERMINE GENETICS</td>
<td>FEW PERSONNEL REQUIRED</td>
</tr>
<tr>
<td>CAN DETERMINE OTOLITH CHEMISTRY</td>
<td>ALL WEATHER CONTINUOUS MONITORING</td>
</tr>
<tr>
<td>OBTAINS ACCURATE MEASUREMENT</td>
<td>LOW OVERHEAD</td>
</tr>
<tr>
<td>CAN DETERMINE FEEDING HABITS</td>
<td>CONTINUOUS DATA STREAM</td>
</tr>
<tr>
<td>CAN GIVE MIGRATION WITHIN AN ACOUSTIC TAG RECEIVER ARRAY</td>
<td>REAL TIME MONITORING W DATA ANALYSES ALLOWS REAL TIME MANAGEMENT USE FOR DECISIONS.</td>
</tr>
<tr>
<td><strong>DISADVANTAGES</strong></td>
<td></td>
</tr>
<tr>
<td>DIRECTLY CONTACTS FISH CAUSING SOME MORTALITY</td>
<td>DOES NOT MONITOR ALL LIFE HISTORY STAGES, JUVS. NOT ASSESSED</td>
</tr>
<tr>
<td>PERSONNEL INTENSIVE</td>
<td>WILL NOT GIVE FEEDING ANALYSES, ALTHOUGH FEEDING MAY PRODUCE SOUND</td>
</tr>
<tr>
<td>LIMITED BY WEATHER</td>
<td>WILL NOT GIVE GENETIC ANALYSES, THOUGH DILECTS ARE ASSOCIATED WITH SUBPOPULATIONS</td>
</tr>
<tr>
<td>HIGH OVERHEAD</td>
<td>WILL NOT REVEAL AGE AND GROWTH, THOUGH CALL QUALITY COULD BE ASSOCIATED WITH SIZE AND AGE.</td>
</tr>
<tr>
<td>LIMITED DATA</td>
<td>WILL NOT GIVE OTOLITH CHEMISTRY, THUS WATER SIGNATURES</td>
</tr>
<tr>
<td>LIMITED BY BIOTOXINS, OTHER DANGEROUS WATER CONDITIONS</td>
<td>BIOFOULING - 2-4 WK MAINTENANCE IN ESTUARIES</td>
</tr>
</tbody>
</table>

Table 5-17: Degree of certainty in obtaining sufficient high quality data that would allow management decisions is presented on a scale of 1-10, 10 being the highest level of certainty.

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>CLASSICAL TECHNOLOGIES</th>
<th>INNOVATIVE TECHNOLOGIES</th>
<th>TOTAL LIFE STAGE SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plankton net (505 um)</td>
<td>Passive Acoustic Array, ECOS</td>
<td>Out of 120</td>
</tr>
<tr>
<td></td>
<td>10 7 7 0 0 0 0 0 7 0 0 0 0 31</td>
<td>0 7 7 0 5 7 5 41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.3 m, 3.2 mm mesh Seine</td>
<td>Passive Acoustic Network, VR2</td>
<td>0 31 31 23 30 15 30</td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 7 4 10 7 0 0 0 0 28</td>
<td>0 0 0 0 7 10 7 100</td>
<td>37 25 35 37 36</td>
</tr>
<tr>
<td></td>
<td>21.3 m Seine</td>
<td>Biosonics Sonar, Long range (1 km)</td>
<td>0 31 31 23 30 15 30</td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 7 4 10 7 0 0 0 0 44</td>
<td>0 8 8 10 7 10 100</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td>67 m, 3.2 mm mesh Seine</td>
<td>DIDSON Sonar, Short range (&lt;30 m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 7 4 10 7 0 0 0 0 52</td>
<td>0 8 8 10 7 10 100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 sq m, 3.2 mm mesh throw net</td>
<td>BLUE VIEW Sonar, Short range (&lt;30m)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 5 10 10 7 0 0 0 0 32</td>
<td>0 8 8 10 8 10 100</td>
<td></td>
</tr>
<tr>
<td>Electro-shock, to 15ppt</td>
<td>SCORE SUM</td>
<td>Telemetry/Communication Station</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 3 3 10 7 1 2 7 10 2 45</td>
<td>Disseminates data continuously real time to processing and data analyses centers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SCORE SUM</td>
<td>Web Site</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 7 7 29 25 50 35 8 2 17 30 12</td>
<td>Disseminates data continuously real time to processing and data analyses centers</td>
<td></td>
</tr>
</tbody>
</table>

Critical life history characters are shaded.
Conclusion
Emphasis can now be placed on specific fish PMs that are likely to aid management decisions using the present assessment evaluation. The first PM is based on fish spawning activity. Spawning intensity based on acoustic measurements will provide a quantitative statistic on spawning success in ecologically and economically valuable species that depend on the estuary. Spawning activity is directly influenced by ambient water quality and riverine environmental conditions. Spawning success relates directly to egg/larval abundance in the water column. The greatest larval abundance is not only at the spawning site but at specific frontal boundaries typically revealed by rapid geographic changes in salinity. Fish larvae usually concentrate at the frontal boundary in a specific salinity zone. This region is within the zero to ten ppt salinity range where salinity changes rapidly in the mid to upper reaches of the coastal river. Mapping the extent and location of this zone and determining the fish egg/larval abundance associated with this zone should be a second PM. A third PM is the abundance and diversity of fishes associated with seagrass habitats, particularly diminutive residents and juvenile fishes. The seagrass fish fauna is the richest and most environmentally sensitive regional estuarine fish fauna and should respond both positively and negatively to various water management scenarios.

These three PMs are quantitatively obtained with totally unrelated independent technologies, but are directly related biologically. All the biological information gained is directly related to fish early life history, the most sensitive periods to environmental perturbation and the larval and juvenile stages. Concentration of fish assessment efforts during the early ontogenetic period allows the dynamics of fish abundance to be obtained during the critical larval-juvenile developmental stages and important adult behavior (spawning). Measurement of physical-chemical parameters simultaneous with these biological parameters over extended periods of time will provide a powerful tool for developing quantitative models of fish abundance and ecology in association with freshwater quantity and quality.

A variety of fish capture and observation techniques and technologies have shown great promise in allowing continuous monitoring of fish population and assemblage activities in the NE. Some of these techniques have decades of use, others are new and must be developed further. Nearly all show promise in providing critical information on fish population/assemblage status during CERP implementation.

The comprehensive and complementary nature of the various fish assessment efforts outlined in this review reveal that if this program is to be effective, it should entail a coordinated effort between various private, state and federal entities. Only a stable long-term collaborative funding base and close communication between investigators will insure the most successful and holistic fish assessment.

Given the great economic and ecological value of fish assessment and conservation within CERP, the best monitoring system possible will have great ecological, economic, social and political value.

**A thorough discussion of water quality issues in the NE can be found in Appendix 5A.**
5.6 Northern Estuaries Module Conclusion

Overall conclusions are difficult to make in the NE due to the fact that the four different waterbodies that are included in this module often have very different types and levels of stress affecting them on any given year. For example, although the CRE and the SLE both receive excessive discharges from LO during wet years, the CRE also suffers from too little discharge on excessively dry years whereas the lack of dry season discharge from LO into the SLE has no discernable detrimental impact. The LRE is affected by both low flow and high flow extremes, but the detrimental effects are more localized and site specific.

Overall the NE monitoring plan has been successfully implemented and although monitoring data for some indicators is limited to just one or two years, some important observations have been made as to the overall condition of the estuaries Pre-CERP condition. In estuaries where several different indicators are being monitored and coverage of the different salinity zones and habitats has been successfully implemented, multiple lines of evidence can be used to begin to paint a picture of the state of that waterbody. It is apparent, even at this early stage, that catastrophic natural events such as recent southeast coast hurricane landings have a huge impact on the natural resources, often overshadowing any pattern of response attributed to anthropogenic disturbances or restoration efforts. Long-term data sets will be necessary for us to begin to tease out natural variability from CERP related changes. The hypothesis clusters in the NE include SAV, oysters, benthic macroinvertebrates and fish.

Monitoring data from the SAV hypothesis cluster indicates that there is a need to better understand the causal mechanisms that control SAV growth, as well as a need for CERP to understand the affect that the timing (duration and time of occurrence) of a freshwater discharge may have on SAV; specifically, changes in water quality must be accounted for with regard to controlling freshwater discharge in the NE. Flows that are altered beyond historic conditions have negatively impacted SAV in the NE. For example, freshwater SAV such as *V. americana*, which was historically found in upper estuaries, have been diminished or extirpated because of their inability to survive prolonged periods of elevated salinity that often results from diminished freshwater flow. Similarly, marine SAV species such as *T. testudinum* and *S. filiforme* are harmed by excessively low salinities and highly variable salinity regimes. Light also appears to be a major factor controlling the depth distribution of seagrasses in the NE with turbidity and color (two major light attenuators) significantly affecting seagrass distributions. For example, elevated freshwater discharges into the SIRL from the SLE result in increased color and turbidity (hence increased light attenuation), which inhibits seagrass coverage especially at the deep edge of a bed. Managing the frequency and duration of freshwater discharges with relation to the species-specific physiological requirements of seagrasses should reduce light attenuation through a reduction in turbidity and color and thus relax this stressor on seagrass growth. While current research may provide insight as to the range of salinities that SAV species may tolerate, little data is available that describes the response of SAV to rapid salinity changes, as might be the case when controlling freshwater discharges in the NE. SAV models and GIS applications need to be developed and linked to hydrodynamic water quality models to refine predictions. Establishing linkages between water quality/quantity and SAV requires real-time *in situ* monitoring of key water quality parameters. A network of sampling units within the NE will be necessary in order to relate assessments to goals and targets.
While the existing sampling design and sampling frequency can adequately assess the direction and magnitude of change in the oyster hypothesis cluster, the sampling protocol may be adjusted to better capture the spatial variation of responses. A significant relationship exists between freshwater inflows and salinities at various points in the CRE. Flows below 3500 cfs into the estuary from S-79 will result in a salinity regime that will enable oysters to survive and grow. Disease prevalence was lower at upstream locations and increased with distance downstream, suggesting that higher salinities result in increased disease incidence. Limited freshwater releases for durations of less than two weeks will result in lower disease prevalence and intensity of oysters and higher survival. Oysters in the CRE appear to spawn actively between May–October, a period that coincides with freshwater releases and or watershed runoff. While downstream locations attract higher spat recruitment due to higher substrate availability and estuarine conditions during high flow summer-fall months, growth and survival of juveniles is poor. Limiting freshwater releases to < 3500 cfs during these months will limit flushing of oyster larvae to downstream locations and create a favorable salinity regime for spat recruitment and survival. Low disease incidence, high CI, sufficient spat recruitment and high growth rate at the upstream locations suggest that with the provision of suitable substrate and limiting freshwater flows during the spawning season, oyster reefs will survive and grow at the upstream locations. The densities of living oysters are being assessed, but a plan to map the extent of oyster reef development (spatial coverage in acres) needs to be developed and implemented. Extent of oyster coverage is described as an interim goal, thus oyster mapping should be conducted on a five year schedule that corresponds to the interim goal schedule. Also, an understanding of larval exchange is a necessary precursor to the proper management of oyster reefs in Florida because that information will reveal those oyster reefs that act as larval sources and are therefore fundamental to the long-term survival of oyster populations in Florida waters.

Data from the benthic macroinvertebrate hypothesis cluster indicates that the benthic communities respond quickly to environmental changes and that they reflect changes in discrete zones within the monitored areas in the SLE and SIRL. The data indicate that the SLE is ecologically degraded, especially in the South Fork and in the middle SLE basin, which receives frequent freshwater discharges from the C-44 canal. The data also indicate that the Hells Gate area may be a transition zone, and the conditions beyond that zone improve dramatically. The infaunal monitoring indicates that the SLE and SIRL display gradients of disturbance. The most disturbed areas occur in the South and North Forks and the middle SLE Basin, which periodically receives high freshwater releases (and nutrients) from the C-23, C-24 and C-44 canals. The North Fork River is in better ecological condition with a mixture of limnic and estuarine taxa. Once a larger dataset is available, it will be possible to develop an accurate picture of long-term changes and to be able to distinguish natural changes, successions and oscillations from anthropogenic impacts.

A variety of techniques have been implemented to assess the fish hypothesis cluster. Experience with historical use of various quantitative fish assessment-monitoring technologies and a variety of new techniques/technologies were used to come to the conclusion that egg/larval, juvenile and adult life history stages should be an integral part of the fish hypothesis cluster for the NE. Spawning intensity based on acoustic measurements will provide a quantitative statistic on spawning success in ecologically and economically
valuable species that depend on the estuary. Spawning activity is directly influenced by ambient water quality and riverine environmental conditions. Spawning success relates directly to egg/larval abundance in the water column. The greatest larval abundance is not only at the spawning site but at specific frontal boundaries typically revealed by rapid geographic changes in salinity. Fish larvae usually concentrate at the frontal boundary in a specific salinity zone. This region is within the zero to ten ppt salinity range where salinity changes rapidly in the mid to upper reaches of the coastal river. Mapping the extent and location of this zone and determining the fish egg/larval abundance associated with this zone will address a portion of the hypothesis cluster. The abundance and diversity of fishes associated with seagrass habitats, particularly diminutive residents and juvenile fishes is also critical to the hypothesis cluster. The seagrass fish fauna is the richest and most environmentally sensitive regional estuarine fish fauna and should respond both positively and negatively to various water management scenarios. Concentration of fish assessment efforts during the early ontogenetic period allows the dynamics of fish abundance to be obtained during the critical larval-juvenile developmental stages and important adult behavior (spawning). Measurement of physical-chemical parameters simultaneous with these biological parameters over extended periods of time will provide a powerful tool for developing quantitative models of fish abundance and ecology in association with freshwater quantity and quality.

5.7 Status of Monitoring in the Northern Estuaries

The following table provides an abbreviated status of monitoring in the LO Module. The table includes a list of monitoring components, links them to the associated hypothesis cluster(s) and PMs, and provides a brief description of the monitoring itself as well as its status. The table is not meant to be exhaustively comprehensive and represents the most current information to date when the table was developed.
### Table 5-18: Status of Monitoring in the NE

<table>
<thead>
<tr>
<th>NE Hypothesis Cluster</th>
<th>MAP Section #</th>
<th>MAP Section Title</th>
<th>Performance Measure #</th>
<th>Description of Effort</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAV Distribution and Function</td>
<td>3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.3.4, 3.3.3.5</td>
<td>1) Salinity Monitoring Network; 2) WQ Network; 3) SAV Mapping from Aerial photography; 4) SAV Monitoring</td>
<td>NE1, NE2, NE3, NE4, NE5, NE6, NE7, NE8, NE9, NE10, NE11, NE16, NE17, NE15</td>
<td>Salinity monitoring is performed at multiple stations in each of the four Northern Estuaries, several stations contain real-time monitoring gauges and some are sampled monthly. WQ monitoring is performed in all estuaries with differing periods of record. SAV mapping and monitoring is currently underway in all four estuaries.</td>
<td>Efforts are underway to utilize newer technologies to obtain more real time salinity and water quality measurements co-located with SAV sites. SAV monitoring is being evaluated to try to bring more standard methodologies to the various estuaries.</td>
</tr>
<tr>
<td>Oyster Health and Abundance</td>
<td>3.3.3.1 &amp; 3.3.3.6</td>
<td>1) Salinity Monitoring Network; 2) Oyster Monitoring Network</td>
<td>NE1, NE2, NE3, NE4, NE12</td>
<td>Salinity monitoring is performed at multiple stations in each of the four Northern Estuaries, several stations contain real-time monitoring gauges and some are sampled monthly. Oyster monitoring is currently underway in all estuaries, the period of record varies between estuaries.</td>
<td>Efforts are underway to utilize newer technologies to obtain more real time salinity measurements to coincide with locations of oyster monitoring. Caloosahatchee estuary has the longest period of record and has established Pre-CERP baseline. An oyster Habitat Suitability Model for use as both a predictive tool (for Interim Goals predictions) as well as in assessments is currently under development.</td>
</tr>
<tr>
<td>Benthic Community Structure</td>
<td>3.3.3.1, 3.3.2, 3.3.3.8</td>
<td>1) Salinity Monitoring Network; 2) WQ Network; 3) Benthic Macroinvertebrate Monitoring</td>
<td>NE1, NE2, NE3, NE4, NE5, NE6, NE7, NE8, NE9, NE10, NE11, NE13, NE16, NE17, NE15</td>
<td>Benthic monitoring in the SLE and SIRL only. Samples are taken 4x/year at stations representing the different salinity zones and bottom types.</td>
<td>This effort is in its third year.</td>
</tr>
<tr>
<td>Fisheries Abundance and Habitat Assessment</td>
<td>3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.3.4, 3.3.3.5</td>
<td>1) Salinity Monitoring Network; 2) WQ Network</td>
<td>NE1, NE2, NE3, NE4, NE14</td>
<td>Fisheries abundance and location of different lifecycles and habitats and their relationship to flows and salinities are being evaluated in the Caloosahatchee and St. Lucie Estuary are being assessed under two different programs on each coast. A pilot study was utilized in the past two years in the SLE to test the feasibility and cost effectiveness of alternative technologies. During the same period of time in the Caloosahatchee Estuary the traditional random sampling design using nets was employed. The future direction is to evaluate and determine what technique or combination of techniques will provide the best quality of data at the lowest cost.</td>
<td></td>
</tr>
</tbody>
</table>
5.8 Northern Estuaries References


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5.9 Acknowledgements

The NE section was a collaborative effort of many scientists. Patti Sime, Aswani Volety, Bill Arnold, Brad Robbins, Becky Robbins, Albrey Arrington, Bjorn Tunberg, Ed Matheson, Grant Gilmore, Dan Haunert, Nenad Iricanin, Greg Graves, Dan Crean and other NE Module Team members played an integral role in the development of this report.
APPENDIX 5A–NORTHERN ESTUARY WATER QUALITY OVERVIEW

5A.1 St. Lucie Estuary Water Quality Baseline

5A.1.1 Background Description

The SLE is a major riverine estuary located on the boundary between Martin and St. Lucie Counties (Figure 5A-1) and connected to LO through canal C-44. The SLE supports a variety of recreational and commercial activities that are of economic importance to the surrounding communities. Large volumes of nutrient laden fresh water drain from the C-23, C-24 and C-44 basins as well as, LO impacting the health of the SLE. In 1987, the SWIM Act (Chapter 373.451–373.4595, Florida Statutes) and (Rule 17-43.035 F.A.C.), FDEP designated the IRL as a priority water body for special protection. The St. Lucie River Watershed and the SLE were recognized as major contributors of fresh water runoff into the receiving waters of the SIRL. The SLE was heavily impacted by three hurricanes in September 2004 (Francis, Jeanne and Ivan) and once again in October 2005 when Hurricane Wilma hit south Florida. The resulting high freshwater flows and signatures can be seen in Figures 5A-2 through 5A-4.

5A.1.2 Methods and Analysis

As part of the SWIM initiative, a long-term water quality monitoring program was started in October 1990 in the SLE. Ten water quality monitoring stations (SE 01, SE 02, SE 03, SE 04, HR1, SE 06, SE 07, SE 08, SE 09 and SE 10) were established to detect long-term spatial and temporal water quality trends in the SLE. In 1997 an eleventh station (SE 11) was added in the St. Lucie inlet to better characterize the water quality values in the estuary (Figure 5A-1). The data set analyzed in this paper includes the period of record from October 1990 through December 2006. Data were collected bi-weekly from October 1990 through December 1996 and monthly from January 1997 to December 2006. All sample collections were conducted in strict accordance with the FDEP approved SFWMD Comprehensive Quality Assurance Plan number 870166G. In addition, the SFWMD received a National Environmental Laboratory accreditation Conference (NELAC) certification on May 1, 2002, in accordance with the FDEP. All samples were collected as close to low tide as possible. In situ physical parameters (e.g., temperature, pH, specific conductance, dissolved oxygen and salinity) were measured using a Hydrolab Surveyor III multi-parameter sampling device. These physical parameters were measured at half-meter increments from the bottom of the water column to the surface. Additionally, a Secchi disk depth was recorded at monitoring station. Missing salinity values were calculated using conductivity and temperature measurements following the method of Millero (1982). Water quality samples were collected using a Wildco 2.2-liter Van Dorn poly-vinyl chloride (PVC) horizontal sampling bottle (or Niskin sampling bottle) at half of the total depth from each sampling site. Samples were analyzed for turbidity, TSS, color, TP, total Kjeldahl nitrogen, orthophosphate, nitrate + nitrite and ammonia. Samples for chlorophyll a analysis were collected at one half of the Secchi disk depth. TN concentrations were calculated from total Kjeldahl nitrogen and nitrate+nitrite concentrations.
Figure 5A-1: Map Showing Surface Water Quality Monitoring Stations, Inflow Structures and Regions of the SLE
Figure 5A-2: Time Series Plot of Total Monthly Freshwater Inflow to the Estuary and Associated Mean Salinity Levels in the Four Regions of the SLE

Note: St. Lucie Inlet (SE 11) site was added to the SLE monitoring program in 1997
Figure 5A.3: Time Series Plot of Total Monthly Phosphorus Loads and Flow Weighted Mean Phosphorus Concentrations to the Estuary and Associated Mean Total Phosphorus Concentrations in the Four Regions of the SLE
Figure 5A.4: Time Series Plot of Total Monthly Nitrogen Loads and Flow Weighted Mean Nitrogen Concentrations to the Estuary and Associated Mean Total Nitrogen Concentrations in the Four Regions of the SLE.
**5A.1.3 Results and Discussion**

For the purpose of this report a limited number of parameters were used to summarize water quality in the SLE. Those parameters are:

- salinity
- color
- total nitrogen
- dissolved oxygen
- total phosphorus
- chlorophyll $a$

In addition, the estuary was divided into four sections (*Figure 5A-1*): the inlet (SE 11); main estuary (SE 01, SE 02 and SE 03); North Fork (SE 04, HR1, SE 06 and SE 07); and South Fork (SE 08, SE 09, SE 10). The period of record used in this summary was July 1992 through December 2006.

A summary of annual fresh water inflow and associated nutrient loads to the estuary from the three main canals is provided in *Table 5A-1*. On average, the estuary receives $1,034 \times 10^6$ cubic meters ($m^3$) of freshwater and 268 and 1,735 metric tons of P and N, respectively. A graphical summary of the effects of these flows and loads on the estuary is provided in *Figure 5A-5* through *Figure 5A-7*. Salinity and TP reveal strong seasonal signals in response to freshwater releases to the SLE. An inverse relationship is observed for salinity and freshwater inflow (*Figure 5A-5*) while TP concentrations in the SLE reveal a direct response to inputs (*Figure 5A-6*). TN demonstrates a seasonal pattern although the effects are not as robust as for P and salinity. In each case, the North and South Forks are more greatly influence than the remainder of the estuary.

This strong seasonal signal to freshwater inflows and nutrient loads to the estuary is expected in a tropical system with a clear demarcation between the wet season (May through October) and the dry season (November through April). Monthly plots demonstrating freshwater inflow and nutrient loads to the SLE and the concomitant change in concentration for the six parameters of interest are provided in *Figures 5A-2* through *5A-4*.

Box and whisker plots were used to analyze seasonal differences for the six parameters in the four regions of the SLE (*Figure 5A-8* and *Figure 5A-9*). In addition, the Mann-Whitney test used to determine seasonal changes were statistically significant (*Table 5A-2*). Based on these plots and the information in *Table 5A-2*, salinity and DO exhibited significant increases during the dry season in four regions of the SLE. Color, TP, TN and chlorophyll $a$ exhibited increases during the wet season. Only color and TP exhibited statistically significant increases in all portions of the SLE. TN did not exhibit a significant increase in the South Fork, while chlorophyll $a$ did not exhibit a significant increase in the inlet region (*Table 5A-2*).

Regression analyses were also performed for color, TN and TP with salinity (*Figures 5A-10* through *5A-12*). These plots demonstrate that these parameters can be used as indicators of freshwater inflow to the estuary as they are inversely correlated with salinity.
Table 5A-1. Annual summary of freshwater flows and nutrient loads to the SLE.

<table>
<thead>
<tr>
<th>Water Year$^a$</th>
<th>Total Freshwater Flow to Estuary$^b$ (m$^3$ X 10$^6$)</th>
<th>Phosphorus</th>
<th>Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Loads$^b$ (metric tons)</td>
<td>Flow Weighted Mean$^b$ (µg/L)</td>
</tr>
<tr>
<td>1993</td>
<td>922</td>
<td>204</td>
<td>221</td>
</tr>
<tr>
<td>1994</td>
<td>216</td>
<td>65</td>
<td>301</td>
</tr>
<tr>
<td>1995</td>
<td>1,391</td>
<td>236</td>
<td>170</td>
</tr>
<tr>
<td>1996</td>
<td>1,898</td>
<td>388</td>
<td>205</td>
</tr>
<tr>
<td>1997</td>
<td>427</td>
<td>71</td>
<td>167</td>
</tr>
<tr>
<td>1998</td>
<td>1,889</td>
<td>397</td>
<td>210</td>
</tr>
<tr>
<td>1999</td>
<td>472</td>
<td>127</td>
<td>270</td>
</tr>
<tr>
<td>2000</td>
<td>958</td>
<td>307</td>
<td>320</td>
</tr>
<tr>
<td>2001</td>
<td>246</td>
<td>53</td>
<td>215</td>
</tr>
<tr>
<td>2002</td>
<td>484</td>
<td>188</td>
<td>389</td>
</tr>
<tr>
<td>2003</td>
<td>728</td>
<td>189</td>
<td>260</td>
</tr>
<tr>
<td>2004</td>
<td>1,216</td>
<td>295</td>
<td>242</td>
</tr>
<tr>
<td>2005</td>
<td>1,470</td>
<td>601</td>
<td>409</td>
</tr>
<tr>
<td>2006</td>
<td>2,153</td>
<td>634</td>
<td>295</td>
</tr>
<tr>
<td>Mean</td>
<td>1,034</td>
<td>268</td>
<td>260</td>
</tr>
</tbody>
</table>

$^a$ Water year based on 12-month period starting in May and ending in April.

$^b$ Determined from gauged flow data and water quality samples collected at S-80, S-49 and S-48.
Graphs show distribution of monthly median values with the inter quartile range (i.e., 25th and 75th percentiles) for the period from July 1992 through December 2006.

**Figure 5A-5: Monthly Distribution of Freshwater Inflow to the Estuary and Associated Median Salinity Levels in the Four Regions of the SLE**
Graphs show monthly median distribution values with the inter quartile range (i.e., 25th and 75th percentiles) for the period from July 1992 through December 2006.

Figure 5A-6: Monthly Distribution of Flow Weighted Mean Total Phosphorus Concentrations at the Three Gauged Inflow Structures to the Estuary and Associated Median Total Phosphorus Concentrations in the Four Regions of the SLE
Graphs show distribution of monthly median values with the inter quartile range (i.e., 25\textsuperscript{th} and 75\textsuperscript{th} percentiles) for the period from July 1992 through December 2006.

**Figure 5A-7:** Monthly Distribution of Flow Weighted Mean Total Nitrogen Concentrations at Gauges Inflow Point to the Estuary and Associated Median Total Nitrogen Concentrations in the Four Regions of the SLE
Figure 5A-8: Notched Box and Whisker Plots Comparing Dry and Wet Season Concentrations of Salinity (A and B); Color (C and D); and Dissolved Oxygen (E and F) Levels in Four Regions of the SLE for the Period from July 1992 through December 2006.
Figure 5A-9: Notched Box and Whisker Plots Comparing Dry and Wet Season Concentrations of Total Phosphorus (A and B); Total Nitrogen (C and D); and Chlorophyll a (E and F) Levels in Four Regions of the SLE for the Period from July 1992 through December 2006
Figure 5A-10: Regression of Color with Salinity within Each Region of the SLE
Figure 5A-11: Regression of Total Phosphorus with Salinity within Each Region of the SLE
Figure 5A-12: Regression of Total Nitrogen with Salinity within Each Region of the SLE

St. Lucie Inlet

Main Estuary

South Fork

North Fork

n = 110
Y = -0.027X + 1.45
r² = 0.29
Spearman Correlation = -0.44

n = 575
Y = -0.028X + 1.43
r² = 0.35
Spearman Correlation = -0.62

n = 546
Y = -0.030X + 1.40
r² = 0.11
Spearman Correlation = -0.39

n = 795
Y = -0.026X + 1.30
r² = 0.19
Spearman Correlation = -0.50
Parameters | North Fork | South Fork | Main Estuary | St. Lucie Inlet
---|---|---|---|---
Salinity | Dry<sup>a</sup> | Dry<sup>a</sup> | Dry<sup>a</sup> | Dry<sup>a</sup>
Dissolved Oxygen | Dry<sup>a</sup> | Dry<sup>a</sup> | Dry<sup>a</sup> | Dry<sup>a</sup>
Color | Wet<sup>a</sup> | Wet<sup>a</sup> | Wet<sup>a</sup> | Wet<sup>a</sup>
Total Phosphorus | Wet<sup>a</sup> | Wet<sup>a</sup> | Wet<sup>a</sup> | Wet<sup>a</sup>
Total Nitrogen | Wet<sup>a</sup> | Wet | Wet<sup>a</sup> | Wet<sup>a</sup>
Chlorophyll <i>a</i> | Wet<sup>a</sup> | Wet<sup>a</sup> | Wet<sup>a</sup> | Wet

<sup>a</sup> Season exhibited a statistically significant increase in concentration

Concentrations of most water quality parameters decreased in a westerly direction from the mouth of the SLE as a result of nutrient laden freshwater inflows to both the North and South Forks. Although the North and South Forks drain different basins, water quality for these two regions is similar. The increased freshwater inputs observed during the wet season through the North and South Forks tend to explain the majority of the seasonal variability (Doering, 1996).

Hand (2004) established median water quality standards for four parameters: chlorophyll <i>a</i> (7.2 mg/m<sup>3</sup>), TN (0.67 mg/L), TP (100 µg/L), and Secchi depth (1.0 m) for Florida estuaries. Although the median TN concentration for the four regions of the SLE ranged from 0.3 mg/L for the inlet and 0.6 mg/L for South Fork (<i>Table 5A-3</i>), they were below the 0.67 mg/L criteria established by Hand (2004). Median TP levels for the SLE far exceeded the median value for comparable Florida estuarine systems (<i>Table 5A-3</i>). These higher TP values can be attributed to increased nutrient laden fresh water inflows (Chamberlain and Hayward, 1996). Median chlorophyll <i>a</i> values and Secchi depth in the SLE (<i>Table 5A-3</i>) were comparable to the water quality values derived by Hand (2004). Chamberlain and Hayward (1996) found that the highest chlorophyll <i>a</i> values were associated with low flow conditions resulting in low nutrient concentrations and color levels. Long flushing time and high light availability under low flow conditions favor the accumulation of chlorophyll <i>a</i> biomass.

Dissolved oxygen is a critical indicator of the health of an estuarine ecosystem (Engle <i>et al</i>, 1999). The majority of stations in the North and South Forks of the SLE exhibit hypoxia with some of the stations exceeding the EPA standards more then 20 percent of the time over the last decade (<i>Figure 5A-13</i>). Since measurements of DO are performed during optimal photosynthetic conditions, the DO levels can be assumed to be lower periods of the diel cycle when respiration is optimal. Stations co-located with structures tended to have higher incident of exhibiting hypoxic and anoxic conditions. This is believed to be a result of
stratification between fresh and brackish waters under low or no flow conditions. Sites not adjacent to structures and still exhibiting hypoxic conditions are of concern.

Table 5A-3: Statistical Summary of Selected Water Quality Parameters in the S for the Period July 1992 through December 2006

<table>
<thead>
<tr>
<th>Parameter</th>
<th>South Fork</th>
<th>North Fork</th>
<th>Main Estuary</th>
<th>Inlet</th>
<th>Entire Estuary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± Standard Deviation</td>
<td>Minimum</td>
<td>5th</td>
<td>25th</td>
<td>50th</td>
</tr>
<tr>
<td>Salinity (PSU)</td>
<td>3.8 ± 5.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>6.1 ± 2.1</td>
<td>&lt;0.1</td>
<td>2.0</td>
<td>4.8</td>
<td>6.4</td>
</tr>
<tr>
<td>Apparent Color (PCU)</td>
<td>72.1 ± 47.5</td>
<td>0.5</td>
<td>27.0</td>
<td>37.0</td>
<td>55.0</td>
</tr>
<tr>
<td>Secchi disk depth (m)</td>
<td>0.8 ± 0.4</td>
<td>&lt;0.01</td>
<td>0.2</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Total Nitrogen (mg/L)</td>
<td>0.75 ± 0.63</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>0.20</td>
<td>0.63</td>
</tr>
<tr>
<td>Total Phosphorus (µg/L)</td>
<td>192.2 ± 84.8</td>
<td>72.0</td>
<td>99.0</td>
<td>136.0</td>
<td>220.0</td>
</tr>
<tr>
<td>Chlorophyll a (mg/m³)</td>
<td>10.4 ± 9.5</td>
<td>0.3</td>
<td>1.6</td>
<td>3.9</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Number of dissolved oxygen values measured in the four regions of the SLE from July 1992 through December 2006 that were less than 2.0 mg/L, greater or equal to 2.0 and less than 4.0 mg/L, and greater than or equal to 4.0 mg/L. Each dissolved oxygen value was calculated as a mean of the vertical profile at stations in the four regions.

**Figure 5A-13: Number of Dissolved Oxygen Values Measured in the Four Regions of the SLE for the Period July 1992 through December 2006**
Appendix 5A  Northern Estuaries Water Quality

5A.2 Southern Indian River Lagoon Water Quality Baseline

5A.2.1 Background Description

The IRL extends approximately 250 km along the east coast of Florida from the Ponce de Leon Inlet in Volusia County to the Jupiter Inlet in Palm Beach County. This study focuses on the southern 75 km of the IRL between the northern St. Lucie County line and the Jupiter Inlet (Figure 5A-14). This portion of the Indian River Lagoon is flushed by Atlantic Ocean water at three inlets: Ft. Pierce, St. Lucie, and Jupiter. As a result, circulation in SIRL is better than in the other portions of the lagoon. Two major freshwater sources to the SIRL are the C-25 canal (Taylor Creek) and the St. Lucie River. Freshwater released through the C-25 canal discharges into the west side of the lagoon across from the Ft. Pierce Inlet. The mouth of the St. Lucie River is located due west of the St. Lucie Inlet (Figure 5A-14) and receives the majority of its freshwater from three canals: C-44 (including regulatory releases from LO), C-23 and C-24 (Figure 5A-15).

The IRL is believed to have the highest species diversity of any estuary in North America (Gilmore 1986) with approximately 2,200 species being identified (Barile 1987). Species diversity is believed to be higher near inlets and toward the southern end of the lagoon (IRL SWIM 1994). However, habitat and species diversity are believed to be impacted by declining water and sediment quality. Two major sources are believed to impact the SIRL: a) pollution from point and non-point sources; and b) alteration of natural circulation in the lagoon and increased freshwater inputs. The SIRL is susceptible to nutrient enrichment and increased turbid conditions which can transform the lagoon from a macrophyte-based to phytoplankton-based. Portions of the SIRL are showing the effects of increased nutrient and suspended material impacts with apparent loss of sea grasses near urbanized areas (Indian River Lagoon SWIM 1994).

The purpose of this report is to summarize the existing water quality conditions in the SIRL. This summary will focus on nutrients and parameters affecting the clarity of the water in the SIRL. Data collected from October 1990 through December 2006 will be discussed.

5A.2.2 Methods and Analysis

Water quality data used in this report was collected at 21 SIRL water quality stations shown in Figure 5A-15. These stations were monitored quarterly from October 1990 through December 1999 at which time the frequency of collection was increased to seven times per year (January, February, May/June, July, August and October) by the SFWMD. Monitoring at these stations is weighed towards the wet season when primary productivity is at its highest in the lagoon.

The SIRL monitoring program was established to detect long-term water quality trends in the lagoon. All water quality samples were collected in strict accordance with the FDEP approved SFWMD Comprehensive Quality Assurance Plan number 870166G. In addition, the SFWMD received a NELAC certification on May 1, 2002, in accordance with the FDEP. In situ physical parameters were taken using a Hydro lab Surveyor III. Physical parameters were measured at surface, mid, and bottom depths; however, when the total depth at the site
was greater than two meters, or less than two meters, measurements were taken at mid depth only.

Physical measurements collected at each monitoring station consisted of:

- temperature
- pH
- salinity
- DO
- conductivity
- Secchi disk depth

Water samples were collected at mid depth using a Wildco 2.2-liter Van Dorn PVC horizontal sampling bottle. Samples were analyzed for the following parameters:

- total Kjeldahl nitrogen
- nitrate + nitrite
- TSS
- turbidity
- ammonia
- TP
- orthophosphate
- volatile suspended solids
- color

Samples for chlorophyll $a$ were collected at half the Secchi disk depth and were corrected for phaeophytin.
Figure 5A-14: Map Showing the SIRL from Jupiter Inlet in the South to the Northern Boundary at Indian River County
5A.2.3 Results and Discussion

The water quality parameters expected to most influence seagrass health are TSS, turbidity, color, chlorophyll \( a \), TP, and TN (Dennison et al. 1993; Steward et al. 1994; Virnstein and Morris 1996). As TSS, turbidity, and color levels increase in the water column, light penetrations will decrease resulting in photosynthetic activity being inhibited. Increased concentrations of nutrients, such as TN and TP can indirectly reduce the amount of light penetrating the water column by promoting the growth of algae in the water column and epiphytes on seagrass blades.

Most of the increased color, turbidity values, and nutrients in the SIRL are being delivered with high flows of fresh water discharge from the SLE and C-25 (Taylor Creek) in Ft. Pierce. Figure 5A-16 represents the total monthly freshwater input from October 1990 through December 2006 at these sources.
Typically, the majority of freshwater entering the lagoon occurs during the wet season (period from May through October). *Figure 5A-17* represents the monthly distribution of freshwater to the SIRL. The figure shows the median volume of water delivered to the lagoon bounded by the inner quartile range (i.e., 25\textsuperscript{th} and 75\textsuperscript{th} percentiles). A peak in the upper quartile also occurs in March when regulatory releases from LO are active.

Flows were measured at four major structures (S-80, S-48, S-49 and S-50) discharging into waters tributary to the lagoon.

*Figure 5A-16: Total Monthly Input of Freshwater into the SIRL for the Period October 1990 through December 2006*
The data was determined from discharge records for four major structures (S-80, S-48, S-49 and S-50) discharging into waters tributary to the lagoon.

**Figure 5A-17: Distribution of Freshwater Input (presented as percentiles) to the SIRL by Month for the Period October 1990 through December 2006**

Freshwater inflows to the SIRL affect turbidity, color and nutrient levels in the lagoon. **Figure 5A-18** represents the monthly distribution of these parameters (turbidity, color, TP and TN). From the figure, it is evident that higher levels occur during or following periods of high freshwater input. In addition, the four parameters shown in **Figure 5A-18** exhibit an increase during the months of March and April coinciding with regulatory releases from LO.

**Figure 5A-19** represents the monthly distribution of salinity for the lagoon. Lower salinity levels are observed during and immediately following the wet season. The relationships between turbidity, color and nutrients with salinity are identified in **Figure 5A-20**. All four parameters (color, turbidity, TN and TP) exhibited a significant inverse relationship with salinity (p<0.05). However, the strongest correlation with salinity was determined to be color and TP. The poor correlation determined for TN and salinity may be a result of the relatively high method detection limit (0.5 mg/L) for TN1. As salinity values increase, the levels for these parameters will decrease. Since the high levels of these four parameters occur when salinities are low (and when freshwater input is high), reduction in freshwater flows to the SIRL should improve the parameters that have an adverse effect on light attenuation in the lagoon.

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1 Total nitrogen is calculated from total Kjeldahl nitrogen and nitrate+nitrite concentrations. The method detection limit for total Kjeldahl nitrogen during the majority of the monitoring period was 0.5 mg/L.
Based on the previous discussion, it is clear that water quality in the SIRL is affected seasonally. **Figures 5A-21 through 5A-25** reveal the distributions for salinity, turbidity, color, TP and TN as a function of distance from Jupiter Inlet to the most northward station (IRL39). The highest variability for all the parameters is observed during the wet season as a result of increased freshwater inflows. As expected, salinity levels are lower due to dilution by freshwater, while the other parameters exhibit higher concentrations. In addition, regions of freshwater input (e.g., St. Lucie River and Taylor Creek [C-25 canal]) reveal a distinct signal on the figures. The only parameter not exhibiting a distinct signal from these freshwater sources is TN (**Figure 5A-25**).

Another parameter of interest in the SIRL is chlorophyll \( a \). **Figures 5A-26 and 5A-27** reveal the monthly and the seasonal distribution of chlorophyll \( a \) in the SIRL, respectively. Notice that in the SIRL chlorophyll \( a \) rarely exceeds 11 mg/m\(^3\) as established in the impaired waters rule 32-303 FAC. The monthly distribution of chlorophyll \( a \) in **Figure 5A-26** is comparable to that of color (**Figure 5A-18B**). Since color can be used as an indicator of freshwater input to the SIRL, chlorophyll \( a \) concentrations appear to be affected by freshwater inflow and associated nutrient inputs.
Figure 5A-18: Distribution of (A) turbidity, (B) color, (C) total phosphorus, and (D) total nitrogen levels (presented as percentiles) to the SIRL by month for the period from October 1990 through December 2006.

Figure 5A-19: Distribution of salinity levels (presented as percentiles) to the SIRL by month for the period from October 1990 through December 2006.
Figure 5A-20: Relationship between Salinity and (A) Turbidity, (B) Color, (C) Total Phosphorus and (D) Total Nitrogen.
The St. Lucie Inlet is located 26 km north of Jupiter Inlet and the Fort Pierce Inlet is located 64 km north of Jupiter Inlet.

Figure 5A-21: (A) Notched Box and Whisker Plot of Salinity Levels and (B) Dry Season and (C) Wet Season Salinity Levels Measured at Monitoring Locations in the SIRL from October 1990–December 2006 with Distance Northward from Jupiter Inlet, Florida
The St. Lucie Inlet is located 26 km north of Jupiter Inlet and the Fort Pierce Inlet is located 64 km north of Jupiter Inlet.

Figure 5A-22: (A) Notched Box and Whisker Plot of Turbidity Levels and (B) Dry Season and (C) Wet Season Turbidity Levels Measured at Monitoring Locations in the SIRL from October 1990–December 2006 with Distance Northward from Jupiter Inlet, Florida
The St. Lucie Inlet is located 26 km north of Jupiter Inlet and the Fort Pierce Inlet is located 64 km north of Jupiter Inlet.

**Figure 5A-23:** (A) Notched Box and Whisker Plot of Color Levels and (B) Dry Season and (C) Wet Season Color Levels Measured at Monitoring Locations in the SIRL from October 1990–December 2006 with Distance Northward from Jupiter Inlet, Florida
The St. Lucie Inlet is located 26 km north of Jupiter Inlet and the Fort Pierce Inlet is located 64 km north of Jupiter Inlet.

**Figure 5A-24:** (A) Notched Box and Whisker Plot of Total Phosphorus Concentrations and (B) Dry Season and (C) Wet Season Total Phosphorus Concentrations Measured at Monitoring Locations in the SIRL from October 1990–December 2006 with Distance Northward from Jupiter Inlet, Florida.
The St. Lucie Inlet is located 26 km north of Jupiter Inlet and the Fort Pierce Inlet is located 64 km north of Jupiter Inlet.

**Figure 5A-25:** (A) Notched Box and Whisker Plot of Total Nitrogen Concentrations and (B) Dry Season and (C) Wet Season Total Nitrogen Concentrations Measured at Monitoring Locations in the SIRL from October 1990–December 2006 with Distance Northward from Jupiter Inlet, Florida
Figure 5A-26: Distribution of Chlorophyll $a$ Levels (presented as percentiles) to the SIRL by Month for the Period from October 1990 through December 2006
The St. Lucie Inlet is located 26 km north of Jupiter Inlet and the Fort Pierce Inlet is located 64 km north of Jupiter Inlet.

Figure 5A-27: (A) Notched Box and Whisker Plot of Chlorophyll $a$ Levels and (B) Dry Season and (C) Wet Season Chlorophyll $a$ Levels Measured at Monitoring Locations in the SIRL from October 1990–December 2006 with Distance Northward from Jupiter Inlet, Florida
5A.3 Caloosahatchee River Estuary Water Quality Baseline

5A.3.1 Background Description

The CRE is a large estuarine system where the marine waters of the Gulf of Mexico mix with freshwater inflows from the river and its associated sloughs, and basin sheetflow. The lower reaches are characterized by a shallow bay housing extensive seagrass beds and sand flats fringed by extensive mangrove forests that dominate undeveloped shoreline areas. Southwest Florida estuaries serve as habitats to more than 40 percent of Florida's rare, endangered and threatened species. The CRE watershed includes the East, West and Tidal Caloosahatchee drainage basins as well as the North Coastal, Telegraph Swamp, C-21 and S-236 drainage basins. The freshwater portion of the river has been reconfigured as a canal (C-43); extending 45 miles from the Moore Haven Lock and Dam (S-77) to Franklin Lock and Dam (S-79), to better convey flood water to the Gulf of Mexico. The river and C-43 canal serve as a waterway that links the west coast of Florida with the east coast through Lake Okeechobee (Figure 5A-28). The CRE extend about 70 miles from LO to San Carlos Bay on Florida's southwest coast.

As with many coastal estuaries, the CRE ecology is affected by water quality issues, specifically salinity variation and nutrient loads. The integrity of riverine and estuarine ecosystems is dependent on water quality. As water quality diminishes, so does the overall quality of the system. The CRE water quality is threatened by altered freshwater inputs, agricultural effluents, and continual urban growth and development within the watershed. The purpose of this report is to summarize the water quality conditions in the CRE from surface water data collected for the period October 1994 through December 2006. This summary will focus on nutrients and parameters affecting the clarity of the water in the CRE.

5A.3.2 Methods and Analysis

As part of the SWIM initiative a long-term water quality-monitoring program was started in October 1994 in the CRE. Eight water quality monitoring stations were established and monitored monthly to detect long-term spatial and temporal trends. Seven of the eight original stations were used for this report (Figure 5A-29). All samples were collected in strict accordance with the FDEP approved SFWMD Comprehensive Quality Assurance Plan Number 870166G and under the auspices of the SFWMD’s NELAC certification (received May 1, 2002) in accordance with the FDEP. All samples were collected as close to low tide as possible. In situ physical parameters were measured using a Hydrolab Surveyor III multi-parameter metering device. These parameters included temperature, pH, conductivity and DO which were sampled at half-meter increments from the bottom to the surface of the water column. Salinity was calculated from conductivity and temperature measurements in cases where salinity measurements were missing (sensu Millero 1982). Water samples were collected using a Wildco 2.2-liter Van Dorn PVC horizontal sampling bottle (or Niskin sampling bottle) at half of the total depth at each sampling site. Samples were analyzed for turbidity, TSS, color, TP, total Kjeldahl nitrogen, orthophosphate, nitrate + nitrite and ammonia. Chlorophyll \textit{a} samples were
Figure 5A-28: Map of Caloosahatchee (C-43)-Lake Okeechobee-St. Lucie (C-44) Waterway

Figure 5A-29: Surface Water Monitoring Stations and Freshwater Inflow Structure on the CRE
collected at one half of Secchi disk depth. In addition, TN concentrations were calculated from total Kjeldahl and nitrate + nitrite.

5A.3.3 Results and Discussion

For purposes of summarizing the water quality data, the estuary was divided into three regions (Figure 5A-29). Region 1 contains water quality monitoring stations located less than 10 km from S-79 (CES01 and CES03); Region 2 contains stations located from 10 to 30 km from S-79 (CES04, CES05, CES06); and Region 3 contains stations located beyond 30 km from S-79 (CES07, CES08).

The water quality summary for the CRE included herein represents a subset of the measured parameters including:

- salinity
- color
- TN
- DO
- TP
- chlorophyll a

A summary of annual fresh water inflow and associated nutrient loads to the estuary from the C-43 canal (measured at S-79) is provided in Table 5A-4. These data encompass the period from January 1991 through December 2006. The data reveals that on average the estuary receives $1,892 \times 10^6 \text{ m}^3$ of freshwater and 246 and 2,791 metric tons of P and N, respectively.

The distribution of water flows, nutrient loads and flow weighted mean concentrations for each of the control structures along the C-43 canal display an increase in flows and loads in a westward directions (i.e., from S-77 to S-79, Figure 5A-30). Also illustrated are mean P loads (31 percent) and N loads (55 percent) seen at S-79 as contributed by outflow from LO through S-77. The flow weighted mean TP concentrations were also shown to increase (Figure 5A-30). In contrast, TN flow weighted mean concentrations decreased westward from S-77 (Figure 5A-30); possibly the result of N removal between S-77 and S-78.

Salinity and DO exhibited statistically (p<0.001) higher concentrations during the dry season than the wet season (Figure 5A-31a) while the remaining parameters exhibited statistically higher levels during the wet season (Figure 5A-31b). This strong seasonal signal (i.e., freshwater inflows and nutrient loads to the estuary) was not unexpected in a tropical system with a clear demarcation between the wet season (May through October) and the dry season (November through April).

Dry and wet season median levels of the six parameters of interest were plotted with distance from Structure S-79 (Figures 5A-32a and 5A-32b) to further explore the extent of the freshwater impact on the estuary. As described above (Figures 5A-31a and 5A-31b), the six parameters displayed the same pattern with salinity and DO concentrations being higher during the dry season, while the other parameters exhibit higher concentrations during the
wet season. Of note was the observation that CES05 located in the estuary’s Region 2 (~20 km downstream of S-79), appeared to be influenced by water less colored than typically seen in the CRE. Specifically, during the wet season, the median color level for CES05 was lower than the corresponding levels at the nearest upstream stations (CES04) and downstream stations (CES06) (Figure 5A-32a). Median TN concentrations also appear to be lower at this station for both the dry and wet seasons. In contrast, median chlorophyll $a$ levels peak at this location in the CRE during both seasons (Figure 5A-32b). Additional statistical summaries of the water quality data in the three regions of the CRE are provided in Table 5A-5.

Color and TN were the only parameters that appeared to exhibit a salinity trend (Figure 5A-33 and Figure 5A-34). In both instances, an inverse relationship with salinity (e.g., as salinity increases color and TN decrease) was present.

Concentrations of most water quality parameters decreased in a westerly direction from S-79 toward the Gulf of Mexico with the downstream flow of nutrient laden freshwater. The increased freshwater inputs observed during the wet season through S-79 contributed to the seasonal variability observed in the CRE.

The median TN concentration for the three regions of the CRE ranged from 1.3 mg/L for to 0.4 mg/L for Regions 1 through 3, respectively (Table 5A-5). Overall, the CRE exhibited a median TN concentration of 1.1 mg/L, higher than the 0.67 mg/L limit. Median TP levels for the CRE (Table 5A-5) were slightly higher in Region 1 at 110 µg/L and then decreasing in Region 2 to 100 µg/L and Region 3 to 70 µg/L. In general the median TP value for the CRE was 93 µg/L. The higher TP values in Region 1 can be attributed to increased nutrient laden fresh water inflows (Chamberlain and Hayward, 1996). Median chlorophyll $a$ values ranged from 6.1 mg/m$^3$ in Region 3 to 11.8 mg/m$^3$ in Region 2 (Table 5A-5). A median chlorophyll $a$ level of 5 mg/m$^3$ was determined for the entire CRE. This level is below the limit established by Hand (2004) for Florida estuaries: chlorophyll $a$ (7.20 mg/m$^3$), TN (0.67 mg/L), TP (100 µg/L), and Secchi depth (1.0 m) for Florida estuaries.

Chamberlain and Hayward (1996) reported highest chlorophyll $a$ values associated with low flow conditions when low nutrient concentrations and color levels were apparent. Long flushing time and high light availability under low flow conditions favor the accumulation of chlorophyll $a$ biomass. DO, a critical indicator of the health of an estuarine ecosystem (Engle et al., 1999) was generally maintained at levels above four mg/L in both the wet and dry seasons across the three regions (Figure 5A-31a). Since measurements of DO were performed during optimal photosynthetic conditions, the DO levels can be assumed to be lower during periods of the diel cycle when respiration is optimal.
Table 5A-4: Summary of Annual Freshwater Inflows, Nutrient Loads and Flow Weighted Mean Concentrations from S-79 to the CRE

<table>
<thead>
<tr>
<th>Water Year&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Inflow Volume (m$^3$ X 10$^6$)</th>
<th>Nutrient Loads (metric tons)</th>
<th>Flow Weighted Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Phosphorus</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>1991</td>
<td>120.9</td>
<td>17.5</td>
<td>208.8</td>
</tr>
<tr>
<td>1992</td>
<td>1126</td>
<td>197</td>
<td>1828</td>
</tr>
<tr>
<td>1993</td>
<td>1783</td>
<td>445</td>
<td>3064</td>
</tr>
<tr>
<td>1994</td>
<td>957.9</td>
<td>139</td>
<td>1968</td>
</tr>
<tr>
<td>1995</td>
<td>2815</td>
<td>264</td>
<td>4521</td>
</tr>
<tr>
<td>1996</td>
<td>3497</td>
<td>274</td>
<td>4097</td>
</tr>
<tr>
<td>1997</td>
<td>954.3</td>
<td>115</td>
<td>1384</td>
</tr>
<tr>
<td>1998</td>
<td>3077</td>
<td>262</td>
<td>4076</td>
</tr>
<tr>
<td>1999</td>
<td>1105</td>
<td>154</td>
<td>1665</td>
</tr>
<tr>
<td>2000</td>
<td>2020</td>
<td>335</td>
<td>3129</td>
</tr>
<tr>
<td>2001</td>
<td>593.2</td>
<td>97.1</td>
<td>850.1</td>
</tr>
<tr>
<td>2002</td>
<td>1153</td>
<td>245</td>
<td>1852</td>
</tr>
<tr>
<td>2003</td>
<td>2232</td>
<td>353</td>
<td>3798</td>
</tr>
<tr>
<td>2004</td>
<td>3039</td>
<td>316</td>
<td>4169</td>
</tr>
<tr>
<td>2005</td>
<td>2503</td>
<td>279</td>
<td>3303</td>
</tr>
<tr>
<td>2006</td>
<td>4331</td>
<td>540</td>
<td>6251</td>
</tr>
<tr>
<td>2007</td>
<td>856.2</td>
<td>156</td>
<td>1277</td>
</tr>
</tbody>
</table>

<sup>a</sup> Water year is defined as a 12-month period starting in May and ending in April
Figure 5A-30: Notched Box and Whisker Plots Comparing Hydraulic, Phosphorus and Nitrogen Loads and Flow Weighted Mean Total Phosphorus and Total Nitrogen Concentrations at Structures S-77, S-78 and S-79 from January 1991 through December 2006
Figure 5A-31a: Notched Box and Whisker Plots Water Quality Parameter Levels for the Dry and Wet Seasons in Three Regions of the CRE for the Period October 1994 through December 2006
Figure 5A-31b: Notched Box and Whisker Plots Water Quality Parameter Levels for the Dry and Wet Seasons in Three Regions of the CRE for the period October 1994 through December 2006
The vertical lines denote the three regions of the estuary. The horizontal line in the dissolved oxygen graph shows the Class III limit of 4.0 mg/l for marine waters.

**Figure 5A-32a: Seasonal Median Levels in the CRE with Distance from Structure S-79**
The vertical lines denote the three regions of the estuary.

**Figure 5A-32b: Seasonal Median Levels in CRE with Distance from Structure S-79**
### Table 5A-5: Summary of Water Quality for Three Regions of the CRE for the Period October 1994 through December 2006

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Stations &lt;10 km from S-79 (Region 1)</th>
<th>Stations 10-30 km from S-79 (Region 2)</th>
<th>Stations &gt;30 km from S-79 (Region 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (PSU)</td>
<td>Mean ± Standard Deviation</td>
<td>Minimum</td>
<td>Minimum</td>
</tr>
<tr>
<td></td>
<td>0.7 ± 2.1</td>
<td>&lt;0.2</td>
<td>0.7 ± 6.4</td>
</tr>
<tr>
<td>Apparent Color (PCU)</td>
<td>103.4 ± 55.6</td>
<td>20.4</td>
<td>108.3 ± 58.9</td>
</tr>
<tr>
<td>Dissolved Oxygen (mg/L)</td>
<td>5.6 ± 2.0</td>
<td>&lt;0.2</td>
<td>5.6 ± 1.9</td>
</tr>
<tr>
<td>Total Phosphorus (µg/L)</td>
<td>120.2 ± 70.9</td>
<td>15.0</td>
<td>111.6 ± 74.2</td>
</tr>
<tr>
<td>Total Nitrogen (mg/L)</td>
<td>1.31 ± 0.35</td>
<td>&lt;0.05</td>
<td>1.04 ± 0.47</td>
</tr>
<tr>
<td>Chlorophyll a (mg/m³)</td>
<td>8.4 ± 12.0</td>
<td>0.3</td>
<td>11.8 ± 17.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentiles</td>
<td>Maximum</td>
<td>Maximum</td>
</tr>
<tr>
<td></td>
<td>5th 25th 50th 75th 95th</td>
<td>5th 25th 50th 75th 95th</td>
<td>5th 25th 50th 75th 95th</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.3 208.1 30.9 450.0 620.0</td>
<td>18.3 208.1 30.9 450.0 620.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.2 2.2 4.3 5.6 7.7</td>
<td>0.2 2.2 4.3 5.6 7.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6 8.1 9.6 19.0 30.0</td>
<td>0.6 8.1 9.6 19.0 30.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.1 6.6 7.4 9.4 10.0</td>
<td>5.1 6.6 7.4 9.4 10.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110.0 140.0 240.0 240.0 320.0</td>
<td>110.0 140.0 240.0 240.0 320.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 7.7 9.4 14.8 22.0</td>
<td>0.8 7.7 9.4 14.8 22.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.7 20.0 28.0 36.0 42.0</td>
<td>7.7 20.0 28.0 36.0 42.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>118.0 379.0 730.0 1130 1190</td>
<td>118.0 379.0 730.0 1130 1190</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.7 20.0 28.0 36.0 42.0</td>
<td>7.7 20.0 28.0 36.0 42.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.3 208.1 30.9 450.0 620.0</td>
<td>18.3 208.1 30.9 450.0 620.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.8 7.7 9.4 14.8 22.0</td>
<td>0.8 7.7 9.4 14.8 22.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.7 20.0 28.0 36.0 42.0</td>
<td>7.7 20.0 28.0 36.0 42.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>118.0 379.0 730.0 1130 1190</td>
<td>118.0 379.0 730.0 1130 1190</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.7 20.0 28.0 36.0 42.0</td>
<td>7.7 20.0 28.0 36.0 42.0</td>
</tr>
</tbody>
</table>
Period of record for these plots is October 1994 through December 2006.

**Figure 5A-33:** Plots of Color and Total Nitrogen versus Salinity in Three Regions of the CRE
Period of record for these plots is January 1990 through December 2006.

**Figure 5A-34:** Plots of Total Phosphorus and Chlorophyll $a$ versus Salinity in Three Regions of the CRE
5A.4 Lake Worth Lagoon Water Quality Baseline

5A.4.1 Background Description

The lagoon is approximately 32 kilometers in length and averages three-quarters of a kilometer wide. The average depth is two meters with some dredged areas over ten meters deep. A barrier island separates the lagoon from the Atlantic Ocean, to which it is connected by two permanent inlets, the Lake Worth and South Lake Worth inlets. The Atlantic Intracoastal Waterway (ICW) runs the entire length of the lagoon, with eight bridges and causeways connecting the barrier island to the mainland. The lagoon’s watershed is approximately 1,200 square kilometers.

LWL is the major estuarine water body located in Palm Beach County, Florida. The ecosystem has undergone significant and widespread man-induced changes during the past one hundred years. Freshwater discharges into the lagoon have introduced excess influxes of nutrients, suspended and dissolved organic matter, contaminants, and toxins, which have affected flora and fauna.

Water quality monitoring has been underway since 1991–initially by PBCERM, then by FDEP 2001-2006, and in 2007 by a cooperative effort by PBCERM and SFWMD. Water quality of the LWL is expected to improve by implementation of CERP. The existing baseline will provide the backdrop against which CERP changes will be tracked and adaptively managed. The two projects most likely to impact the lagoon in the near term are the L-8 Reservoir and the C-51 Sediment Management projects. The L-8 Reservoir involves conversion of a rock mining site into a storage reservoir to attenuate L-8 Basin run-off, which may be operational by 2009. The intent of this facility is to divert large discharges from the L-8 Basin that would otherwise result in large volume releases to the lagoon through the C-51 canal structure. The C-51 Sediment Management Project is a $2 Million Partnership with Palm Beach County and the City of West Palm Beach that commenced in 2006 and may be complete in 2008. The two main purposes of this project is to remove approximately 130,000 cubic yards of accumulated organic material from the canal, and to utilize the dredged area as a trap for future sediment that would otherwise be discharged to the lagoon.

5A.4.2 Methods and Analysis

The monitoring network has undergone several revisions since 1991, with stations added or discontinued, with few site locations possessing relatively long datasets. There are currently a total of eighteen active monitoring locations in the lagoon (Figure 5A-35), six of which were formerly sampled by the FDEP for the TMDL baseline monitoring program. Thus there is a fairly high quality dataset extending back to 2001, and with few caveats, back to 1994. Prior to 1994, samples were collected irrespective of tidal cycle and corrective efforts have not yet been completed such that pre-1994 data could be used. Currently monthly measured parameters include DO, pH, salinity; Kjeldahl nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, total and ortho phosphorus, turbidity, fecal coliform, and chlorophyll a. The metals arsenic (As), copper (Cu), cadmium (Cd), and lead (Pb) are collected from the water column quarterly. The list of parameter has been variously revised over the years, with most parameters (e.g. TP) possessing long-term consistency while others less so (e.g., ortho P or copper). As a consequence, only a few parameters were evaluated.
Lake Worth Lagoon
Water Quality Stations

FDEP Tidal Stations to be monitored by PBC
All stations monthly sampling

Legend
Lake Worth Lagoon WQ Station
- Former FDEP-Tidal (6)
- New LVL WQ (12)
- NPDES-Tidal (4)

Seagrass
- Seagrass
- Patchy Seagrass

February 2005 Aerial Photography

Figure 5A-35: LWL Sampling Site Locations
Data was provided by PBCERM or extracted from Florida Storet as appropriate. Correlations between data were determined by the nonparametric Spearman rank method, which was deemed significant only in those cases where the 95 percent confidence interval determined by bootstrap resampling circumscribed critical values all possessing P values less than 0.05; in those cases where this criteria was met, the P value reported is that determined by the statistic (Zar 1998). Trends were evaluated utilizing the nonparametric Seasonal Kendall Trend test, using the twelve months as individual seasons.

5A.4.3 Results and Discussion

Water quality was in general compliance with existing state water quality criteria during the analyzed period of record. Of principal concern insofar as aquatic health is concerned, DO values 1994-2006 (Figure 5A-36) averaged 5.9 mg/l with a 95 percent confidence interval of 5.8 to 6.0 mg/l, well above the regulatory minimum set for Florida's estuaries of four mg/l. Although these values were all taken during daylight, and thus do not address diurnal fluctuation, it appears that DO depression is not a problem. Additionally, DO concentration evidences a significant upward trend (P<0.001).

![Figure 5A-36: Mean and 95 Percent Confidence Interval of Dissolved Oxygen by Year](image)

Mean and median values 1994-2006 for TP are 0.138 and 0.67 mg/l, respectively. The mean TP value reflects obvious outliers (Figure 5A-37) still remaining in the earlier data (e.g., 22 mg/l P). Evaluating only data within the 2000-2006 timeframe results in mean and median
TP concentrations of 0.061 and 0.057 mg/l, respectively, values which are well below the median TP value among Florida estuaries of 0.100 mg/l (Hand 2004). The data is not amenable to trend analysis at this time.

Mean and median values 1994-2006 for TN are 0.83 and 0.72 mg/l, respectively. However, the mean may reflect outliers (Figure 5A-38) still remaining in the earlier data (e.g., 9.2 mg/l N). In addition, the 2002 data likely reflects problems encountered by FDEP with the Kjeldahl analysis of brackish waters which induced a low bias in the results. Evaluating only data within the 2003-2006 timeframe results in mean and median TN concentrations of 0.75 and 0.72 mg/l, respectively, values which are above the median TN value among Florida estuaries of 0.67 mg/l (Hand 2004). TN data covering the entire period of record is not amenable to trend analysis; however, a significant upward trend is apparent in the 2001 and later data. This trend may be actual or may be an artifact of the aforementioned analytical problems; data forthcoming in the next year or two should provide a definitive answer.

Chlorophyll a data is only available from 2001 (Figure 5A-39). Mean and median chlorophyll a concentrations are 4.4 and 3.2 ug/l, respectively, values which are lower than the median value among Florida estuaries of 6.1 ug/l (Hand 2004). Persistent or frequent algal blooms, as measured by chlorophyll a concentration, do not appear to be a problem in the lagoon; however, a significant upward trend is apparent in the current dataset (P<0.001).
A best subset regression of transformed data indicates that TN is the most likely causative agent driving chlorophyll $a$ dynamics.

Figure 5A-38: Mean and 95Percent Confidence Interval of Total Nitrogen by Year
Mean and median turbidity concentrations are 4.6 and 3.1 NTU, respectively, values which are in general agreement with the median value among Florida estuaries of 3.1 ug/l (Hand 2004). No significant trend exists in the period of record dataset (Figure 5A-40); however, there is a significant (P<0.01) upward trend in the data from 2001 on. This increasing trend appears to support the authenticity of the upward trend in TN. An examination of salinity showed that increasing freshwater discharges from the C-51 Canal results in a general freshening of the lagoon. Salinity was inversely correlated with TN (N=427, ρ=-0.555, P<0.001), TP (N=639, ρ=-0.261, P<0.001), and turbidity (N=691, ρ=-0.309, P<0.001), which argues that C-51 discharges result in increases in these constituents. These effects are more pronounced as the distance to the C-51 canal mouth decreases (Figure 5A-41).
Appendix 5A  Northern Estuaries Water Quality

Turbidity vs Year

Figure 5A-40: Mean and 95 Percent Confidence Interval of Turbidity by Year

The C-51 canal mouth is located near 14km.

Figure 5A-41: Turbidity as a Function of Location

Since the C-51 plays a pivotal role both in the water quality of the lagoon as well as the focus of restoration efforts, a better examination of its direct effects may be facilitated by restricting the analysis to only the pair of water quality monitoring sites immediately above
and below the canal mouth. Within this limited zone, discharge (cfs) is significantly correlated (P<0.001) with chlorophyll \(a\), TN, turbidity, and inversely as anticipated to conductivity. At these two sites adjacent to the canal (Table 5A-6), turbidity is higher than the median value among Florida’s estuaries (3.1 NTU; Hand 2004) more than 75 percent of the time, and about double that value in half of the observations. The turbidity maximum of 16 NTU is cause for probable concern. Chlorophyll \(a\) concentrations are higher than the Florida’s guidelines for impairment (11 ug/l; 62-303 FAC) in more than 25 percent of the samples. Nearly a quarter of the samples taken contained TN concentrations in excess of 1.0 mg/l. Discharge was not correlated with TP, DO, pH, or temperature.

Table 5A-6: Basic Statistics of Those Water Quality Constituents that were Significantly Correlated to Discharge from the C-51 Canal, From the Two Sites Adjacent to the Canal Mouth

<table>
<thead>
<tr>
<th></th>
<th>Turbidity</th>
<th>Chlorophyll (a)</th>
<th>Total Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>N of Cases</td>
<td>101</td>
<td>98</td>
<td>86</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.500</td>
<td>0.820</td>
<td>0.150</td>
</tr>
<tr>
<td>Maximum</td>
<td>16.000</td>
<td>59.150</td>
<td>1.670</td>
</tr>
<tr>
<td>Mean</td>
<td>6.237</td>
<td>9.609</td>
<td>0.773</td>
</tr>
<tr>
<td>Median</td>
<td>6.000</td>
<td>6.309</td>
<td>0.758</td>
</tr>
<tr>
<td>25%</td>
<td>4.000</td>
<td>3.210</td>
<td>0.514</td>
</tr>
<tr>
<td>75%</td>
<td>8.000</td>
<td>12.310</td>
<td>0.995</td>
</tr>
</tbody>
</table>

5A.4.4 Conclusions

In general, water quality in LWL is good, but increasing proximity to the C-51 Canal equates with worsening water quality condition. Freshwater inflows affect turbidity, salinity, and \(n\) levels in the lagoon. \(N\) is likely the limiting nutrient for algal blooms. Near the C-51 canal mouth algal blooms are either more intense or more frequent or both, as denoted by elevated and potentially regulatory problematic chlorophyll \(a\) concentration. The fact that the C-51 affects the entire lagoon, albeit diminishing effect with distance, the lagoon-wide increasing trend in chlorophyll \(a\) concentration is worrisome.

The available dataset for the lagoon covers over 16 years, and in general provides a quality baseline with which to detect future change. However, analysis of this dataset is severely hampered by the continued presence of obvious outliers and data entry errors. Failure to continue to resolve these issues will prevent full utilization of the investment that the dataset represents.

5A.5 Loxahatchee River Estuary Water Quality Baseline

5A.5.1 Background Description

The LRE encompasses approximately 400 ha and drains a watershed of approximately 700 km\(^2\) located in northeastern Palm Beach County and southeastern Martin County, Florida.
Freshwater discharges into the estuary from the North Fork, the Northwest Fork and the Southwest Fork of the Loxahatchee River. The hydrology of the basin has been substantially altered by flood control efforts since the 1950s. Historically (pre-1950), most surface water runoff reaching the estuary originated in the Loxahatchee and Hungryland Sloughs and flowed gradually to the Northwest Fork. In the 1930s the Lainhart Dam, a small fixed-weir dam, was constructed in the Northwest Fork at river mile 14.5 to reduce “over” drainage of upstream reaches of the Northwest Fork during the dry season. In 1958 a major canal (C-18) and flood control structure (S-46) were constructed to divert flows from the Northwest Fork to the Southwest Fork, which increased the intensity and decreased the duration of storm-related discharge to the estuary. Furthermore, since 1947 Jupiter inlet, the eastern link to the ocean, has been kept permanently open through ongoing dredging projects, which increased saltwater intrusion into the primarily freshwater Northwest Fork. Ongoing restoration efforts seek to increase base flows into the Northwest Fork, while not compromising the ecological integrity of downstream reaches (i.e., estuary) nor impairing valued ecosystem components of the estuary such as oysters and seagrasses (SFWMD 2006).

5A.5.2 Methods and Analysis

Water quality samples were collected once every other month (i.e., bi-monthly) at each station identified in Figure 5A-42. At each station, physical water quality conditions (e.g., temperature, pH, conductivity, salinity and dissolved oxygen) were evaluated using a Hydrolab multiprobe at the surface (0.3 m depth), though for stations 60 through 66 we also sampled at mid-depth and within 20 cm of the bottom. Nutrient, bacteriological, chlorophyll a, turbidity, total suspended solids and water color samples were processed following Standard Methods by the Loxahatchee River District’s (LRD) Wildpine Laboratory, which is certified under the NELAC. Total nitrogen concentrations were the sum of total Kjeldahl nitrogen and nitrate + nitrite nitrogen. Photosynthetically active radiation (PAR) was assessed by taking 3 replicates of PAR using 3 LI-COR spherical sensors (4 π) simultaneously located at 20 cm, 50 cm, and 100 cm below the water surface. Data were recorded on a LI-COR LI-1400 data logger.

Following LRD’s previous work and the Restoration Plan for the Northwest Fork of the Loxahatchee River (SFWMD 2006), water quality was assessed for five zones of the river: marine, polyhaline, mesohaline, wild and scenic and freshwater tributaries. The marine zone was characterized by stations 10, 20 and 30. The polyhaline zone was characterized by stations 51, 60 and 72. The mesohaline zone was characterized by stations 62, 63 and 64. The wild and scenic zone was characterized by stations 67, 68 and 69. The freshwater tributaries were characterized by stations 81 (C-18), 95 (Jupiter Farms) and 100 (Cypress Creek).
S-46, the flood control structure, is located immediately downstream of station 81.

**Figure 5A-42: Map of the LRE Showing LRD’s Water Quality Sampling Stations**
5A.5.3 Results and Discussion

Water quality results, based on sampling over the previous years (1991-2006), is presented using two different graphical approaches and one table in order to highlight various aspects of the data. First, Figure 5A-43 shows how select water quality parameters change as you travel upstream in the river from the inlet to the G-92 structure, immediately downstream of the C-18 canal. Second, Table 1 presents a summary of key water quality parameters for five regions of the Loxahatchee River and Estuary. Finally, Appendix A shows among-site differences for all of the RiverKeeper sample sites using one box and whisker plot per parameter. These plots clearly show spatial trends in data across the sampling period.

Because the Loxahatchee River is a tidally influenced coastal river that flows relatively unimpeded from its headwaters (the G-92 structure) to the Jupiter inlet, it is reasonable to expect both physical (e.g., salinity) and chemical (e.g., nitrogen) characteristics of the water to vary as it travels from upstream to downstream locations. Figure 5A-43 shows how salinity, dissolved oxygen, nitrate + nitrite, and orthophosphorus concentrations vary along the upstream–downstream gradient (i.e., from the inlet (station 10) to the G-92 structure (station 92)). It is immediately apparent that not all parameters show the same longitudinal trend (e.g., not all parameters have their peak at the same site). Salinity was highest in the inlet, which received the largest marine influence, and lowest in upstream reaches. Upstream from station 67 the waters were nearly always totally fresh. Dissolved oxygen, measured as percent saturation, was highest in the downstream marine waters. The availability of nitrate + nitrite was the lowest in the marine waters and highest near Trapper Nelson’s zoo (station 67). Orthophosphorus concentrations were low in the headwaters (station 92) and in the marine and downstream estuary sites (stations 10, 40, 42), with the highest concentrations of orthophosphorus observed at the freshwater locations between station 67 and station 62. It appears that transport, biological transformation, sedimentation, and dilution drive upstream – downstream gradients in physical and chemical characteristics observed. Future work is needed to determine the relative magnitude of these processes, and their relative importance across both temporal and spatial scales in the Loxahatchee River watershed.

Assessment of the box and whisker plots provided in Figure 5A-44 show among-site differences in water quality across all LRD sampling sites. Similar to Figure 5A-43 the salinity box and whisker plot shows the diminution of salinity between stations 10 and 66. Additional statistical summaries of the water quality data in the five salinity-defined regions of the Loxahatchee River are provided in Table 5A-7.
Appendix 5A  Northern Estuaries Water Quality

Figure 5A-43: Downstream (Jupiter inlet @ station 10) to upstream (G-92 @ station 92) Trends in Physical Conditions and Nutrient Concentrations Vary According to Parameter of Interest
Table 5A-7: Summary of Water Quality for Five Regions of the LRE for the Period from January 1991 through November 2006

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>± Standard Deviation</th>
<th>Minimum</th>
<th>Percentiles</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Marine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity (ppt)</td>
<td>31.75</td>
<td>± 4.536</td>
<td>14.6</td>
<td>21.6</td>
<td>24.8</td>
</tr>
<tr>
<td>Apparent Color (pcu)</td>
<td>15.65</td>
<td>± 13.557</td>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Dissolved Oxygen (% sat)</td>
<td>93.95</td>
<td>± 9.318</td>
<td>61</td>
<td>76.58</td>
<td>81.84</td>
</tr>
<tr>
<td>Total Phosphorus (mg-P/l)</td>
<td>0.03</td>
<td>± 0.029</td>
<td>0.001</td>
<td>0.005</td>
<td>0.008</td>
</tr>
<tr>
<td>Total Nitrogen (mg-N/l)</td>
<td>0.93</td>
<td>± 0.440</td>
<td>0.1</td>
<td>0.322</td>
<td>0.44</td>
</tr>
<tr>
<td>Chlorophyll a (ug/l)</td>
<td>4.00</td>
<td>± 4.789</td>
<td>0.2</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Polynine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity (ppt)</td>
<td>25.81</td>
<td>± 8.244</td>
<td>0.7</td>
<td>7</td>
<td>11.9</td>
</tr>
<tr>
<td>Apparent Color (pcu)</td>
<td>43.69</td>
<td>± 39.506</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Dissolved Oxygen (% sat)</td>
<td>87.10</td>
<td>± 11.064</td>
<td>50</td>
<td>68.28</td>
<td>72.9</td>
</tr>
<tr>
<td>Total Phosphorus (mg-P/l)</td>
<td>0.04</td>
<td>± 0.033</td>
<td>0.006</td>
<td>0.01475</td>
<td>0.02</td>
</tr>
<tr>
<td>Total Nitrogen (mg-N/l)</td>
<td>1.25</td>
<td>± 0.552</td>
<td>0.1</td>
<td>0.511</td>
<td>0.594</td>
</tr>
<tr>
<td>Chlorophyll a (ug/l)</td>
<td>9.11</td>
<td>± 10.225</td>
<td>0.5</td>
<td>1.6</td>
<td>2</td>
</tr>
<tr>
<td>Mesohaline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity (ppt)</td>
<td>11.48</td>
<td>± 8.043</td>
<td>0.5</td>
<td>0.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Apparent Color (pcu)</td>
<td>58.53</td>
<td>± 30.104</td>
<td>12</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Dissolved Oxygen (% sat)</td>
<td>65.67</td>
<td>± 15.524</td>
<td>3.2</td>
<td>42</td>
<td>48.2</td>
</tr>
<tr>
<td>Total Phosphorus (mg-P/l)</td>
<td>0.06</td>
<td>± 0.028</td>
<td>0.018</td>
<td>0.0267</td>
<td>0.0347</td>
</tr>
<tr>
<td>Total Nitrogen (mg-N/l)</td>
<td>1.44</td>
<td>± 0.592</td>
<td>0.34</td>
<td>0.7225</td>
<td>0.81</td>
</tr>
<tr>
<td>Chlorophyll a (ug/l)</td>
<td>6.18</td>
<td>± 5.007</td>
<td>0.5</td>
<td>1.425</td>
<td>2.38</td>
</tr>
<tr>
<td>Wild &amp; Scenic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity (ppt)</td>
<td>0.50</td>
<td>± 0.500</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Apparent Color (pcu)</td>
<td>64.50</td>
<td>± 27.894</td>
<td>0.5</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Dissolved Oxygen (% sat)</td>
<td>60.77</td>
<td>± 17.299</td>
<td>12</td>
<td>26.835</td>
<td>34.02</td>
</tr>
<tr>
<td>Total Phosphorus (mg-P/l)</td>
<td>0.05</td>
<td>± 0.033</td>
<td>19.5</td>
<td>0.02</td>
<td>0.022</td>
</tr>
<tr>
<td>Total Nitrogen (mg-N/l)</td>
<td>1.03</td>
<td>± 0.349</td>
<td>0.01</td>
<td>0.54</td>
<td>0.63</td>
</tr>
<tr>
<td>Chlorophyll a (ug/l)</td>
<td>3.07</td>
<td>± 3.055</td>
<td>0.11</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Freshwater Tributaries</td>
<td></td>
<td></td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity (ppt)</td>
<td>21.33</td>
<td>± 14.111</td>
<td>0.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Apparent Color (pcu)</td>
<td>48.67</td>
<td>± 34.242</td>
<td>5</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Dissolved Oxygen (% sat)</td>
<td>75.14</td>
<td>± 19.403</td>
<td>3.2</td>
<td>28.125</td>
<td>37.35</td>
</tr>
<tr>
<td>Total Phosphorus (mg-P/l)</td>
<td>0.05</td>
<td>± 0.034</td>
<td>0.001</td>
<td>0.014</td>
<td>0.02</td>
</tr>
<tr>
<td>Total Nitrogen (mg-N/l)</td>
<td>1.14</td>
<td>± 0.501</td>
<td>0.1</td>
<td>0.5755</td>
<td>0.64</td>
</tr>
<tr>
<td>Chlorophyll a (ug/l)</td>
<td>5.52</td>
<td>± 6.797</td>
<td>0.2</td>
<td>0.64</td>
<td>1.27</td>
</tr>
</tbody>
</table>
Each parameter monitored is presented in a separate box and whisker plot (e.g., Temperature [°C] – see above). Sampling sites are arranged across the x-axis. See Figure 5A-42 for a map of sample site locations.

**Figure 5A-44: Box and whisker plots of Loxahatchee River District’s RiverKeeper Data for the Period January 1991 through November 2006**
5A.6 References


APPENDIX 5B–MAP METADATA

All maps appearing in this document meet the standards and guidelines as defined in the CERP GIS SOP Manual. These maps are NOT to be used as Stand Alone Documents. To utilize a map as a stand alone hand out, please contact the map creator for additional map elements.

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Figure: Northern Estuaries Boundaries
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: March 26, 2007
Map Location: \cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\NE_Site_cmn4598.mxd
Base Imagery: Land Sat Imagery 2004
Datasets used:
St Lucie Estuary Boundaries-
\cerp\projects\GIS\PRGM_03\spatial\shp\cmn4598\StLucieEstuary.shp
Loxahatchee Estuary and Lake Worth Lagoon Boundaries–CERP SDE; GISLIB.FDEP_HYSUR_CLSS_BND_AREA;
\cerp\projects\GIS\PRGM_03\spatial\shp\cmn4373_SSR\NE_ICW_redraw_07.shp
Caloosahatchee Estuary Boundary-
\cerp\projects\GIS\PRGM_03\spatial\shp\cmn4603\caloosahat_estuary.shp
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Figure: St Lucie Benthic Infauna Monitoring Sites
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: April 30, 2007
Map Location: \cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\NE_Benthic_cmn4598.mxd
Base Imagery: Land Sat Imagery 2004
Datasets used:
Benthic Infauna Monitoring Sites–CERP SDE; RECOVER_MONITORING; NE_BENTHIC_INFAUNA
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Figure: Loxahatchee Estuary Monitoring Sites
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: June 7, 2007
Map Location:
\cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\NE_Eas\tCoast_Monitoring_LOX_cmn4598.mxd
Base Imagery: Land Sat Imagery 2004
Datasets used:
Oyster Monitoring Sites–CERP SDE; RECOVER_MONITORING;
GISLIB.NE_Oyster
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Figure: Lake Worth Lagoon Monitoring Sites
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: June 7, 2007
Map Location:
\cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\NE_Eas\tCoast_Monitoring_LWL_cmn4598.mxd
Base Imagery: Land Sat Imagery 2004
Datasets used:
Oyster Monitoring Sites–CERP SDE; RECOVER_MONITORING;
GISLIB.NE_Oyster
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Figure: St Lucie Monitoring Sites
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: June 4, 2007
Map Location:
\cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\NE_Eas\tCoast_Monitoring_STL_cmn4598.mxd
Base Imagery: Land Sat Imagery 2004
Datasets used:
Oyster Monitoring Sites–CERP SDE; RECOVER_MONITORING;
GISLIB.NE_Oyster
Seagrass Monitoring Sites–CERP SDE; RECOVER_MONITORING; NE_Seagrass
St. John’s Seagrass Monitoring Sites -
\cerp\projects\GIS\PRGM_03\spatial\shp\cmn4373_SSR\Seagrass\StJohns_Seagrass.shp
Fish Monitoring Sites-CERP SDE; RECOVER_MONITORING;
NE_FISH_EASTCOAST
Benthic Infauna Monitoring Sites–CERP SDE; RECOVER_MONITORING;
NE_BENTHIC_INFAUNA
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Figure: Caloosahatchee Monitoring Sites
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: April 25, 2007
Map Location:
\\cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\NE_WestCoast_Monitoring_cmn4598.mxd
Base Imagery: Land Sat Imagery 2004
Datasets used:
FGCU Oyster Monitoring Sites–CERP SDE; RECOVER_MONITORING;
GISLIB.NE_FGCU_OYSTER_SITES
Caloosahatchee Seagrass Monitoring Sites–CERP SDE;
RECOVER_MONITORING; NE_SEAGRASS_CAL
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Figure: Caloosahatchee Fish Monitoring Sites
Map Author: Laura Biddison, CERP GIS Map Technician
Map Updated: April 25, 2007
Map Location:
\\cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\NE_WestCoast_Monitoring_FISH_cmn4598.mxd
Base Imagery: Land Sat Imagery 2004
Datasets used:
Fish Monitoring Boundaries-
\\cerp\projects\GIS\PRGM_03\spatial\shp\cmn4373_SSR\NE\FishMonitoringOutline.shp
6.0 GREATER EVERGLADES WETLANDS MODULE

6.1 Brief Description and Background Information for the Greater Everglades Wetlands Module

The remaining portion of the Greater Everglades (GE) wetlands includes a mosaic of interconnected freshwater wetlands and estuaries located primarily south of the EAA, in addition to the LO littoral zones, hydric pinelands and seasonal wetlands of the J.W. Corbett/Pal Mar/Dupuis Wildlife Management Area. A ridge and slough system of patterned, freshwater peatlands extends throughout the WCAs into Shark River Slough in Everglades National Park (ENP). The ridge and slough wetlands drain into tidal rivers that flow through mangrove estuaries into the Gulf of Mexico. Higher elevation wetlands that flank either side of Shark River Slough are characterized by marl substrates and exposed limestone bedrock. Those wetland areas located to the east of Shark River Slough include the drainage basin for Taylor Slough, which flows through an estuary of dwarf mangrove forests into northeast Florida Bay (NEFB). The Everglades marshes merge with the forested wetlands of Big Cypress National Park (BCNP) to the west of WCA 3 and ENP. Major stressors currently impacting GE wetlands include disruption of sheet flow and associated hydropatterns, sea level rise, nutrient inputs and eutrophication and invasive non-native plants and animals.

Major progress and results are reported in the context of groups of hypothesis clusters as described in the 2006 Assessment Strategy for the MAP (MAP Part2) (RECOVER 2006a):

- Integrated Hydrology and Water Quality
- Everglades Mangrove Estuary
- Ridge and Slough Landscape Dynamics
- Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base
- Everglades Crocodilian Populations

The hypotheses relate changes in major physical and chemical stressors, as influenced by CERP, to targeted changes in the ecosystem. This module report represents an update to the 2006 SSR (RECOVER 2006b) and extends the assessment from wet season 2006 through the beginning of the 2006/2007 dry season. Many of the monitoring components have been successfully implemented and integrated at the system-wide scale of the GE wetlands. Table 6-3 in Section 6.9 details the status of monitoring for all five hypothesis clusters. The monitoring program to support the Predator-Prey Interactions of Wading Birds and Aquatic Forage Base set of hypotheses are the most fully implemented; therefore, these are reported in greater detail. Not all of the monitoring components for the GE wetlands module have been fully implemented and the status of each component is presented in Table 6-3 of this report.
WCA 1 is contained within the A.R.M. Loxahatchee National Wildlife Refuge.

**Figure 6-1: Greater Everglades Wetlands Module Boundary**
6.2 Greater Everglades Wetlands Hypothesis Cluster–Integrated Hydrology and Water Quality

6.2.1 Abstract
The status of the monitoring effort associated with this hypothesis cluster will be addressed in this section, while the application and integration of data with respect to the other hypothesis clusters will be addressed in following sections. This approach is taken because the hydrology and water quality data associated with this program underpin the assessment of the other four hypothesis groups. A primary product of the integrated hydrology monitoring effort is the EDEN which is now operational and being utilized in the 2007 assessments. Another product of this effort is the system-wide map of soil nutrients developed from cores collected in 2004 and reported in the 2006 SSR. An analysis assessing spatial variation of this 2004 soil core data has begun. The nutrient monitoring component of this group also indicates that the spatial patterns of periphyton TP in the WCAs generally correspond to patterns of eutrophication as described in the 2006 SSR. The most significant new results not covered in the 2006 SSR show a correspondence of periphyton TP measured during the 2005 wet season to aquatic prey nutrient status and productivity in southern ENP.

6.2.2 Background Description
Restoration of the Everglades ecosystem depends on restoring the volume, timing and distribution of sheet flow and on restricting inputs of P and other chemical constituents to levels approximating those in direct rainfall. Sheet flow and inputs of P fundamentally affect all the GE wetlands working hypotheses. Monitoring of hydrology and water quality for the MAP includes EDEN, Everglades soil nutrients and Everglades periphyton mat. The original intent was that data associated with this hypothesis group would be independently assessed, but it has become evident that the analyses from these data underpin the assessment of the other four hypothesis clusters.

Everglades Depth Estimation Network
EDEN is an integrated multi-agency network of real-time water level monitoring, ground elevation modeling, and water surface modeling that provides scientists and managers with current (2000-present) on-line water depth information for the entire freshwater portion of the GE (includes WCAs 1, 2, and 3, BCNP, and ENP). The information will be used to provide real-time water levels and water depth estimates across the GE landscape. EDEN simulations will provide the ability to associate biological field data to the actual hydrology of the system, thus integrating hydrology and ecological functions. EDEN simulations will be used both in assessment and evaluation models. A list of significant products and hydrologic tools, such as water depth, hydroperiod and water surface elevation are available on the EDEN web (sofia.usgs.gov/eden) (USGS 2006).

Sediment Nutrient Concentration Monitoring
Monitoring of soil nutrient concentrations across the GE wetlands is based on the working hypothesis that P and nitrogen (N) concentrations in soil and flocculent organic matter reflect patterns and trends in surface water concentrations, integrated over time scales of months to years. Thus nutrient concentrations in soil, along with those in periphyton, provide measures
of site nutrient status and extent of eutrophication that show less temporal variability and are more cost effective to monitor than surface water nutrient concentrations.

A stratified random sampling design was used to produce maps of freshwater soil nutrient gradients across the Everglades (Sklar et al. 2006). The methods and resulting soil nutrient distribution maps were reported as the pre-CERP condition in the 2006 SSR (RECOVER 2006b). It was originally estimated that this regional soil core collection would be repeated at about five-year intervals (RECOVER 2004). The spatial variance associated with this data is currently being assessed to determine the sample number that is adequate to detect regional changes in soil P concentration. The result of this study will be used to determine the temporal and spatial scope of future soil cores collected for nutrient analysis.

Everglades Periphyton Mat Nutrient Concentration Monitoring
Monitoring of periphyton mats across the GE wetlands is based in the working hypothesis that mat structure and community composition integrate hydrology and water quality over relatively short time scales (RECOVER 2006a). Periphyton responds quickly (weeks to months) to alterations in water management and can serve as early warning indicators of ecosystem change (Gaiser 2006). Monitoring of the periphyton community also contributes data to the understanding of the working hypotheses that the periphyton-bladderwort complex is the basis of the oligotrophic Everglades food web, both as a food source and a refuge for aquatic invertebrates that are consumed by small fish, crayfish and grass shrimp (RECOVER 2006a).

Periphyton samples were collected concurrently with throw-trap samples for aquatic fauna prey populations (Trexler and Robertson 2006). The sampling design follows guidelines described by Philippi (2003, 2005) and is based on a spatially balanced generalized recursive tessellation (Stevens and Olsen 2004).

Total phosphorus (TP) concentrations within periphyton mats were measured from samples collected across the GE wetlands during the 2005 wet season and interpolated with standard kriging methodology; the nutrient concentrations were extrapolated to a landscape scale. Generally, isolated areas of TP concentrations in excess of 800 µg/g occurred along the edges of LO and inflow points to the Corbett Pal-Mar and WCA 3A, while the majority of the landscape had TP concentrations of less than 200 µg/g, with the notable exception being elevated periphyton TP in southern ENP above the marsh-mangrove ecotone of the Gulf of Mexico drainages (Figure 6-2) (Gaiser unpublished data). Patterns of periphyton TP in WCAs generally correspond to patterns of eutrophication as described by Gaiser (2006) and Gaiser et al. (2006). The most significant new results from the 2005 wet season pertain to a correspondence of periphyton TP to nutrient status and productivity in southern ENP. These results are particularly relevant to trophic interactions between wading bird nesting and aquatic fauna prey populations and are further discussed in the section on the wading bird predator-prey hypothesis cluster.
Figure 6-2: Periphyton Total Phosphorus Across the Everglades in Late Wet Season 2005 Interpolated (via ordinary kriging) Across the Sampling Domain of the Everglades

(Gaiser unpublished data)
6.3 Greater Everglades Wetlands Hypothesis Cluster–Everglades Mangrove Estuary

6.3.1 Abstract
The pre-CERP condition of the Everglades mangrove estuaries is characterized by saltwater intrusion into the headwater of most coastal tributaries and by low to non-existent soil accretion in mangrove forests of the Shark River Basin. The first full three years of data for the coastal gradients of flow and salinity indicated an absence of persistent freshwater-oligohaline zones at headwater sites across most of the coastal Everglades between 2003 and 2006, except the Bottle Creek headwaters of the Harney and Shark Rivers. Soil accretion, as measured by sediment elevation tables (SET), was low to non-existent between 1998 and 2006 at most of these sites in the mangrove zone of the coastal Everglades.

6.3.2 Background Description
Ecological processes and attributes in the mangrove coastlines of the southern Everglades are proximately controlled by interactions between overland sheet flow from freshwater wetlands and sea level in the Gulf of Mexico and Florida Bay. Implementation of CERP will affect the mangrove estuary by altering volumes and patterns of freshwater flow. Monitoring of coastal gradients of flow, salinity and nutrients in the southern Everglades is conducted to assess the working hypothesis that restoring freshwater sheet flow and persistent freshwater pools of water above the marsh-mangrove interface will increase discharge rates, lower salinities in coastal tributary streams and re-establish broader oligohaline zones in coastal wetlands. Sheet flow is also expected to maintain low nutrient conditions in the coastal mangrove forests. Monitoring of mangrove soil accretion is conducted to assess the working hypothesis that the combination of increased freshwater flow and low nutrient conditions will increase rates of peat accretion in the mangrove forests due to below-ground productivity by the mangroves. Mangrove soil accretion will ultimately enhance the ability of these low salinity forests to maintain their integrity against sea level rise.

6.3.3 Methods and Analysis
Monitoring of Coastal Gradients
Nine transects extending from freshwater to marine conditions have been established in the coastal Everglades (Figure 6-3). As part of the PES program, the USGS has been monitoring a series of sites along several of these creeks and rivers since 1995. RECOVER supplemented this monitoring with ten additional sites to add recorders at the upstream ends of transects (Woods and Zucker 2007). Water level, flow, salinity and temperature recorders at these sites provide data both for model development and calibration as well as to serve as a long-term hydrologic dataset to assist in detecting change in this critical area.

Data collected at all flow sites is transmitted in near real-time (every one to four hours) by satellite telemetry to the USGS Automated Data Processing System (ADPS) database in Ft. Lauderdale, Florida. In addition to the fixed monitoring network, moving boat surveys along the nine transects collect salinity, temperature and site location obtained from boat-mounted Global Positioning System (GPS) sensors. Additional information regarding the USGS
coastal monitoring sites and the PES program is available through the USGS South Florida Information Access (SOFIA) web page at URL:  http://sofia.er.usgs.gov/.

Monitoring of Mangrove Soil Accretion
Mangrove soil accretion has been monitored beginning in 1998 along the Shark-Harney River and Lostman’s River systems (Figure 6-3) (Smith et al. 2007). Sites along each river are located in upstream freshwater wetlands, along the middle reach of the river in a brackish marsh-mangrove community and downstream near the river’s mouth in a pure stand of mangrove forest. Two additional sites were established on the Shark River to examine smaller scale variation and mangrove encroachment onto marshes across the mangrove ecotone. One additional site was established at Big Sable Creek on northwest Cape Sable in an area where mangroves have disappeared due to past disturbances. Soil elevation and elevation change are measured using SETs (Cahoon et al 2002). A combination of shallow-rod SETs and deep-rod SETs allows comparison of elevation dynamics in shallow and deep layers of sediment. Surface and groundwater levels are recorded using wells at each site, and vegetation is sampled using both permanent and non-permanent plot techniques at each site.
Figure 6-3: Location of Transects and Monitoring Stations for Salinity Gradients and Sediment Elevations in the Coastal Everglades
6.3.4 Discussion

Coastal Gradients

It is hypothesized that under re-drainage conditions, headwater sites along the marsh-mangrove interface of the coastal Everglades had persistent freshwater to oligohaline salinities. The first three years of the pre-CERP period of record for the coastal gradients indicates an absence of persistent freshwater-oligohaline zones at headwater sites across most of the coastal Everglades (USGS 2007). Mean monthly discharge and salinity at upstream and downstream sites are presented for the period of October 2003 to October 2006 for five Gulf of Mexico coastal drainages and five Florida Bay drainages of the Everglades (Figure 6-4). Salinity predictably dropped during periods when discharge increased in each drainage area. The only site with persistent freshwater-to-oligohaline conditions was the Bottle Creek headwaters of the Harney and Shark Rivers, which was located in Everglades herbaceous wetlands well above the marsh-mangrove interface (Figure 6-4 panels C and D). Freshwater-to-oligohaline conditions also prevailed at the Broad River headwaters, although salinity rose to > ten ppt during low discharge periods of 2004 and 2005 (Figure 6-4 panel B). Upstream and downstream salinities fluctuated together in the Lostman’s River, North River and all Florida Bay drainages, where oligohaline conditions occurred only during high-discharge periods (Figure 6-4 panels B, C and E).

The salinity regime for the southwest coast differed from that of NEFB. For the southwest coast, salinities were usually fresh throughout the wet season and rose during the dry season and during major tidal surges. When these sites were compared to NEFB, saltwater intrusion via surface water in the Taylor Slough and C-111 basin occurred more rapidly during the transitional period between the wet and dry seasons and occasionally persisted to July or August.
Figure 6-4: Mean Monthly Discharge and Salinity at Upstream and Downstream Monitoring Stations on Coastal Tributaries of the Everglades

Gulf transects, 2003–2006 (USGS 2007) (continues to next page)
Figure 6-5 continued: Mean Monthly Discharge and Salinity at Upstream and Downstream Monitoring Stations on Coastal Tributaries of the Everglades
Mangrove Soil Accretion
Soil accretion was low to non-existent between 1998 and 2006 at most SET sites in the mangrove zone of the southwest coastal Everglades (Smith et al. 2007). Accumulations were zero to two centimeters at upstream and mid-stream sites. Accretion was higher at the three downstream mangrove forested sites, where there had been two to four centimeters of accretion prior to the passage of Hurricane Wilma (illustrated for the mouth of the Shark River in Figure 6-6). Accretion balanced shallow subsidence at the downstream mangrove sites prior to Hurricane Wilma, resulting in a fairly constant sediment elevation. Hurricane Wilma caused major increases in elevation at the lower Lostman’s and Shark River mangrove sites due to sediment deposition. The Big Sable Creek mangrove site, which is closer to the Gulf of Mexico, experienced erosion before and then deposition following Wilma. This produced no net change in elevation. Following Hurricane Wilma’s sediment deposition, all downstream sites have shown a pattern of elevation loss of one to two centimeters. The Big Sable Creek mudflat sites have steadily eroded since their establishment and Hurricane Wilma eroded them by approximately another three centimeters.

Deep and shallow-rod SETs were installed at the mangrove site at the mouth of the Shark River in 2002. Most elevation change during the first year of measurement occurred in the deepest layer and was significantly related to changes in groundwater level. This pattern continued until 2004 when accretion began to dominate the elevation signal, even before Wilma’s passage. There appears to have been subsidence in both the middle and deeper layers after Wilma. None of the elevation change measured at this site can be ascribed to the upper layer of the sediment which contains the root zone.

![Figure 6-6: Sediment Elevation, Accretion, and Subsidence in Mangrove Forest at the Mouth of Shark River, 1998-2006](image)

(Smith 2007)
6.4 Greater Everglades Wetlands Hypothesis Cluster–Ridge and Slough Landscape Dynamics

6.4.1 Abstract
A very important accomplishment during 2007 for the landscape hypothesis cluster was the development of a probability-based sampling design for monitoring of the ridge and slough landscape. This design incorporates random selection of primary sampling units (PSU) of 2 x 4 kilometers across the ridge and slough landscape so that all areas have a chance for inclusion, but density of sampling units can be higher in areas expected to be most impacted by CERP. This approach allows inferences to be drawn about regions with different degrees of management impacts (pre- and post-CERP) across the entire ridge and slough landscape. A pilot monitoring project is planned for 2008 to identify a set of landscape attributes for ridge, slough and tree island monitoring utilizing this probability-based sampling design.

6.4.2 Background Description
Monitoring of ridge and slough landscape dynamics is based on the hypothesis that ecological processes and attributes in the patterned peatlands of the Everglades are controlled by sheet flow, hydroperiod, water depth, fire and nutrient dynamics. Together these factors interact to maintain organic soil accretion and loss in a state of dynamic equilibrium. Altered patterns of sheet flow and related variables in the present system have caused disequilibrium of accretion and loss processes, which is exacerbated by eutrophication. That disequilibrium causes degradation in the ridge, slough and tree island micro-topography toward a flattening of the landscape. Degradation of micro-topography interacts with hydrology, eutrophication, fire and exotic plants to reduce the diversity and stability of habitats which were previously long-term, large-scale features of the Everglades ridge and slough landscape. Declines in ridge and slough habitat diversity and stability during the last century have included expansion of sawgrass into sloughs and wet prairies, tree island drowning, tree island burn-out, conversion to cattail under eutrophic conditions and takeover by exotic plant species.

Ridge and slough landscape monitoring is conducted to assess the working hypothesis that resumption of sheet flow and related patterns of hydroperiod, water depth, water quality and fire with the implementation of CERP will restore and sustain the micro-topography, directionality, spatial extent and habitat characteristics of ridges, sloughs and tree islands in the landscape.

These data will closely link, and are dependent upon, the MAP monitoring components described elsewhere in this report (i.e., EDEN, vegetation classification and periphyton analysis). Additionally, system-wide sediment nutrient information that was presented in the 2006 SSR will provide baseline information for this analysis (RECOVER 2006b).

6.4.3 Methods and Analysis
Probability-based Landscape Sampling Design
The most important accomplishment during 2007 for the landscape hypothesis cluster was the development of a probability-based sampling design for the monitoring of the ridge and slough landscape (Philippi 2007). This design incorporates random selection of PSUs of
2 x 4 kilometers across the ridge and slough landscape so that all areas have a chance for inclusion (Figure 6-7). Density of sampling units can be greater in areas expected to be most impacted by CERP. This approach allows inferences to be drawn about regions with different degrees of management impacts (pre- and post-CERP) across the entire ridge and slough landscape. The probability-based sampling design is a major departure from the non-random monitoring designs of previous and ongoing studies which do not allow inferences to be drawn across the entire ridge and slough landscape.

Implementation of a pilot monitoring project is planned for 2008 to identify a set of landscape attributes for ridge, slough and tree island monitoring utilizing this probability-based sampling design. The set of landscape attributes for monitoring includes fundamentally different topologies. Attributes such as percent ridge/tree island/slough, ridge size and elongation are measured on areas, while soil depth and accretion are measured at specific points, and some, such as elevational amplitude between ridges and sloughs, are derived from relative elevations measured at points along transects. Therefore, the monitoring design must capture these attributes in a multi-stage sampling design, by nesting point measures in transects and tree islands within PSUs of sufficient area for calculation of the pattern metrics.

The elongation and curvature of the PSUs reflect the general landscape patterning of the ridges in order to reduce the number of ridge and tree island features straddling the PSU boundaries. However, the historic direction of sheet flow inferred from the orientation of ridges and sloughs is not the only axis likely to be relevant for analysis of data from this sampling design. Sub-surface flow appears to be to the east and west sides of the Everglades and the locations of control structures putting water into the Everglades may direct sheet flow in directions different from the historic ridge and slough orientation. Therefore, rather than maximizing the ability to make inferences in a single direction, the PSUs are located to support analyses targeted at regional (e.g., WCA-3 v. ENP) or directional changes.

In order to provide the flexibility from finite sampling theory for future analyses, the GE wetlands was tiled with a set of 761 elongated cells, each two kilometers wide, approximately eight square kilometers in area, and oriented in the approximate direction of the ridges. Of these cells, 117 clipped edge cells with areas less than four square kilometers were dropped, leaving 644 in the population. Using these cells, a draw based on the major principals associated with generalized recursive tessellation sample design (GRTS) (Stevens and Olsen 2004) was produced (Figure 6-7). This produces a spatially-balanced probability sample that supports several different forms of design-based inference as well as spatial model-based inference. Another useful property of the GRTS design is that for sample sizes of 1, 2, 3...N, any subset of samples 1 to N is itself spatially-balanced. This is useful in two major ways. First, not all secondary sampling need be performed at all PSUs, or, conversely, one-shot sampling may occur at more sites than just the N PSUs. GRTS allows other sampling to occur at sites 1 - N, with complete co-location for the smaller sample draw, and spatial balance for both the smaller and larger draws. Second, without accurate estimates of the time and money costs per sample for this complex set of measurements, it is difficult to specify the exact sample size a priori, a necessity for determining the grid density in a regularly-spaced grid design. GRTS allows a rolling start: whatever number of sites can be
sampled in Year 1 (e.g., 8-16) becomes \(N/5\) for the five-year rotating panel, with both the complete \(N\) sites and each year's panel of sites approximately spatially-balanced.

It is currently envisioned that within each PSU, a permanent transverse transect (two kilometers long) will be drawn at a random location along the long axis. At some prescribed interval along this transect, the relative elevation will be recorded. If adjacent relative elevations differ by more than ten centimeters, additional relative elevations will be measured within these intervals in order to characterize the slope between the slough and ridge. These measurements will characterize changes in the amplitude of the ridge to slough elevation, but also the elevational pattern of changes in the ridge and slough widths detected from aerial photo-interpretation. Soil depth, nutrient content, periphyton, vegetation biomass and species composition will be measured in a randomly chosen slough crossed by the transect. For each tree island in the PSUs, attributes such as forest structure (species and size composition), soil and tissue nutrients, and relative elevation will be quantified.

Most landscape-level change is expected to occur slowly enough that sites need not be revisited every year. Therefore, the sample draw is divided into five PSU panels. The first panel will be sampled in years 1, 6, 11...\(N\); the second in years 2, 7, 12...\(N\), thus allowing for a staggered implementation that will support an entry point for monitoring changes related to the adaptive management (AM) process.
Figure 6-7: Generalized Recursive Tessellation Probability-Based Spatially Distributed Sampling Design for Monitoring Ridge, Slough and Tree Island Dynamics in the Everglades Ridge and Slough Landscape

(Phillippi 2007)
6.5 Greater Everglades Wetlands Hypothesis Cluster–Predator-Prey Interactions of Wading Birds and Aquatic Fauna Forage Base

6.5.1 Abstract

The strategy for the integrated assessment of wading bird/aquatic fauna predator-prey relationships is to annually track the production of aquatic fauna populations during the wet season, the concentration of those populations during the subsequent dry season and the distribution and size of wading bird nesting colonies in response to the prey populations. This report assesses wading bird response to prey populations during the 2005-06 water year (WY) by comparing the distribution and biomass of the wet and dry season prey populations to the distribution and size of wading bird nesting colonies. Hydrologic conditions across the Everglades during the 2005 wet season and 2006 dry season supported a successful year for wading bird nesting throughout much of the system in terms of overall nest numbers, unusually high nesting success for all wading bird species and few colony abandonments.

Standing crops of marsh fishes captured in throw traps during the 2005 late wet season indicated a region of low biomass in southern ENP that was in the area above the marsh-mangrove ecotone of the Gulf of Mexico drainages where periphyton TP was elevated and where productivity was high in most other producers. The discrepancy of low marsh fish biomass in this area of otherwise high productivity is unexpected and may be important regarding the wading bird predator-prey hypothesis. Standing crops of crayfish captured in throw traps during the 2005 late wet season indicated a region of high biomass in the Ochopee Marl Prairies and Lostman’s Slough to the west of Shark River Slough in ENP. Crayfish standing crops were uniformly low throughout most of the remaining Everglades. Crayfish populations were dominated by the Everglades crayfish (Procambarus alleni) in ENP and by the slough crayfish (Procambarus fallax) north of ENP. Standing crops of marsh fish and crayfish did not increase as water levels declined during 2006 until the surface water receded into isolated pools, and then the levels were orders of magnitude higher than in areas that were previously flooded.

Although 2006 was a strong nesting year for wading birds throughout the Everglades and nesting in southern colonies was higher than previous years (Cook and Call 2006), colony sizes in southern ENP remained low compared to the WCAs and compared to the period prior to the collapse of the southern colonies. Depressed nesting in southern ENP corresponded to the low fish standing crop in an area of otherwise high productivity. A possible explanation for the low initiation of nesting in coastal regions of ENP in 2006, despite water recession rates conducive to prey concentration, is that low wet season fish biomass was insufficient to produce dry season prey concentrations that were adequate to support nesting. The correspondence of low fish biomass to reduced wading bird nesting in the southern Everglades is relevant to the hypothesis that collapse of traditional coastal nesting colonies is related to declines in prey populations along the freshwater-estuarine interface of the southern Everglades.

The three watersheds used by nesting roseate spoonbills in NEFB indicate a temporal sequence in peak prey availability across the landscape that was conducive to spoonbill nesting success during 2006. The sequential drying across the landscape that occurred in the
coastal wetlands above NEFB was conducive to high spoonbill nesting success despite a low number of nests in that sub-region during 2006. The apparent pattern of drying from tidally-influenced sites to non-tidal sites in Cape Sable and southern Whitewater Bay appeared conducive both to high spoonbill nesting success and to a high number of nests in the northwest sub-region of Florida Bay.

### 6.5.2 Background Description
The collapse of wading bird nesting colonies in the southern Everglades is attributed to declines in population densities and seasonal concentrations of marsh fishes and other aquatic prey organisms (RECOVER 2006a). Monitoring of wading bird/aquatic fauna predator-prey interactions across the GE wetlands is based on the hypothesis that restoration of natural hydrologic conditions will re-establish distributions of prey densities and concentrations across the landscape that, in turn, will support the return of large, successful wading bird nesting colonies to the southern Everglades. The strategy for the integrated assessment of wading bird/aquatic fauna predator-prey relationships is to annually track the production of aquatic fauna populations during the wet season, the concentration of those populations during the subsequent dry season and the distribution and size of wading bird nesting colonies in response to the prey populations. This report assesses wading bird response to prey populations during the 2005-06 WY by comparing the distribution and biomass of the wet and dry season prey populations to the distribution and size of wading bird nesting colonies.

### 6.5.3 Methods and Analysis

#### Monitoring of Aquatic Fauna Prey Populations during the Late Wet Season
During the late wet season of 2005, aquatic fauna prey populations were monitored in 149 PSUs, which were distributed across the 38 CERP landscape sub-units deemed feasible for throw trap usage (Trexler 2004, Trexler and Robertson 2006). Selection of PSUs followed guidelines described by Philippi (2003, 2005) and was based on a spatially-balanced generalized recursive tessellation (Stevens and Olsen 2004). Throw trap locations within a PSU were three fixed coordinates within a 10m x 10m cell drawn randomly from the habitat. Landscape estimates for standing crop of aquatic fauna prey populations were interpolated via standard kriging across the sampling domain.

#### Monitoring of Aquatic Fauna Prey Populations during the Early/Late Dry Season
Aquatic fauna prey populations during the early and late dry season 2006 were monitored in a subset of ten of the 38 CERP landscape sub-units deemed feasible for throw trap usage (Trexler 2004, Trexler and Robertson 2006). Criteria for random site selection within each landscape unit were the same as for late wet season sampling.

#### Monitoring of Aquatic Fauna Prey Populations in Concentration Patches during the Dry Season
Aquatic fauna prey concentrations in isolated pools during the 2006 dry season were monitored in random samples from a subset of 32 PSUs, which were distributed across seven CERP landscape units (Botson and Gawlik 2006). Criteria for site selection were the same as for late wet season sampling. Utilization of a multi-stage sampling design
(Cochran 1977) that produced means and confidence intervals were an adequate measure to assess changes in prey density across space and over time.

**Monitoring of Oligohaline Marsh Fish Populations in Coastal Mangrove Habitats of the Everglades**

Drop trap samples were collected during November 2005 to April 2006 at fixed locations at 17 sites along the freshwater-estuarine interface from southern Biscayne Bay to Lostman’s River (Figure 6-8). Location of sampling sites is necessarily influenced by logistics of access and the ability to construct permanent drop trap structures in remote areas.

**Monitoring of Roseate Spoonbill Prey Populations during the Wet and Dry Season**

Prey base fishes were collected using a 9m² drop trap as per Lorenz et al. (1997) at 14 spoonbill foraging locations along the northern mangrove coast of Florida Bay, southeastern Biscayne Bay, and the Gulf of Mexico (Figure 6-8). Drop trap samples were collected eight times a year (June, September and monthly from November through April) to cover the spoonbill nesting period. The ten sites were grouped into four watersheds: southern Biscayne Bay, the C-111 Basin, Taylor Slough and Cape Sable. Two sub-habitats were sampled at each location: flats and creek. The flats are defined as seasonally inundated peripheral wetlands that are flooded during the wet season with each site experiencing differing hydropodiod lengths depending upon elevation. The creeks are defined as habitat that is wetted year round and serve as a refuge for wetland fishes forced from the flats during drying events.

Available biomass is defined as the cumulative fish/m² for either the flats or the creeks sub-habitat depending on which is larger. Because the amount of flats habitat drained by the creek is different at each site, the catch at each site was standardized by comparing it to the maximum monthly catch at each site (resulting in a value ranging from zero to one). The reason for using this process is that a site at which the creek drained only five acres of flats, for example, would not have as high a concentration of fish as a site that drained 50 acres. To account for this disparity in site concentration potential, the data for each site was placed on a zero-to-one scale making all sites relative to one another. Once all eight samples for each site were standardized, the data were combined into total percent catch for each watershed for each sample month.

**Monitoring of Wading Bird Colony Location, Size, and Timing in the Mainland Everglades during Winter-Spring Nesting Season**

Two types of systematic surveys were used to document wading bird nesting in the WCAs and LO during 2006; aerial and ground surveys (Frederick et al. 2006, Cook and Call 2006). On or about the 15th of each month from January through June, systematic aerial surveys for colonies were performed. Observers sat on both sides of a Cessna 182, flight altitude at 800 feet above ground level (AGL), and flew east-west oriented flight transects spaced 1.6 nautical miles apart. GPS-guided belt transects in north-south orientations resulted in overlapping coverage on successive transects under a variety of weather and visibility conditions; this method has been used continuously since 1986. Systematic ground surveys of colonies by airboat were carried out from early April through late May, and were designed to locate and document small colonies or those of dark-colored species that are difficult to
detect from aerial surveys. In mainland ENP, only aerial colony surveys were conducted monthly January through June.

Monitoring of Roseate Spoonbill Colony Location, Timing and Nesting Success in Florida Bay during Winter-Spring Nesting Season
Roseate spoonbill nests were counted from November 2005 through April 2006 on 34 keys that have been used historically by spoonbills as nesting colonies in Florida Bay. The colonies were divided into five distinct nesting sub-regions based on each colony’s primary foraging location (Lorenz et al. 2001). Nest counts were performed by entering the active colony and thoroughly searching for nests on foot. Nesting success was estimated for the four active sub-regions through mark and re-visit surveys of the most active colony within the sub-region. These surveys entailed marking between 15 and 50 nests shortly after full clutches had been laid and re-visiting the nests on an approximate two week cycle to monitor chick development.

Crayfish Population Dynamics
Seasonal crayfish population dynamics during 2005 were monitored using throw traps in a subset of 36 PSUs, which were distributed across six of the CERP landscape units described above (Trexler and Robertson 2006, Volin and Lott 2006) (Figure 6-8). The stratified random sampling design for crayfish sampling is based on Philippi (2003). Landscape estimates for crayfish abundance by species were interpolated via standard kriging across the sampling domain.

The Role of Mangrove Creeks as Dry-down Refuges in the Coastal Everglades
Fish community dynamics in the upper reaches of Gulf of Mexico mangrove creeks during 2005 and 2006 were monitored at ten study sites in Rookery Branch and five sites in the North and Roberts River (Loftus and Rehage 2006) (Figure 6-8; note sites are denoted by researcher name and sampling year). Sampling focused on the oligohaline stretches of mangrove creeks at the marsh-mangrove ecotone. Samples were collected in November 2005, February 2006 and April 2006 using minnow traps for small fishes and electrofishing for large fishes.

Aquatic Fauna Prey Populations in Forested Wetlands
Protocols for sampling aquatic fauna prey populations in forested wetlands were tested in 2006 in cypress forests and mangrove forests. Drop trap, bottomless lift net, throw trap, drift fence and gill net sampling methods were compared in cypress forests at three sites in BCNP: L-28, Bear Island and Raccoon Point (Liston et al. 2006) (Figure 6-8; note sites are denoted by researcher name and sampling year). Drop trap, bottomless lift net, drift fence and block net sampling methods were compared in mangrove forests at four sites in ENP: Lower Shark River, Mid-Harney River, Tarpon Bay and Big Sable Creek (Figure 6-8; note sites are denoted by researcher name and sampling year).
Figure 6-8:  Comprehensive Map of Sample Locations for Sampling of Aquatic Fauna Prey Populations in South Florida
6.5.4 Discussion

Hydrologic Conditions Affecting Prey Population Dynamics and Wading Bird Nesting in the Everglades during the 2005 Wet Season and 2006 Dry Season

Hydrologic conditions across the Everglades during the 2005 wet season and 2006 dry season supported a successful year for wading bird nesting throughout much of the system (Cook and Call 2006). Average stages in the WCAs and ENP during the 2005 wet season rose sharply in June to levels exceeding ten feet mean sea level, which persisted through December (Figure 6-9). Water levels were well above average at the start of the dry season. Hydrologic conditions during the 2006 dry season were close to optimal for wading bird nesting as suggested by Gawlik (2002). A steady and prolonged water level recession was unimpeded by major reversals. Furthermore, the late onset of the wet season in 2006 continued to provide ample foraging patches for fledging birds late in the nesting season.

Stage values represent a mean of 13 gages. Rainfall is reported as a mean of nine gages. Figure reproduced from Botson and Gawlik (2006).

Figure 6-9: Mean Rainfall and Stage Level throughout the Everglades during the Wet and Dry Seasons of 2005-2006

Periphyton Total Phosphorus during Late Wet Season of 2005: Implications Concerning Nutrient Status and Productivity in the Southern Everglades

The distribution of TP concentrations in periphyton mats during the late wet season of 2005 (Figure 6-2) indicates the nutrient status of the Everglades at the times and locations of throw trap sampling for aquatic fauna prey biomass. The most notable new pattern to emerge from this map is the elevated periphyton TP in southern ENP above the marsh-mangrove ecotone of the Gulf of Mexico drainages. This area represents a zone of peak productivity in most producers that appears to be caused by the convergence of marine P and freshwater N sources as well as marine-derived P loadings from groundwater (Childers 2006, Price et al.
Other patterns of periphyton TP north of the Park are similar to those reported by Gaiser (2006) and Gaiser et al. (2006).

**Biomass of Aquatic Prey Populations during Late Wet Season of 2005**

Interpolation of standing crops of marsh fishes captured in throw traps during the 2005 late wet season indicated a region of low biomass < 0.2 g/m² in southern ENP (*Figure 6-10*). The low fish biomass in southern ENP was in the area above the marsh-mangrove ecotone of the Gulf of Mexico drainages where periphyton TP was elevated (*Figure 6-2*) and where productivity was high in most other producers (Childers 2006, Price et al. 2006, Iwaniec et al. 2006, Ewe et al. 2006, Childers et al. 2006). The discrepancy of low marsh fish biomass in this area of otherwise high productivity was unexpected and may be important regarding the wading bird predator-prey hypothesis as this area encompasses the “fertile crescent” of freshwater and oligohaline marshes that represent important feeding grounds within the nine kilometer flight distances of historic wading bird nesting areas in the southwest Everglades (Bancroft et al. 1994). Future assessments will integrate EDEN simulation outputs to examine hydrologic characteristics of the southern Everglades that might impact marsh fish populations despite overall higher productivity of the region.

North of the southern coastal area the marsh fish standing crops were uniform across most of the Everglades and ranged from 0.2 – 0.4 g/m². Regions of greater periphyton P concentration in the LO littoral zone, WCA 1, and WCA 3B appear to be associated with fish standing crops averaging 0.4 – 0.8 g/m².

Interpolation of the standing crops of crayfish captured in throw traps during the 2005 late wet season indicated a region of high biomass to the west of Shark River slough in ENP, where standing crops averaged 0.9–1.5 g/m² in the Ochopee marl prairies and Lostman’s slough basin (*Figure 6-10*). Crayfish standing crops of < 0.2 g/m² were uniformly low throughout most of the remaining Everglades except regions of higher biomass in other marl prairies of the ENP and in WCA 1 where crayfish standing crops averaged 0.3 – 0.6 g/m². Crayfish populations were dominated by the Everglades crayfish (*Procambarus alleni*) in ENP and by the slough crayfish (*Procambarus fallax*) north of ENP (*Figure 6-11*).

Results reported in the 2006 SSR (RECOVER 2006) from a study of crayfish population dynamics are consistent with the above findings. Volin and Lott (2006) captured no crayfish in WCA 3A during the 2005 wet season, concluding that populations were either depauperate or too dispersed to be sampled. Volin and Lott also reported greater crayfish densities in marl prairie habitats compared to other areas of ENP.

Standing crops of grass shrimp captured in throw traps during the 2005 late wet season indicated that grass shrimp represented less than ten percent of the aquatic fauna prey biomass throughout the GE wetlands. Relatively high grass shrimp standing crops in WCA 1, western WCA 3A, WCA 3B, and PalMar/Corbett averaged 0.1–0.3 g/m² in comparison to standing crops of < 1 g/m² throughout other Everglades wetlands (*Figure 6-10, Figure 6-11*), while most of ENP was devoid of grass shrimp. Because of the small contribution of grass shrimp to the prey biomass during the 2005 wet season, emphasis is
placed on fish and crayfish in the following discussions of prey concentrations during the 2006 dry season.

Standing crop of aquatic fauna prey populations during the 2005 late wet season interpolated (via ordinary kriging) across the sampling domain of the Everglades (Trexler and Robertson 2006). Circles indicate PSUs for throw trap sampling.

**Figure 6-10: Standing Crop of Aquatic Fauna Prey Populations during the 2005 Late Wet Season**
Figure 6-11: Crayfish Abundance by Species during the 2005 Late Wet Season
Biomass of Aquatic Prey Populations during Early and Late Dry Season 2006

Standing crops of marsh fish and crayfish during the late wet season of 2005 represented the prey population that was potentially available for concentration and wading bird foraging as water levels receded during the 2006 dry season. However, standing crops did not increase as water levels declined during 2006 until the surface water receded into isolated pools. Wet and dry seasons did not significantly (alpha = 0.05) differ in fish and crayfish standing crops in ten landscape regions that were sampled during the 2005 late wet season and during February and April of the 2006 dry season (Figure 6-12). Surface water persisted during the February and April sampling periods in the region, with the exception of western Shark River Slough, where dry conditions in April 2006 prevented throw trap sampling.
Figure 6-12: Average Standing Crop of Marsh Fishes and Crayfish during the Late Wet Season of 2005 and the Early and Late Dry Season of 2006 Dry Season at Selected Landscape Sampling Units of the Everglades
Biomass of Aquatic Prey Populations in Concentration Patches during 2006 Dry Season

As surface water receded into isolated pools during the 2006 dry season, standing crops of fish and crayfish rose to levels that were orders of magnitude greater than areas flooded during the previous wet season. Prey concentrations were sampled in randomly selected isolated pools in seven landscape regions of the Everglades during spring 2006 (Figure 6-13).

Averages of standing crops of marsh fishes in isolated pools in WCA 2A and WCA 3A were about 20 times greater than those in ENP during the 2006 dry season (Figure 6-13). Mean fish standing crops of 0.2–0.4 g/m² during the 2005 wet season were concentrated to 135 and 70 g/m² during the 2006 dry season in isolated pools in southern WCA 2A and northwest WCA 3A. In ENP, the wet season standing crops also averaged 0.2 – 0.4 g/m² during the prior wet season but were concentrated only to 2 g/m² to 13 g/m² during the 2006 dry season in isolated pools in western Shark River Slough, Lower Lostman’s Slough, Ochopee Marl Prairies, eastern Perrine Marl Prairies, and the Rocky Glades.

In contrast to marsh fish standing crops, mean crayfish standing crops in isolated pools were about 16 times greater in the ENP compared to the WCA 2A and WCA 3A during the 2006 dry season (Figure 6-13). Mean crayfish standing crops of 0.3 – 1.5 g/m² during the 2005 wet season were concentrated to eight to 36 g/m² during the 2006 dry season in ENP. In the WCAs, wet season standing crops which averaged <0.3 g/m² during 2005 did not change in southern WCA 2A and increased to only 1.8 g/m² in northwest WCA 3A during the 2006 dry season. Higher dry season standing crops of crayfish in concentration patches in ENP, in comparison to the WCAs, corresponded to higher standing crops of crayfish during the previous wet season.

Wading Bird Nesting in the Mainland Everglades during 2006

Nest Numbers and Nesting Success. The 2006 nesting season represented a successful year for wading birds in terms of overall nest numbers (Cook and Call 2006). The total number of wading bird nests in the GE wetlands during 2006 is estimated to exceed 63,000 excluding cattle egrets and anhingas (Figure 6-1). This number includes 39,677 nests in the WCAs, 10,000 nests in ENP, and 13,693 nests in the LO littoral zone. The strong initiation of nesting in 2006 is characteristic of resurgence in total numbers of nesting birds since 1999 (Frederick et al. 2006).

In addition to the large numbers of nest initiations during 2006, nesting success was unusually high for all wading bird species and few colony abandonments were noted (Frederick et al. 2006). Inter-colony average probability of a nest fledging at least one young (nesting success) in 2006 was 75-80 percent for both large and small herons, with an average number of young fledged per nest 2.5 – 3.2. Average nesting success of 54 percent for white ibis from Alley North and Loxahatchee colonies was high for the species. Wood stork nests were initiated in December to January during 2006 in comparison to typical January to February initiation. Average nesting success of wood storks at the Tamiami West colony was 71 percent with an average of 2.6 young fledged per nest.
Average standing crop of marsh fishes and crayfish in concentration patches during the dry season of 2006 in selected landscape sampling units of the Everglades (Botson and Gawlik 2006), plotted over standing crops during 2005 late wet season (Trexler and Robertson 2006). Data on standing crops in concentration patches are from random sites and are shown as the mean and SE for each landscape sampling unit (LSU) sampled during 2006.

**Figure 6-13: Average Standing Crop of Marsh Fishes and Crayfish in Concentration Patches during the Dry Season of 2006**
Table 6-1: Numbers of Wading Bird Nests in the Greater Everglades Wetlands during 2006

<table>
<thead>
<tr>
<th></th>
<th>Water Conservation Areas</th>
<th>Everglades National Park</th>
<th>Lake Okeechobee Littoral Zone</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Egret</td>
<td>7,497</td>
<td>2,629</td>
<td>2,117</td>
<td>12,243</td>
</tr>
<tr>
<td>Snowy Egret</td>
<td>8,258</td>
<td>1,755</td>
<td>3,700</td>
<td>13,713</td>
</tr>
<tr>
<td>White Ibis</td>
<td>20,892</td>
<td>4,430</td>
<td>6,980</td>
<td>32,302</td>
</tr>
<tr>
<td>Wood Stork</td>
<td>190</td>
<td>1,124</td>
<td>0</td>
<td>1,314</td>
</tr>
<tr>
<td>Total Wading Birds</td>
<td>39,677</td>
<td>10,000</td>
<td>13,693</td>
<td>63,370</td>
</tr>
</tbody>
</table>

Total wading bird nests exclude anhingas and cattle egrets. Data are taken from Cook and Call (2006).

Comparison of Colony Distribution and Size to Distribution of Prey Biomass. Although 2006 was a strong nesting year for wading birds throughout the Everglades and nesting in southern colonies was higher than previous years (Cook and Call 2006), colony sizes in southern ENP remained low compared to the WCAs and compared to the period prior to the collapse of the southern colonies. The one notable exception was a large wood stork colony in southern ENP at Paurotis Pond. Depressed nesting in southern ENP corresponded to the low fish standing crop in an area of otherwise high productivity (Figure 6-14). The high crayfish biomass in western ENP did not appear to support extensive wading bird nesting in the southern Everglades during 2006; only small numbers of all wading bird species nested near the region of high crayfish biomass, and all large colonies of white ibis colonies were located in WCAs and the LO littoral zone.

A possible explanation for the low initiation of nesting in coastal regions of ENP in 2006, despite water recession rates conducive to prey concentration, is that low wet season fish biomass (Figure 6-10) was insufficient to produce dry season prey concentrations that were adequate to support nesting. The correspondence of low fish biomass to reduced wading bird nesting in the southern Everglades is relevant to the hypothesis that collapse of traditional coastal nesting colonies is related to declines in prey populations along the freshwater-estuarine interface of the southern Everglades (Ogden 1994).
Figure 6-14: Wading Bird Colony Locations and Numbers of Nests in the Everglades during 2006 Nesting Season
Wading bird colony locations and numbers of nests in the Everglades during 2006 nesting season (Cook and Call 2006), plotted over fish standing crop during 2005 late wet season (Trexler and Robertson 2006). White ibis, great egret, and snowy egret nest numbers are from colonies with > 50 nests for all wading bird species combined, excluding anhingas and cattle egrets. Wood stork nest numbers are from all colonies.

**Figure 6-13 continued: Wading Bird Colony Locations and Numbers of Nests in the Everglades during 2006 Nesting Season**
Roseate Spoonbill Nesting in Florida Bay during 2006 in Relation to Prey Availability

Availability of Marsh Fish Prey Populations. Spoonbills nesting in NEFB foraged in the Taylor Slough, C-111 Basin, and southern Biscayne Bay watersheds of the coastal mainland. These watershed indicate a temporal sequence in peak prey availability across the greater landscape that was conducive to spoonbill nesting success during 2006 (Figure 6-15). The sequential drying across the landscape allowed brooding spoonbill parents to follow the drying front across the landscape, thereby minimizing the need to search for patches of prey concentrations.

The mean hatch date for spoonbill chicks in northeastern Florida Bay was December 15 with the earliest monitored nest occurring on December 13 and the last hatched on January 8. Because spoonbills chicks are ready to fledge at three months post-hatch, the critical months for prey availability in the 2005-06 nesting cycle were December through March. Although somewhat less critical, November was also important as it was a period of high energetic demands on the female parent while the eggs were developing internally.

In November, available biomass peaked in the C-111 Basin. Fish availability began to increase in December and peaked in January in southern Biscayne Bay. In Taylor Slough, prey availability began to increase in January and peaked in February and March. The C-111 Basin also had relatively high prey abundance in February and March. From these data, it is apparent that nesting spoonbills had access to relatively high prey availability throughout the 2005-06 nesting cycle.

Within each watershed, temporal and spatial changes in availability indicate a drying front moving across the landscape, thereby sequentially concentrating the prey base fishes. In southern Biscayne Bay, prey concentrations peaked sequentially from south to north with Manatee Bay peaking in December, Barnes Sound and Card Sound peaking in January and Turkey Point peaking in February (excluding the highest availability occurring in June, which is outside the breeding period for spoonbills). In the C-111 Basin, the concentration peaked sequentially from east to west with Highway Creek and Sunday Bay having high concentrations in February and Joe Bay reaching peak concentrations in March. The exception is that Sunday Bay had peak concentrations and Highway Creek had high concentrations in November, as well. This may be due, in part, to water management activities as this basin is the one most directly impacted by C-111 canal operations. In the Taylor Slough Basin, concentrations peaked sequentially from west to east with Seven Palm and Taylor River experiencing peak concentrations in February and East Creek and West Joe Bay peaking in March.

Spoonbills nesting in northwestern Florida Bay principally use the Cape Sable and southern Whitewater Bay as their primary foraging grounds. Unfortunately, similar spatial coverage for the fish sampling in this region is not available unlike the northeast section of Florida Bay. Only two sites (Bear Lake and Lake Ingram) were sampled through December 2005 with a third site (North River) added in January 2006. As a result, the Cape Sable prey concentration patterns were not as clear as in the northeastern bay. In November, prey availability peaked at Lake Ingraham with North River peaking in February and Bear Lake peaking in April. This suggests a pattern of drying from highly tidally influenced sites (Lake...
Ingraham) to non-tidal sites (Bear Lake) with North River being intermediate in tidal influence.

Data obtained from Lorenz et al. (2007)

**Figure 6-15: Availability of Marsh Prey Base Fishes for Roseate Spoonbill Foraging at Drop Trap Sites in the Coastal Everglades during 2005 and 2006**
Roseate Spoonbill Nesting in Florida Bay during 2006. The sequential drying across the landscape that occurred in the coastal wetlands above NEFB was conducive to high spoonbill nesting success despite a low number of nests in that sub-region during 2006. Figure 6-16 displays spoonbill nesting colony locations and numbers of nests in Florida Bay during 2006. The count of 127 spoonbill nests in the northeast sub-region during 2006 was well below the average nesting effort of 211 nests in this region since 1984. However, the estimate of 1.61 chicks produced per nest attempt during 2006 was well above the average of 0.79 since 1984 and was the highest nest productivity recorded in more than a decade (Cook and Call 2006). Sixty-three of the nests were successful at fledging one or more chicks during 2006 in comparison to a three percent success rate during the previous year.

The apparent pattern of drying from tidally influenced sites to non-tidal sites in Cape Sable and southern Whitewater Bay appeared conducive both to high spoonbill nesting success to a high number of nests in the northwest sub-region of Florida Bay. The northwest sub-region produced 262 spoonbill nests during 2006 in comparison to an average of 211 nests since 1984. The estimate of 1.33 chicks produced per nest attempt during 2006 was above the average of 1.25 since 1984. The rate of nesting success of 61 percent during 2006 was comparable to the success rate of 63 percent in the northeast sub-region.
Data was obtained from Lorenz et al. (2007)

Figure 6-16: Roseate Spoonbill Colony Locations and Numbers of Nests in Florida Bay during 2006 Nesting Season
The Role of Mangrove Creeks as Dry-down Refuges in Coastal Everglades. Fish monitoring in mangrove creeks during the contrasting dry seasons of 2005 and 2006 demonstrated effects of marsh drying on the movement of freshwater fishes between creek sites and upstream marshes, and on the potential availability of the fishes as prey for nesting wading birds (Loftus and Rehage 2006). Freshwater marsh fish species accounted for much of the seasonal change in fish communities in Rookery Branch creeks, downstream of the main freshwater drainage in the southern Everglades-Shark River Slough. Fish communities changed comparatively little at higher salinity sites on the North and Watson Rivers, where influxes of freshwater fishes were less evident during the dry season and thus marsh-mangrove connectivity is suspected to be lower.

During the relatively dry winter-spring of 2005, both small prey and large fishes were forced from surrounding marshes into deep creeks early in the dry season, where they likely suffered high mortality from predation (Figure 6-17A). Larger marsh species of fishes, such as largemouth bass, Florida gar, bowfin, and sunfish entered the creeks earlier than small fishes as the surrounding wetlands dried, and used the creeks as dry season refuge. Mass mortality of small fishes appears to occur when the marshes dry early and force the two assemblages together.

During the wetter winter-spring of 2006, the longer flooding period of the wetlands adjacent to the creeks and the uniform pattern of recession allowed prey fishes to remain on the marsh for longer, where these prey fishes should have been more available to wading birds (Figure 6-17B). These results correspond to the 2006 nesting season which was more successful for wading birds compared to 2005 when extensive nest failures occurred. Prolonging the flooding period of wetlands at the marsh-mangrove interface, and maintenance of oligohaline conditions, as a result of increased freshwater flows from CERP projects, should improve productivity and survival of prey species in the region.
Rookery Branch

A. 2004 - 2005

B. 2005 - 2006

Figure 6-17: Catch per Unit Effort of Large Fishes (Electrofishing) and Small Fishes (Minnow Traps) in Mangrove Creeks in Rookery Branch during the Wet, Transition, and Dry Seasons of (A) 2004-2005 and (B) 2005-2006

Aquatic Fauna Prey Populations in Forested Wetlands-Cypress Forests. Throw trap sampling was identified as the most effective method for monitoring aquatic fauna prey populations in the forested wetlands of BCNP (Liston et al. 2006). In comparison to drop trap and lift trap sampling, throw traps were the only method that effectively captured both fish and macro-invertebrates. Drop trap sampling yielded significantly lower density and biomass estimates for all common fish species, and both drop trap and lift trap sampling failed to capture important macro-invertebrates such as crayfish. Logistical problems in cypress forests impede the application of a probability-based sampling design such as that used for throw trap sampling in Everglades herbaceous wetlands. A continuation of this study will investigate statistical approaches to integrate a sampling design in BCNP with the probability-based design for the Everglades to provide a system-wide assessment of aquatic...
fauna prey populations based on throw trap sampling throughout freshwater wetlands of the GE.

Baseline data collected with throw traps in 2005-2006 indicate the contribution of crayfish (*Procambarus alleni* and *P. fallax*) to total prey biomass is relatively high throughout the hydrologic year (≥ 50 percent), and is especially high early in the wet season immediately following forest re-flooding (>90 percent). Extreme intra-annual hydrologic fluctuation (> 1 m) resulted in concentration of fishes in high density prey patches throughout much of the dry season (≈1200 fish/m²). The extent to which wading birds utilized these resources is unknown.

*Aquatic Fauna Prey Populations in Forested Wetlands-Mangrove Forests.* Six m² bottomless lift nets and block nets across intertidal rivulets proved successful for sampling fish and macro-invertebrates fringing mangrove forests along Shark River and Big Sable Creek (Liston et al. 2006). Fish and macro-invertebrate densities were low (< 1 animal/m²), but comparable to Atlantic and Gulf coast salt marshes as well as temperate mangroves in Australia. Catches in block nets placed on the ecotone between forest and river suggested a higher abundance, expressed as catch per unit effort (CPU), of fish and macro-invertebrates in these lower elevation features. Efforts are ongoing to make these estimates from block nets more quantitative. Significant problems were encountered with drop traps, because of the inability to adapt a method developed in soft marl sediments to work in forests with firm peat substrates where achieving a seal on the bottom of the net proved impossible. Drift fences also proved to be ineffective in mangrove forests along Shark River because of highly seasonal heights of tidal flooding and incomplete inundation of all traps in an array at certain times of the year. The same logistical problems described for sampling in cypress forests also impede the application of a probability-based sampling design to monitoring fish and macro-invertebrates in tidal mangrove forests along Shark River Slough.

### 6.6 Greater Everglades Wetlands Hypothesis Cluster—Everglades Crocodilian Populations

#### 6.6.1 Abstract

**American Alligator**

Alligators occurred in higher relative densities in canals compared to marsh and estuarine survey areas throughout most of the Everglades during 2005 and 2006, except for the interior marsh survey area in central WCA 1 where high alligator densities were recorded. Mean alligator densities during 2005-2006 were similar to those for the period of record beginning in 1998. Higher alligator densities in canals found in 2005-2006 support the hypothesis that a combination of shortened hydroperiods, increased nest flooding, creation of canal habitats, and increased salinities has reduced alligator populations throughout much of the natural Everglades system.

Fulton’s K condition index was similar in canals and marsh survey areas during 2005 and 2006. Initial power analysis revealed effects of area on body condition can be detected; additional analyses of the relationship to time and hydrology are underway. While body condition varies temporally and spatially, the hypothesis states that sustained increases in
body condition should occur once the feedback loop of increased alligator populations and alligator holes leads to increased aquatic fauna density.

American Crocodile
A trend of higher numbers of crocodile nests in the ENP since 2000 resulted from increased nesting on Cape Sable after the plugging of the East Cape Canal, which blocked salt water intrusion into the interior of Cape Sable. Nest numbers in other primary crocodile nesting areas of south Florida did not show the magnitude of increase that was observed on Cape Sable. The measurable response to the management action on Cape Sable demonstrates the ability to detect change in crocodile nesting resulting from altered hydrology and salinity in coastal ENP.

Growth, survival and dispersal of juvenile crocodiles were low in ENP in comparison to other primary crocodile nesting areas of south Florida. More than 50 percent of crocodiles captured in 2005 and 2006 were recaptures, which is unprecedented for a crocodilian study. Analyses of temporal patterns of growth and survival and relationships of growth and survival to hydrological parameters are underway.

6.6.2 Background Description
Monitoring of the American alligator across the greater Everglades wetlands is based on the working hypothesis that alligator distribution, abundance, reproduction and body condition are related to hydroperiod and water table in the Rocky Glades, salinity in the mangrove estuaries and water depth patterns in the ridge and slough system (RECOVER 2006). With the resumption of natural patterns of volume, timing and distribution of flow to the Everglades, the American alligator is expected to repopulate and resume nesting in the Rocky Glades and freshwater reaches of tidal rivers in the mangrove estuaries, and to increase in population size and body condition throughout most of the GE wetlands.

American crocodile monitoring in coastal regions of south Florida is conducted to assess the working hypothesis that growth and survival of juvenile crocodiles increase when salinity fluctuates below 20 ppt in shoreline, pond, and creek habitats in the Everglades mangrove estuaries. Restoration of natural volume, timing and distribution of freshwater flow is expected to re-establish salinity gradients that will increase growth and survival of juvenile crocodiles in the mangrove estuaries of the Everglades.

6.6.3 Methods and Analysis
Alligator Relative Density
Numbers of alligators ≥ 25 centimeters in length were counted per kilometer along airboat survey routes during spring and fall night surveys in 17 marsh and canal areas in the WCAs, ENP, and eastern BCNP.

Alligator Body Condition
Fulton’s K condition index was measured for alligators > 25 centimeters in length that were captured along airboat survey routes during spring and fall night surveys in 12 marsh and canal capture areas in the WCAs, ENP, and eastern BCNP.
Crocodile Nesting
Crocodile nest surveys were conducted throughout coastal areas of southern Florida during the June through August hatching period beginning in 1978. Nests were located from evidence of crocodile activity (tail drags, digging and scraping) and successful nests were determined by the presence of hatchlings or hatched shells.

Crocodile Juvenile Growth and Survival
Growth of juvenile crocodiles was estimated from recaptured individuals that were marked between 1978 and 2002 at three nesting areas in southern Florida: Turkey Point, Crocodile Lake National Wildlife Refuge, and ENP. The proportion of hatchling crocodiles that survived for > 12 months was estimated from recaptured individuals that were marked between 1977 and 2004 at the three nesting areas. Hatchlings were defined as animals < 50 centimeters in length and juveniles were defined as animals 50–149.9 centimeters in length.

6.6.4 Discussion
American Alligator
Alligators occurred in higher relative densities in canals in comparison to marsh and estuarine survey areas throughout most of the Everglades during 2005 and 2006 (Figure 6-18). Mean relative densities in canals of 6.2 and 8.2 alligators per kilometers during the two years were five to eight times higher than densities of 1.3 and 1.1 alligators per kilometers along most marsh survey routes. An exception was the interior marsh survey area in central WCA 1, where unusually high densities of 5.0 and 6.5 alligators per kilometers were recorded during the two years. Mean densities at the mangrove estuary survey area in ENP of 0.8 and 1.0 alligators per kilometer were comparable to those in most of the freshwater marsh survey areas. Mean alligator densities during 2005-2006 were similar to those reported by Rice and Mazzotti (2006) for the period of record beginning in 1998. Alligator density during the period of record was higher in canals compared to marsh survey areas, and density in the interior WCA 1 marsh was high compared to other marsh survey areas. Higher alligator densities in canals found in 2005-2006 support the hypothesis that a combination of shortened hydroperiods, increased nest flooding, creation of canal habitats, and increased salinities has reduced alligator populations throughout much of the natural Everglades system.
Mean density of alligators in capture areas of the Everglades during 2005 and 2006 (Rice and Mazzotti 2006). Densities represent numbers of alligators \( \geq 25 \) centimeters in length counted per kilometer along airboat survey routes during spring and fall night surveys. Means are for spring and fall night surveys combined.

**Figure 6-18: Mean Density of Alligators in Capture Areas of the Everglades during 2005 and 2006**
Fulton’s K condition index was similar in canals and marsh survey areas during 2005 and 2006 (Figure 6-19). Fulton’s K condition index averaged 10.8 and 10.6 for alligators in canals during the two years, in comparison to 9.9 and 10.1 for alligators in marsh survey areas. Body condition in the interior marsh of WCA 1 was similar to that in other marsh survey areas along which high alligator densities were found. Mean values for Fulton’s K condition index for alligators captured during 2005-2006 were similar to those reported by Rice and Mazzotti (2006) for the period of record beginning in 1998. Initial power analysis revealed that effects of an area on body condition can be detected; additional analyses on the relationship to time and hydrology are underway.

American Crocodile
The 40-50 crocodile nests recorded in ENP during 2005 and 2006 is consistent with the trend of higher numbers of nests in ENP since 2000 (Figure 6-20). Mazzotti et al. (2007) reported that after Buttonwood and East Cape canals in ENP 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. Nesting began at East Cape Canal after the canal was plugged by the National Park Service in 1986 (and again in 1990). The purpose of this plug was to retain freshwater in interior marshes and prevent saltwater intrusion. Mazzotti (1983) hypothesized that the canal plug worked as intended, lowering salinities interior to the plug, making the habitat more suitable for nesting by the few crocodiles that were known to be in the area and that the lowered interior salinities adjacent to nest sites increased both growth and survival of hatchling crocodiles. The rapid increase in nesting that occurred in 2000-2001 is coincident with when these first hatchlings would have been expected to reach sexual maturity and enter the breeding population. 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. The measurable response to the management action on Cape Sable demonstrates the ability to detect change in crocodile nesting resulting from altered hydrology and salinity in coastal ENP (Mazzotti et al. 2007).

More than 50 percent of crocodiles captured in 2005 and 2006 were recaptures, which is unprecedented for a crocodilian study. This will allow the application of sophisticated quantitative models for analysis of growth and survival. Growth, survival and dispersal of juvenile crocodiles were low in ENP in comparison to other primary crocodile nesting areas of south Florida (Figure 6-2). Analyses of temporal patterns of growth and survival and relationships of growth and survival to hydrological parameters are underway.
Table 6-2: Growth, Survival and Dispersal of American Crocodiles in Southern Florida

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean Juvenile Growth cm/day (Range)</th>
<th>Number Survived for &gt;12 months (%)</th>
<th>Number Dispersed from Natal Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey Point</td>
<td>0.11 (-0.8 to 1.30)(^a) (N=205)</td>
<td>59 (1.71 %) (N(_1) = 3452)</td>
<td>17 (29.0 %) (N(_2) = 59)</td>
</tr>
<tr>
<td>Crocodile Lake NWR</td>
<td>0.10 (0.000 to 0.42)(^a) (N=246)</td>
<td>94 (17.9 %) (N(_1) = 523)</td>
<td>14 (15.0 %) (N(_2) = 94)</td>
</tr>
<tr>
<td>Everglades National Park</td>
<td>0.07 (-0.057 to 0.16)(^b) (N=93)</td>
<td>28 (1.50 %) (N(_1) = 1871)</td>
<td>2 (7.0 %) (N(_2) = 28)</td>
</tr>
</tbody>
</table>

Growth, survival (proportion of hatchling crocodiles that survived for at least 12 months) and dispersal (proportion of hatchling crocodiles that survived and dispersed out of their natal area) of American crocodiles in southern Florida. Growth was different among the three nesting areas (ANOVA, F = 3.91; p = 0.02; LSD T-test, \(\alpha = 0.05\)). Crocodiles grew fastest at Turkey Point and Crocodile Lake National Wildlife Refuge (CLNWR), but with greater variability at Turkey Point. Further, while crocodiles at CLNWR tended to grow faster they could not be distinguished from ENP. More hatchlings survived at CLNWR \((\chi^2 = 423.9; p \leq 0.001)\) than at Turkey Point or ENP, and more hatchlings dispersed from the Turkey Point site \((\chi^2 = 7.4; p \leq 0.025)\) than from CLNWR or ENP.
Mean Fulton’s K condition index of alligators in capture areas of the Everglades during 2005 and 2006 (Rice and Mazzotti 2006). Condition values are for alligators ≥ 25 centimeters in length captured on airboat survey routes during the night surveys. Means are for spring and fall night surveys combined.

**Figure 6-19**: Mean Fulton’s K Condition Index of Alligators in Capture Areas of the Everglades during 2005 and 2006
Data obtained from (Rice and Mazzotti 2006)

**Figure 6-20:** Total Number of American Crocodile Nests Found Between 1978 and 2006 in Everglades National Park, Turkey Point Power Plant, and Crocodile Lake National Wildlife Refuge

6.7 Greater Everglades Wetlands Module Conclusion
The main objective of this report was to provide information regarding the status of the GE wetlands monitoring program. In addition, this report provides a preliminary integrated
assessment of the pre-CERP condition. AM of the timing and operation of CERP projects will require this information. Baseline data will also be useful for refining the hypothesis clusters and their associated monitoring strategies. The assessments were reported in the context of groups of working hypotheses as described in the 2006 Assessment Strategy for the MAP. These hypotheses relate changes in major physical and chemical stressors, as influenced by CERP, to targeted changes in the ecosystem (RECOVER 2006a). The integration of the primary datasets for this report was achieved via a visual overlay of the various spatial data layers; and for that reason, this assessment represents the first step in larger and more complex statistical integration of the data. It must be recognized that the processes to complete the statistical analysis of this integration are currently undefined and will require an iterative and interactive process between various scientists and agencies.

In general, the monitoring components have been successfully implemented and integrated across the GE system, with the exception of those components associated with the ridge and slough landscape hypothesis cluster. It has become evident that the hypothesis group relating hydrology and water quality will not be assessed independently but that these data underpin the assessment of the other four hypothesis groups. Additionally, analysis of the periphyton TP concentration has shown that this may prove to be a better and more sensitive metric to overall ecosystem nutrient load assessment than water column P concentrations. Analysis indicates that patterns of periphyton TP concentration in the WCAs generally correspond to patterns of eutrophication as described in the 2006 SSR. Lastly, results from the 2005 wet season pertain to a correspondence of periphyton TP nutrient concentration to trophic nutrient status and productivity in southern ENP.

The pre-CERP condition of the Everglades mangrove estuaries is characterized by saltwater intrusion into headwaters of most coastal tributaries, and by low to non-existent soil accretion in mangrove forests of the Shark River Basin. Future assessments will strive to provide connectivity between this critical habitat area and the upstream marsh ecosystem. Also, it is clear that collaboration with groundwater hydrologists working in the mangrove coastal area must be increased to better understand and characterize any effects of groundwater upwelling on the trophic structure in this area. EDEN hydrologic output data will be integrated into this monitoring and assessment scheme to further assess the effect of hydroperiod on when fish leave the marsh and seek refuge in the coastal rivers. During the relatively dry winter-spring of 2005, small fishes were forced from surrounding marshes into the creeks early in the dry season, where they suffered high mortality from predation by larger fishes. During the wetter winter-spring of 2006, the longer flooding period of the wetlands adjacent to the creeks allowed prey fishes to remain on the marsh where they should have been more available to wading birds. These results correspond to the 2006 nesting season which was highly successful for wading birds, in contrast to 2005 when extensive nest failure occurred.

The strategy for the integrated assessment of wading bird/aquatic fauna predator prey relationships is to annually track the production of aquatic fauna populations during the wet season, the concentration of those populations during the subsequent dry season and the distribution and size of wading bird nesting colonies in response to the prey populations. This report indicates how wading birds may have responded to prey populations and water conditions during the 2005-06 WY by comparing the distribution and biomass of the wet and
dry season prey populations to the distribution and size of wading bird nesting colonies in addition to hydrologic conditions prior and during the nesting season.

Clearly hydrologic conditions across the Everglades during the 2005 wet season and 2006 dry season supported a successful year for wading bird nesting throughout much of the system, with water levels well above average at the start of the dry season and a steady and prolonged water level recession during the dry season. Furthermore, the late onset of the wet season in 2006 continued to provide ample foraging patches for fledging birds late in the nesting season and the 2006 nesting season was successful for wading birds in terms of overall nest numbers. In addition to the large numbers of nest initiations during 2006, nesting success was unusually high for all wading bird species, and few abandoned colonies were noted.

However, wading birds had lower nesting numbers in southern ENP where marsh fish standing crops were depressed during the previous wet season. Wading bird colony locations and nest numbers during 2006 were concentrated in the WCAs and LO littoral zone where fish biomass was moderate to high during the previous wet season. The high crayfish biomass in western ENP did not support extensive wading bird nesting in the southern Everglades during 2006, as only small numbers of all wading bird species nested near the region of high crayfish biomass.

A possible explanation for the low initiation of nesting in coastal regions of the ENP in 2006, despite water recession rates conducive to prey concentration, is that low wet season fish biomass was insufficient to produce dry season prey concentrations that were adequate to support nesting. The correspondence of low fish biomass to low wading bird nesting in the southern Everglades is relevant to the hypothesis that collapse of traditional coastal nesting colonies is related to declines in prey populations along the freshwater-estuarine interface of the southern Everglades.

The distribution of TP concentrations in periphyton mats during the late wet season of 2005 indicates elevated periphyton TP in southern ENP above the marsh-mangrove ecotone of the Gulf of Mexico drainages; clearly representing an incongruity. The discrepancy of low marsh fish biomass in this area of otherwise high productivity was unexpected and may be important regarding the wading bird predator-prey hypothesis as this area encompasses the “fertile crescent” of freshwater and oligohaline marshes that represented important feeding grounds within nine kilometer flight distances of historic wading bird nesting areas in the southwest Everglades (Bancroft et al. 1994). Future assessments will integrate EDEN simulation outputs to examine hydrologic characteristics of the southern Everglades, especially given that this area represents a zone of peak productivity in most producers that appears to be caused by the convergence of marine P and freshwater N sources as well as marine-derived P loadings from groundwater.

The 2006 Florida Bay roseate spoonbill nesting season had a strong response to hydrologic and prey conditions prior to and during the nesting season. The three watersheds used by nesting roseate spoonbills in NEFB indicated a temporal sequence in peak prey availability across the landscape that was conducive to spoonbill nesting success during 2006. The
sequential drying across the landscape that occurred in the coastal wetlands above NEFB was conducive to high spoonbill nesting success despite a low number of nests in that sub-region during 2006. The apparent pattern of drying from tidally-influenced sites to non-tidal sites in Cape Sable and southern Whitewater Bay appeared conducive both to high spoonbill nesting success and to a high number of nests in the northwest sub-region of Florida Bay.

Alligators occurred in higher relative densities in canals in comparison to marsh and estuarine survey areas throughout most of the Everglades during 2005 and 2006. Higher alligator densities in canals found in 2005-2006 support the hypothesis that a combination of shortened hydroperiods, increased nest flooding, creation of canal habitats, and increased salinities has reduced alligator populations throughout much of the natural Everglades system. Fulton’s K condition index was similar in canals and marsh survey areas during the 2005 and 2006. Initial power analysis showed effects of area on body condition can be detected and additional analyses on the relationship to time and hydrology are underway.

The 40-50 crocodile nests recorded in ENP during 2005 and 2006 is consistent with the trend of higher numbers of nests in ENP since 2000 and appears to be associated with a decrease in salinity levels that resulted from plugs placed in the East Cape and Buttonwood canals to reduce saltwater intrusion in ENP.

More than 50 percent of crocodiles captured in 2005 and 2006 were recaptures, which is unprecedented for a crocodilian study. This will allow the application of sophisticated quantitative models for analysis of growth and survival. Growth, survival and dispersal of juvenile crocodiles were low in ENP in comparison to other primary crocodile nesting areas of south Florida. Analyses of temporal patterns of growth and survival and relationships of growth and survival to hydrological parameters are underway.

### 6.8 Status of Monitoring in the GE Module

The following table provides an abbreviated status of monitoring in the GE Module. The table includes a list of monitoring components, links them to the associated hypothesis cluster(s) and performance measures, and provides a brief description of the monitoring itself as well as its status. The table is not meant to be exhaustively comprehensive and represents the most current information to date when the table was developed.
### Table 6-3: Status of monitoring in the GE Module

<table>
<thead>
<tr>
<th>GEW Hypothesis Cluster</th>
<th>MAP Section #</th>
<th>MAP Section Title</th>
<th>Performance Measure #</th>
<th>Description of Effort</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everglades Depth Estimate Network (EDEN)</td>
<td>3.1.3.1</td>
<td>Interior Gradients of Water Quality</td>
<td>GE1, GE2, GE3</td>
<td>Depth and hydroperiod characterization based on stage gauge readings; hindcasting underway; supports all sections</td>
<td>Major components in place; maintenance, support and enhancements occurring; pre-CERP condition monitoring effort is ongoing.</td>
</tr>
<tr>
<td>Integrated Hydrology and Water Quality</td>
<td>3.1.3.1</td>
<td>Interior Gradients of Water Quality</td>
<td>GE6, GE7, GE11, GE17</td>
<td>Water quality and soil analysis in WCAs 1 and 2A; water quality, soils, invertebrate, and periphyton taxonomy at WCA3A sites</td>
<td>Interior gradients downstream of canal structures; module re-assessing water quality sampling design.</td>
</tr>
<tr>
<td>Coastal Transgression, Tidal Channel Characteristics, Salinity Gradients, and Mangrove Forest Productivity</td>
<td>3.1.3.2</td>
<td>Regional Distribution of Soil Nutrients</td>
<td>GE8</td>
<td>Soil cores sampled spatially to produce an estimate of regional soil TP concentration for the GE</td>
<td>Statistical power analysis on-going; pre-CERP condition map complete.</td>
</tr>
<tr>
<td>Coastal Transgression, Tidal Channel Characteristics, Salinity Gradients, and Mangrove Forest Productivity</td>
<td>3.1.3.3</td>
<td>Coastal Gradients of Flow, Salinity, and Nutrients</td>
<td>GE12, GE16</td>
<td>Measures salinity gradients across the freshwater-marine interface of the mangrove estuaries; and freshwater flow volumes and nutrient inputs into the salinity transition zone of the mangrove estuary and into Florida Bay and Gulf estuaries</td>
<td>Pre-CERP condition monitoring ongoing.</td>
</tr>
<tr>
<td>Wetland Landscape and Plant Community Dynamics</td>
<td>3.1.3.4</td>
<td>Landscape Pattern–Vegetation Mapping</td>
<td>GE13</td>
<td>Production of regional landscape vegetation map to assess plant communities using aerial photo-interpretation techniques.</td>
<td>Aerials flown December 2001 and January 2004; may be re-flown in 2009. Photo interpretation of aerials currently ongoing.</td>
</tr>
<tr>
<td>Wetland Landscape and Plant Community Dynamics</td>
<td>3.1.3.7</td>
<td>Landscape Pattern–Tidal Creek Delineation</td>
<td>GE16</td>
<td>Developed a channel surface mapping protocol for creating accurate surface models from survey data.</td>
<td>Completed 2005 but airborne and acoustic techniques may be assessed at a later date.</td>
</tr>
<tr>
<td>Wetland Landscape and Plant Community Dynamics</td>
<td>3.1.3.9</td>
<td>Trophic Level–Primary–Mangrove Forest Soil Accretion</td>
<td>GE18</td>
<td>Measurement of mangrove soil accretion rates at fixed stations within the coastal gradients project.</td>
<td>Project ongoing; began 2006.</td>
</tr>
<tr>
<td>Section</td>
<td>Landscape Pattern</td>
<td>GEx</td>
<td>Monitoring/Project Details</td>
<td>Historic/Pre-CERP Monitoring Details</td>
<td></td>
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</tr>
<tr>
<td>3.1.3.5</td>
<td>Marl Prairie/Slough Gradients</td>
<td>GE14</td>
<td>Monitoring of two east-west oriented transects within the southern marl prairies and adjacent sloughs, traversing nesting habitats for the Cape Sable Seaside Sparrow</td>
<td>Historic sites that have been incorporated into the landscape monitoring plan as sentinel sites; project ongoing.</td>
<td></td>
</tr>
<tr>
<td>3.1.3.6</td>
<td>Ridge, Slough, and Tree Island Gradients</td>
<td>GE15</td>
<td>Landscape monitoring plan development; ridge/slough and tree island emphasis</td>
<td>Unified ridge/slough and landscape monitoring design complete; pre-CERP condition monitoring may begin as early as 2007.</td>
<td></td>
</tr>
<tr>
<td>3.1.4.4</td>
<td>Ridge and Slough Landscape Sustainability</td>
<td>GE15</td>
<td>Research effort to gain understanding of some ecological processes that control the persistence of ridge and sloughs</td>
<td>Ongoing</td>
<td></td>
</tr>
<tr>
<td>3.1.3.8 &amp; 3.1.3.10</td>
<td>(1)Trophic Level - Primary-Periphyton Mat Cover, Structure, and Composition; (2)Trophic Level - Secondary - Aquatic Fauna Regional Populations</td>
<td>GE17, GE19, GE20</td>
<td>To gather and assess information regarding the wet season aquatic fauna (marsh fish and macroinvertebrates) population and periphyton production and community composition data across the GE ecosystem</td>
<td>Pre-CERP condition monitoring and regional assessments ongoing.</td>
<td></td>
</tr>
<tr>
<td>3.1.3.11 &amp; 3.1.3.12</td>
<td>(1)Trophic Level - Secondary - Aquatic Fauna Seasonal Populations; (2)Trophic Level - Wading Bird Foraging Distribution and Abundance</td>
<td>GE20</td>
<td>Provides key baseline information that forms the link between small aquatic animals and wading birds in the Everglades. The monitoring is designed to identify where and when concentrations of wading bird prey form and whether those concentrations are precursors to successful feeding and nesting by wading birds, as has been hypothesized</td>
<td>Pre-CERP condition monitoring and seasonal assessments ongoing.</td>
<td></td>
</tr>
<tr>
<td>3.1.3.8 &amp; 3.1.3.10</td>
<td>(1)Trophic Level - Primary-Periphyton Mat Cover, Structure, and Composition; (2)Trophic Level -</td>
<td>GE18, GE19, GE20</td>
<td>Methods development for sampling fish in cypress and mangrove forests</td>
<td>Scope for one-year regional test being developed. If implemented scope will include statistical analysis to ensure integration and</td>
<td></td>
</tr>
<tr>
<td>Task ID</td>
<td>Task Description</td>
<td>Methodology</td>
<td>Status</td>
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<tr>
<td>3.1.3.8</td>
<td>Trophic Level - Primary-Periphyton Mat Cover, Structure, and Composition</td>
<td>GE17</td>
<td>Methodology development research using chemotaxonomy to speciate periphyton. Contract began April 2006; research ongoing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.3.13 &amp; 3.1.3.14</td>
<td>Trophic Level - Wading Bird Nesting Colony, Location, Size, and Timing</td>
<td>GE21, GE22</td>
<td>Nesting success for Wood Storks and Roseates (measured as number of young produced per nest) providing a relative measure that is comparable across years and across the system; Counts of White Ibis across system. Pre-CERP condition monitoring and assessments ongoing.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.4.6</td>
<td>Crayfish Population Dynamics - Hydrological Influences</td>
<td>GE19</td>
<td>Determine basic life histories and population dynamics of the two species of crayfish found in the GE wetlands in relation to season and hydrology. Provide quantitative estimates of population density, growth, survival, recruitment, and dispersal. Population estimates ongoing and are utilized in conjunction with regional sampling estimates.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1.4.7</td>
<td>Aquatic Refugia - Coastal Ecotone, Alligator Holes, and Solution Holes</td>
<td>GE19</td>
<td>Role of marsh-mangrove interface habitats as aquatic refuges for wetland fishes and other aquatic animals in tidal channels. Scope for one-year regional test being developed. If implemented scope will include statistical analysis to ensure integration and compatibility with existing marsh sampling design.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Section 6

#### Greater Everglades Wetlands Module

**3.1.4.10 Sub-lethal Effects of Contaminants on Wading Bird Reproduction**
- Performance measure: no performance measure
- Description: Experimentation to determine the sub-lethal effects of mercury exposure on the development and reproductive aspects of White Ibises.
- Status: Contract started 2006; research ongoing.

#### Everglades Crocodilian Populations

**3.1.6.15 American Alligator Distribution, Size, Nesting, and Hole Occupancy**
- Performance measure: GE23
- Description: Monitoring alligator health (size and condition) to determine population response to CERP throughout system and return of reproducing alligator population to southern marl prairies and mangrove estuaries.
- Status: Pre-CERP condition monitoring and assessments ongoing.

**3.1.6.16 American Crocodile Juvenile Growth and Survival**
- Performance measure: GE24
- Description: Surveys to assess nesting success and survival of the American Crocodile.
- Status: Pre-CERP condition monitoring and assessments ongoing.
6.9 Greater Everglades References


USGS. 2007. South Florida Information Access (SOFIA) Data Exchange:
http://sofia.usgs.gov/exchange/coastal_grads/
http://sofia.usgs.gov/exchange/patino/patinoflow.html#Joe
http://sofia.usgs.gov/exchange/swcoast_est/


6.10 Acknowledgements

7.0 SOUTHERN ESTUARIES MODULE

7.1 Brief Description and Background Information for the Southern Estuaries Module

The SE influenced by the CERP include Florida Bay, the coastal lakes inland from Florida Bay, Biscayne Bay, and estuaries within southwest Florida’s mangrove zone from Whitewater Bay to Lostmans River (Figure 7-1). Altered freshwater inflows have affected circulation, water quality and salinity patterns of the SE, in turn altering the structure and function of these ecosystems. Changes in SAV habitat structure and distribution have been of particular concern because of their effects upon animal populations.

Figure 7-1: Geographic Domain of the SE MAP Module

Southwest Florida’s Mangrove Zone
While no comprehensive CEMs have been developed as yet for the mangrove zone of southwest Florida, it is well recognized that Whitewater Bay and the rivers connecting the Shark River Slough to the southwest Florida shelf (e.g., Shark, Harney and Lostmans) are critical components of the integrated SE Ecosystem. Whitewater Bay is a very important nursery area for many recreationally and commercially significant fisheries species and the southwest Florida shelf has repeatedly been shown to be dynamically connected to western Florida Bay. MAP monitoring is underway in all these regions and this monitoring will eventually be included in the integrated assessments of the SE. Florida Bay and Biscayne Bay are the largest and best studied components within the SE.
Florida Bay
Florida Bay is a triangularly shaped estuary with an area of about 2,200 square kilometers that lies between the southern tip of the Florida mainland and the Florida Keys. About 80 percent of this estuary is within the boundaries of ENP and much of the remainder is within the Florida Keys National Marine Sanctuary (FKNMS). A defining feature of the bay is its shallow depth, which averages about one meter (Schomer and Drew 1982). Light sufficient to support photosynthesis can reach the sediment surface in almost all areas of the bay (Kelble et al, 2005), resulting in the dominance of seagrass beds as both a habitat and a source of primary production. The shallowness of Florida Bay also affects its circulation and salinity regime. Except for basins near the northern coast (near freshwater sources), the bay’s water column is vertically well-mixed and usually isohaline. In contrast, its complex network of shallow mudbanks restricts horizontal water exchange amongst the bay’s basins and between these basins and the Gulf of Mexico (Smith 1994; Wang et al. 1994). In areas of Florida Bay with long residence times, the salinity of the water can rise rapidly during drought periods due to an excess of evaporation relative to precipitation and freshwater inflow (Nuttle et al. 2000; Kelble et al, 2007). Salinity levels as high as twice that of seawater have been measured (McIvor et al., 1994). Another defining feature of the bay is that its sediments are primarily composed of carbonate mud, which can scavenge inorganic phosphorus (P) from bay waters (DeKanel and Morse 1978). Until the 1980s, Florida Bay was perceived by the public and environmental managers as being a healthy and stable system, with clear water, lush seagrass beds, and highly productive fish and shrimp populations. In the mid-1980s, however, catches of pink shrimp decreased dramatically (Browder et al. 1999), and in 1987, a mass mortality of turtle grass (*Thalassia testudinum* Banks ex. König) beds began (Robblee et al. 1991). By 1992, the ecosystem appeared to change from a clear water system dominated by benthic primary production, to a turbid water system with algae blooms and resuspended sediments in the water column.

Florida Bay’s salinity regime varies greatly over time and space. This variation ranges from coastal areas that can be nearly fresh during the wet season, to large areas of the central bay that can have salinity levels near 70 ppt during prolonged droughts, to nearly stable marine conditions (approximately 35 psu) on the western boundary of the bay or near the Florida Keys’ passes. The main factors that determine the salinity regime in the bay are the inflow of freshwater from the Everglades, the difference between rainfall and evaporation over the bay, and exchange with marine waters of the Gulf of Mexico and Atlantic Ocean (Kelble et al., 2007; Lee et al, 2006). Both freshwater inflow and exchange with the Atlantic Ocean have changed drastically in the past hundred years, resulting in an alteration of the bay’s salinity regime (Swart et al. 1999; Brewster-Wingard et al. 2001; Dwyer and Cronin 2001). Freshwater inflow to Florida Bay decreased in volume and changed in timing and distribution during the twentieth century due to water management. Hydrologic alteration began in the late 1800s but accelerated with construction of drainage canals by 1920, the Tamiami Trail by 1930, and the C&SF Project and the South Dade Conveyance System from the early 1950s through 1980 (Light and Dineen 1994). With diversion of freshwater to the Atlantic and Gulf of Mexico coasts to the north, the bay’s mean salinity inevitably increased.

Two important natural controls of salinity, sea-level rise and the frequency of major hurricanes must also be considered. Florida Bay is a very young estuary, the product of sea
level rising over the shallow slope of the Everglades during the past 4,000 years (Wanless et al. 1994). With rising sea level, the bay not only became larger but also became deeper. With greater depth, exchange of water between the ocean and the bay increased. All else being equal, this would result in a more stable salinity regime with salinity levels increasingly similar to the ocean. However, a factor that has counteracted rising sea level is accumulation of sediment, which makes the bay shallower. Major hurricanes are thought to be important high-energy events that cannot only introduce a significant amount of freshwater over a short period (Kelble et al. 2007) but flush the bay of accumulated sediments. Until very recently, no major hurricane has directly affected Florida Bay. Resultant sediment accumulation, with associated alteration of depth, circulation patterns, residence time, salinity, and nutrient storage may have contributed to ecological changes in recent decades. For example, sediment accumulation can affect nutrient availability and the total areal extent of the bay that has sediment depths conducive to seagrass growth.

The degree to which external nitrogen (N) and P inputs have stressed Florida Bay is unclear. In general, the bay is relatively rich in N and poor in P, especially towards the eastern region of the bay (Boyer et al. 1997). This spatial pattern is at least partly a function of natural biogeochemical processes (e.g., P retention by the bay’s carbonate sediments and relatively low N in adjacent marine waters) and thus may have existed prior to recent human influences. Anthropogenic nutrients that enter Florida Bay are derived not only from local sources (fertilizers and other wastes from agricultural and residential areas), but also from remote sources. Contributions of nutrients from atmospheric deposition and from the Gulf of Mexico are significant external nutrient sources (Rudnick et al. 1999) and include inputs from Florida’s large geologic deposits of phosphate and urban development from Tampa to Naples. Different sub-regions and basins within the bay are differentially influenced by these local or remote sources, depending on the magnitude of inputs, relative abundance of different nutrients, internal cycling pathways and rates, and water residence time (Boyer et al. 1997, Rudnick et al. 1999, Childers et al. 2005).

Biscayne Bay

Biscayne Bay is a naturally clear-water bay with tropically-enriched flora and fauna. Prior to the development of Miami-Dade County, much of the bay was bordered by mangroves and, otherwise, with herbaceous wetlands. The bay was once connected to the GE ecosystem hydrologically through tributaries, sloughs, and ground-water flow. It possessed not only marine habitats, flora and fauna, but also a substantial area of estuarine habitat and associated organisms. Because of the bay’s shallow depths and naturally clear waters, its productivity is largely benthic-based (Roessler and Beardsley 1974). Benthic communities in the central and southern bay (i.e., south of the Rickenbacker Causeway) consist of several species of seagrasses, a mix of soft and hard corals, attached macroalgae and sponges, and coral-algal bank fringes that alternate in dominance in different areas. Benthic communities in northern Biscayne Bay are dominated by seagrasses intermixed in some cases with calcareous green algae.

Altered freshwater flow into Biscayne Bay is the stressor that CERP will most directly affect by modifying flow volume, timing and spatial distribution. CERP may also indirectly affect the input of solids, nutrients, toxicants, and pathogens. Construction of major canals through
the Everglades and dredging of natural tributaries and transverse glades that carried fresh water to Biscayne Bay resulted in lowered regional and coastal water tables (Parker et al. 1955), reduced water storage in the watershed, decreased groundwater flow to the bay, and eliminated many tributaries. Drainage of the watershed greatly affected the natural salinity gradients and ecotones from the Everglades through coastal wetlands and tidal creeks into the bay, and reduced or eliminated critical estuarine habitat for bay species requiring low-to-moderate salinity waters. In addition, constructed drainage systems result in pulsed, point-source discharge degrading estuarine habitat near canal mouths by creating biologically damaging zones of bottom scouring and rapid salinity fluctuation.

Departures from natural salinity patterns are ecologically damaging to many species because salt concentration affects growth, survival, reproduction, and other critical physiological processes in both plants and animals (see, for example, Kinne 1971). The general lowering of the water table on the east coast ridge and diversion of both surface and ground water into canals has degraded not only estuarine habitats within the bay, but also adjacent coastal wetland communities, including herbaceous freshwater marshes and coastal mangrove wetlands that were once functionally connected to estuarine habitats. The few coastal tropical hammocks that remain have been detrimentally affected by the lowered water table (M. Roessler, pers. comm.). The bay has also been significantly affected by watershed development made possible by water management (Alleman et al. 1995). Before drainage of the watershed, urban and agricultural development was restricted to the highest ground along the Atlantic Coastal Ridge, consisting of hammocks and pinelands (University of Miami and SFWMD 1995). As land was drained, development encroached into lower lands and removed wetlands.

Today, most new development is occurring in former wetlands. Development has had many detrimental consequences. The continued loss of open, pervious land increases stormwater runoff velocity and pollutant loads, and reduces the quantity of water storage in the watershed. Other dramatic changes occurred in northern Biscayne Bay as a result of dredging and filling. Bottom dredging resulted in the loss of seagrass beds in northern Biscayne Bay and has affected the stability of bay sediments and the capacity to assimilate nutrients and trap particulates. Stormwater runoff from urban development has increased the bay’s exposure to contaminants and excessive nutrients. At the same time, the filling and destruction of coastal wetlands has eliminated natural filtering capacity. The dredging of inlets at Haulover and Government Cuts significantly increased salinity in northern Biscayne Bay (Wanless 1969, Wanless et al. 1984), changing much of it from an estuary to a more marine system. Alternatively, Biscayne Bay’s water quality has improved substantially in the past 30 years because of the elimination of direct discharge of sewage into the bay and other pollutant control measures (McNulty 1970; Alleman et al. 1995; Miami-Dade County Department of Environmental Resources Management [DERM] 2005). Parts of North Biscayne Bay (NBB) now support substantial seagrass beds. Extensive seagrass beds have always been characteristic of South Biscayne Bay (SBB).
7.2 Southern Estuaries Hypothesis Cluster-Water Quality

7.2.1 Abstract

South Florida’s bays, and the plants and animals that they support, reflect the volume, distribution, and quality of fresh water flowing into these aquatic systems (Figure 7-2). Past changes to the quality, quantity, timing, and distribution of freshwater flow have degraded water quality and compromised estuarine community structure and function in some areas of the SE. Current water quality monitoring programs provide adequate spatial and temporal coverage throughout the SE with the possible exception of the southwest Florida shelf where the temporal variability may not be adequately captured. Chlorophyll $a$ was selected as an indicator of water quality because its biomass is an integrator of many of the water quality factors which may be altered by CERP. There is concern that increased freshwater flow due to CERP activities may result in more frequent, intense, and persistent phytoplankton blooms in the SE. The baseline conditions indicate that most of the SE are oligotrophic with median chlorophyll $a$ concentrations of less than or approximately 1 ppb. This baseline data was used as the reference condition to assess the 2006 SE data, and only the Barnes, Manatee, and Blackwater Sound sub-region was found to have chlorophyll $a$ biomass significantly higher than the baseline. This algal bloom was the result of an increase in total P in this sub-region from the combined effects of highway construction and hurricane impacts, including the pre-hurricane freshwater release. This phytoplankton bloom illustrates the sensitivity of the SE to small increases in nutrient loading, because it took only a small increase in TP ($>10$ ppb) to trigger this large phytoplankton bloom, which continues to persist. The ability of our methodologies to adequately detect this decline in water quality due to altered environmental conditions indicates the applicability of this technique to detect changes in water quality as a result of CERP activities. Understanding how CERP affects water quality in the SE will facilitate adaptively managing and guiding restoration efforts.

7.2.2 Background Description

Water quality in the SE is dependent upon the volume, distribution, and quality of freshwater flowing to the system. The biotic components (e.g., phytoplankton, benthic habitats) of estuaries are sensitive to salinity variability and nutrient loading which may be modified by CERP. Complex interactive mechanisms between water quality and hydrologic drivers as well as internal nutrient cycling will influence CERP effects.
Major Relevant CERP Hypotheses

- Through modifications of 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:

1. *Changes in the distribution and timing* of nutrient inputs through increased flow via Shark River Slough and diversion of canal flows from “point source” to more “diffuse” delivery through coastal wetlands and creeks;
2. *Changes in the quantity* of nutrient inputs to the estuaries through alteration of 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; and
3. *Changes in the bioavailability* of nutrients which depend on both the *quality* of nutrients (e.g., inorganic nutrients and DOM) from the watershed and internal estuary mechanisms (e.g., P limitation of DOM decomposition);

- Internal nutrient cycling rates (e.g., N fixation and denitrification) and biogeochemical processes, such as phosphate sorption, 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.

The spatial extent, duration, density, and composition of phytoplankton blooms are controlled by several factors that will be influenced by CERP. These include:

1. External nutrient loading;
2. Internal nutrient cycling (seagrass productivity/die-off, sediment resuspension);
3. Light availability (e.g., modified by sediment resuspension and CDOM);
4. Water residence time; and
5. Biomass of grazers (e.g., zooplankton, benthic filter-feeders).

Nutrient inputs from groundwater discharges can affect water quality in coastal wetlands and estuaries. If CERP implementation increases groundwater discharge in the coastal zone, this may alter nutrient loads to the estuaries.

Interim Goals
The desired condition is maintaining good water quality in Florida Bay by minimizing the magnitude, duration, and spatial extent of algal blooms that can adversely affect light penetration and thus the bay’s ability to sustain healthy and productive seagrass habitat. The IG for Florida Bay algal blooms is to prevent any increase in the intensity, duration, or spatial extent of such blooms in Florida Bay or adjacent waters. The proposed assessment along with current monitoring components is capable of addressing this IG in all of the ten sub-regions with the possible exception of the southwest Florida shelf where sampling frequency may not be adequate. The current assessment shows that there has been an increase in algal blooms in one sub-region (Blackwater, Manatee, and Barnes Sounds [BMB]); however, this increase was not due to CERP, and instead was the result of a combination of hurricanes, managed water releases, and road construction.

The ability to predict water quality and chlorophyll \(a\) response to CERP is dependent upon the further refinement of the Environmental Fluid Dynamics Code Model that is being developed as a task of CERP’s Florida Bay and Florida Keys Feasibility Study. This model will be used to predict the intensity, duration, and spatial distribution of algal blooms in Florida Bay and the nearshore southwest Florida shelf as CERP is implemented. A similar model may be required for Biscayne Bay. The current MAP is adequate, except perhaps upon the southwest Florida shelf, to detect changes in the intensity, duration, and spatial distribution of algal blooms and assess the accuracy of the model.

7.2.3 Methods and Analysis
Systematic monitoring of water quality at fixed stations in the SE has been ongoing since late 1989 as part of Florida International University’s Southeast Environmental Research Center’s (FIU/SERC) Water Quality Monitoring Network. This effort began in Florida Bay and by the mid-1990s had expanded to the entire SE, including the mangrove transition zone (MTZ) (Table 7-1). Also, beginning in the mid-1990s the National Oceanic and Atmospheric Administration’s Atlantic Oceanographic and Meteorological Laboratory (NOAA/AOML) began monitoring water quality and circulation throughout the SE via fixed station and continuous synoptic sampling. All of the fixed stations except those located on
the southwest Florida shelf (SWFS) were sampled monthly by both programs until recent funding shortcomings forced NOAA to reduce sampling frequency to six times per year (*Table 7-1*).

The continuous synoptic sampling by NOAA/AOML measures sea surface temperature, salinity, chlorophyll $a$ fluorescence (that can be converted to biomass estimates), beam transmission ($\lambda=660$) (that can be used to estimate TSS), and CDOM fluorescence. These measures can then be used to estimate light attenuation along the underway track which is useful to determine if phytoplankton and/or seagrass growth is light-limited within specific regions of the SE. At each of the fixed stations, samples are collected for chlorophyll $a$ biomass and dissolved inorganic nutrients. Additionally, NOAA/AOML samples light attenuation, TSS, Dissolved Organic Carbon (DOC), and pH at each station, and FIU/SERC samples Total Organic Carbon (TOC), Total Phosphorous (TP), Alkaline Phosphatase Activity (APA), and Total Nitrogen (TN) at each station. Recent analyses of water quality in the SE include: Boyer et al. (1997; 1999) for Florida Bay and MTZ water quality distributions and trends, Rudnick et al. (1999) for Florida Bay nutrient loading, Kelble et al. (2005) for Florida Bay light attenuation, Kelble et al. (2007) for Florida Bay salinity variability, Caccia and Boyer (2005) for Biscayne Bay water quality distributions and Jurado et al. (2007) for bloom dynamics on the SWFS. Much of these data are available to the public at [www.aoml.noaa.gov/sfp/](http://www.aoml.noaa.gov/sfp/) and [http://serc.fiu.edu/wqmnetwork/SFWMD-CD/index.htm](http://serc.fiu.edu/wqmnetwork/SFWMD-CD/index.htm).

In addition to the NOAA/AOML sampling program underway and moored continuous salinity measurements in the SE, Biscayne National Park (BNP) maintains an array of continuous salinity and temperature recorders. These are deployed at 34 sites in Biscayne Bay and measure bottom conditions every 15 minutes. Eleven of these sites also record surface condition for a total of 45 instruments deployed. Some of the recorders are positioned along west to east transects intended to document the dynamics of the salinity regime from nearshore outward. Fourteen sites are located within the mangrove zone where changes in salinity due to CERP implementation will be most pronounced. Instruments were also deployed at Black Point, Turkey Point, Barnes Sound, and Manatee Bay in response to particular environmental concerns in these key areas.

Based upon the major relevant CERP water quality hypotheses, it was determined that chlorophyll $a$ biomass should be utilized as the primary indicator to assess the status and trends in water quality for the SE. The hypotheses state that CERP will affect the rates of external nutrient loading and internal nutrient cycling by several different mechanisms. These rates along with three other factors (light availability, water residence time, and biomass of grazers) that may also be influenced by CERP activities control the magnitude, duration, and spatial extent of phytoplankton blooms for which chlorophyll $a$ is a proxy. Moreover, phytoplankton blooms are a major concern to the overall health of the SE (Rudnick et al. 2005). These blooms decrease light penetration through the water column that can lead to seagrass mortality. Seagrass mortality often results in the release of more nutrients via decomposition and increased sediment resuspension, which in turn stimulates more phytoplankton growth (Rudnick et al. 2005; Zieman et al. 1999). This potential to propagate a positive feedback loop throughout the ecosystem elevates the importance of monitoring water quality and chlorophyll $a$. 
The role of nutrient inputs from the Everglades in initiating and perpetuating algal blooms in the SE is unclear and likely varies throughout the region. Several studies have hypothesized that this is an important factor and that increased freshwater flow with CERP may intensify algal blooms in the SE (CROGEE 2002; Brand 2002; Jurado et al. 2007). Given this possibility, it is necessary to quantify and understand the baseline conditions for salinity and chlorophyll $a$ and be capable of identifying deviations from this baseline that may occur as CERP is implemented. The behavior of water quality variables, particularly salinity and chlorophyll $a$, is distinct throughout individual sub-regions of the SE due to differences in freshwater runoff patterns (Kelble et al. 2007; Nuttle et al. 2000), circulation (Lee et al. 2006), sediment biogeochemistry (Zhang et al. 2004), nutrient inputs (Rudnick et al. 1999), grazer biomass (Peterson et al. 2006), and phytoplankton species composition (Philips and Badyak 1996). Therefore, it was necessary to subdivide the SE module into ten sub-regions based upon statistical methodologies (Boyer et al. 1999; Caccia and Boyer 2005) and analysis of circulation patterns (Lee et al. 2006; Lee et al. 2007).

### Table 7-1: Number of Fixed Station Samples for Water Quality in Each Sub-region

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<thead>
<tr>
<th></th>
<th>SWFS</th>
<th>MTZ</th>
<th>WFB</th>
<th>SFB</th>
<th>NCFB</th>
<th>NEFB</th>
<th>BMB</th>
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<td>126</td>
<td>114</td>
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<td>60</td>
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The ten subregions are SWFS, MTZ, west Florida Bay (WFB), north-central Florida Bay (NCFB), south Florida Bay (SFB), NEFB, Blackwater, Manatee, and Barnes Sounds, SBB, central Biscayne Bay (CBB), and NBB). The data from both NOAA/AOML and FIU/SERC were combined, and the grab samples collected at all of the stations were utilized to determine the status of chlorophyll $a$ in the SE for this assessment. The distribution of chlorophyll $a$ concentrations was not normal in any of these sub-regions, always being heavily weighted towards lower concentrations (Figure 7-3). As such, the midpoint of the data was best represented by the median, and it was necessary to conduct non-parametric statistical tests to analyze the data. EPA guidelines were applied to establish the reference conditions for chlorophyll $a$ concentrations and set criteria for determining what constitutes elevated levels of chlorophyll $a$ (EPA 2001). This approach established that a median concentration greater than the reference conditions 75<sup>th</sup> percentile would be classified as...
elevated from baseline. Furthermore, Kruskal-Wallis tests were employed to statistically test for differences in chlorophyll \( a \) between 2006 and all data collected prior to 2006. If any differences were measured, more detailed analyses were undertaken to identify underlying changes in water quality parameters and determine the ultimate cause(s) of the observed change.
Figures 7-3: Histograms of Chlorophyll $a$ (ppb in Each Sub-region.)

- Blackwater, Manatee, & Barnes
- Northeast FB
- North-central FB
- South FB
- West FB
- South BB
- Central BB
- North BB
- Southwest Florida shelf
- Mangrove transition zone

Frequencies are on Y-axis and Chlorophyll $a$ Intervals Are on the X-axis
7.2.4 Discussion

Chlorophyll $a$ was utilized as an indicator to assess the status and trends in water quality for the SE. CERP implementation may affect external nutrient loading, internal nutrient cycling, light availability, water residence time, and biomass of grazers; factors which control the magnitude, duration, and spatial extent of phytoplankton blooms for which chlorophyll $a$ is a proxy. Phytoplankton blooms are a major concern to the overall health of the SE as they can decrease light penetration that can lead to seagrass mortality. Moreover, seagrass mortality can result in a positive feedback loop via the release of more nutrients through decomposition and increased sediment resuspension, which in turn can stimulate further phytoplankton growth (Rudnick et al. 2005; Zieman et al. 1999).

Present Condition

The present condition of water quality in the SE has been the subject of numerous previously mentioned peer-reviewed papers. For consistency when undertaking the bi-annual assessment effort, the current condition of chlorophyll $a$ was examined by a standard easily applied methodology. To examine the distribution of chlorophyll $a$ throughout the SE, the data were divided between months that typically have high salinities (April-September) and those that have low salinities (October-March). This was determined based on analysis of salinity patterns in Florida Bay and Biscayne Bay (Figure 7-4). Then, the median for each station during high and low salinity months was calculated and the results were plotted with Surfer (Figure 7-5). The highest chlorophyll $a$ concentrations are consistently measured along the southwest Florida coast, both in the MTZ and on the SWFS. During low salinity, the elevated chlorophyll $a$ water expands further west onto the shelf, further south towards the Keys, and further east along the northern edge of Florida Bay. The SFB, NEFB, BMB, SBB, CBB, and NBB sub-regions had consistently lower chlorophyll $a$ concentration for both high and low salinity periods.

The median monthly chlorophyll $a$ concentration was calculated in each sub-region and the typical annual cycles of chlorophyll $a$ were examined (Figure 7-6). As depicted in the contour maps, there were significant differences in the magnitude of chlorophyll $a$ between sub-regions. The three regions of Biscayne Bay displayed similar annual cycles in chlorophyll $a$ with elevated concentrations from early summer through the end of the year. However, the NBB sub-region had over double the median chlorophyll $a$ for each month compared to the other two sub-regions. There were significant differences in the annual cycles for the five sub-regions of Florida Bay, although they all had higher concentrations in the second half of the year. NCFB displayed the largest degree of variability with a peak in October that was over three times the lower values observed from January through June. SFB had the second largest amount of variability with values in the second half of the year almost double those for the first half of the year. WFB had the highest median values for almost all months with all of the median monthly values greater than one ppb. BMB and NEFB had the lowest chlorophyll $a$ concentrations without much variability. The southwest Florida coast had significant differences between its two sub-regions. The MTZ had consistently high levels of chlorophyll $a$ with a slight seasonal shift of decreased chlorophyll $a$ during the second half of the year, which is the opposite of all other sub-regions in the SE. SWFS had a large degree of seasonal variability with a large peak in median chlorophyll $a$ in November. However, this peak may be an artifact of the sampling effort in this sub-region.
which is done on a quarterly basis. Thus each month has not been sampled each year and the results may be biased by sampling during November only in years with elevated chlorophyll $a$ concentrations in this sub-region.

Figure 7-4: Salinity Cycles in Biscayne Bay (top two panels) and Florida Bay (bottom panel)
Figure 7-5: Contour Plots of the Median Chlorophyll a Distribution in the SE During Low Salinity Months (October-March) and High Salinity Months (April-September)
Figure 7-6: Annual Cycle of Median Chlorophyll $a$ (ppb) in Each Sub-region
Detecting Change
To detect change, the data were analyzed with respect to the EPA guidelines outlined above. The median and quartiles were calculated to quantify the reference conditions for the ten sub-regions of the SE (Table 7-2). These reference conditions were then used to establish criteria from which the status of chlorophyll \(a\) and thus water quality in each of the sub-regions can be evaluated on an annual basis. If the annual median chlorophyll \(a\) concentration is greater than the reference median, but lower than the 75\(^{th}\) percentile, the sub-region is marked yellow. If the annual median concentration is greater than the 75\(^{th}\) percentile of the reference, the sub-region is marked red. This approach sets low thresholds (almost half of the sub-regions are red at less than or approximately one ppb) and regions with higher thresholds like FBNC will still turn yellow at slightly over one ppb. The only exception is the MTZ which has significantly higher thresholds. The data is plotted as a series of annual box and whisker plots to provide a visual representation of the analysis and account for the variability in the data. This also allows the criteria to be somewhat malleable, because a significant change in the variability will be observed even if there is not a coincident change in the median (Figure 7-7). The box and whisker plots have the median as their centerline, the 95\% confidence intervals of the median as the notches in the box, the 25\(^{th}\) and 75\(^{th}\) percentiles demark the edges of the box and the whiskers extend to the 10\(^{th}\) and 90\(^{th}\) percentile. Thus, the notches and the boxes can be utilized as a pseudo-test for significant differences between medians.

### Table 7-2: Criteria for Evaluating Chlorophyll \(a\)

<table>
<thead>
<tr>
<th>Sub-region</th>
<th>Valid N</th>
<th>25th Percentile</th>
<th>Median</th>
<th>75th Percentile</th>
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</thead>
<tbody>
<tr>
<td>Blackwater, Manatee, Barnes</td>
<td>BMB 1704</td>
<td>0.306</td>
<td>0.526</td>
<td>0.910</td>
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<tr>
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<tr>
<td>North Biscayne Bay</td>
<td>NBB 635</td>
<td>0.670</td>
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<td>1.648</td>
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<tr>
<td>North-central Florida Bay</td>
<td>NCFB 1399</td>
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<td>3.710</td>
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<tr>
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<td>NEFB 1979</td>
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<td>0.417</td>
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<tr>
<td>South Biscayne Bay</td>
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<tr>
<td>South Florida Bay</td>
<td>SFB 1695</td>
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<td>0.533</td>
<td>1.059</td>
</tr>
<tr>
<td>Southwest Florida Shelf</td>
<td>SWFS 1297</td>
<td>0.739</td>
<td>1.180</td>
<td>1.976</td>
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<tr>
<td>West Florida Bay</td>
<td>WFB 2304</td>
<td>0.653</td>
<td>1.345</td>
<td>2.845</td>
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</table>
Figure 7-7: Box and Whisker Plots of Median Annual Chlorophyll $a$ Overlaid on the Reference Conditions
From this box and whisker analysis, a stoplight map was produced to display the status of chlorophyll $a$/water quality in each sub-region (Figure 7-8). The sub-regions that received yellow ratings may undergo further analysis if a Kruskal-Wallis test shows there has been a significant change in median chlorophyll $a$ concentration. The additional statistical test is required because a random sample will be higher then the median and thus yellow 50 percent of the time, even if no significant change has occurred. The sub-regions that received red ratings will be further evaluated to understand the cause of degradation in water quality and whether it was the result of CERP, natural variability, and/or other anthropogenic activities. The physical environment of the SE, particularly salinity, responds to meteorological events, such as tropical cyclones and El Niño (Figure 7-9). Thus, water quality likely responds to these natural events and it is against this natural variability that changes due to CERP need to be discerned.

![Figure 7-8: The Circle in Each Sub-region Displays the Current Status of Chlorophyll $a$](image-url)
The 2006 SSR analysis showed that of the ten sub-regions, one was green, eight were yellow, and one was red (Figure 7-8). Two sub-regions, the MTZ and BMB, had the highest median chlorophyll $a$ concentrations of any year on record. The red sub-region incorporates Blackwater, Manatee, and Barnes Sounds, and the entire 95 percent confidence interval of the median is located in the red region of the graph, indicating there was a substantial increase in chlorophyll $a$ in this sub-region in 2006. This is an area that has been subject to significant disturbances unrelated to CERP over the past two years. In April 2005, a road construction project began to expand U.S. Highway 1 in this region. This involved a significant amount of cutting and mulching of mangroves and soil tilling. Also, from August to October 2005, this area was affected by the passing of three hurricanes over the region. In addition to causing a great deal of physical disturbance, there was a large managed release of water that contained elevated levels of $P$ prior to the first hurricane.

Figure 7-9: The Mean Bay-wide Salinity of Florida Bay Displays Significant Deviations due to Climactic Phenomena and Tropical Cyclones

The result of these occurrences was the initiation of an atypical algal bloom in this sub-region shortly after October 2005. Levels of chlorophyll $a$ far exceeded previously measured values in this sub-region. Furthermore, the long residence times of this sub-region acted to maintain the location of the algal bloom and helped the bloom to persist throughout 2006. The minimal flushing did not dilute the bloom and its persistence is likely due to the creation of a positive feedback loop - the bloom shades the seagrasses which senesces and decays releasing nutrients and destabilizes the bottom; this leads to increases sediment and nutrient resuspension further fueling the bloom. Monitoring results indicate that the bloom was likely initiated by a large increase in total $P$ prior to initiation of it, and total $P$ has remained elevated throughout its persistence, indicating the importance of $P$ in fueling the bloom (Figure 7-10). The bloom is spatially associated with the road construction activities and temporally associated with the impacts of hurricanes. Thus, it is likely that the bloom was
the result of these two events occurring coincidentally in the fall 2005. For more information on this phenomenon and its underlying causes, please refer to Rudnick et al. (2007).

Salinity
In response to reviewers' requests, a separate salinity section has been delineated in the SSR. The proposed hypotheses are founded in previous work (i.e., Florida Bay Feasibility Study and SE Evaluation Subteam) and may be altered or expanded later.

Proposed Hypotheses:

- Establishment of persistent low salinities, with a positive salinity gradient from wetlands to bay, in western nearshore SBB, will lead to an increase in the number of species in the estuarine fish and invertebrate community.
- Reduction in the intensity, frequency, and duration of hypersaline conditions in NCFB will lead to an increase in species diversity and production.

Synoptic salinity data collection by NOAA/AOML is already underway and details were presented in the previous water quality section to help interpret the chlorophyll \(a\) data (Figure 7-II). In this salinity section, this data is further discussed, data from the MAP continuous recording stations in Biscayne Bay (Figure 7-II) is presented, and the methodology for a separate salinity section in future SSRs to determine the impact of CERP...
activities on salinity in the SE is proposed. Continuous recording stations also exist in Florida Bay, which are maintained by ENP, but these are not discussed in this SSR. The sampling efforts in terms of the number of synoptic sampling cruises per year by NOAA/AOML and number of observations per site for the BNP continuous salinity recorders are given in Table 7-3 and Table 7-4, respectively.

Table 7-3: Number of Synoptic Underway Sampling Cruises conducted by NOAA/AOML in Biscayne Bay and Florida Bay Each Year Since the Projects Inception

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Table 7-4: Numbers of Observations Per Site for the Biscayne National Park Continuous Salinity Monitoring Project

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<td>68</td>
<td>29555</td>
</tr>
<tr>
<td>19</td>
<td>35921</td>
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<td>70266</td>
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<td>48</td>
<td>69414</td>
<td>70</td>
<td>73798</td>
</tr>
<tr>
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<td>85794</td>
<td>50</td>
<td>74825</td>
<td>72</td>
<td>12411</td>
</tr>
<tr>
<td>24</td>
<td>84452</td>
<td>52</td>
<td>79400</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 7-11: Map of the Typical Cruise-Track for the Underway Synoptic Salinity Sampling and Locations of the Biscayne Bay Continuous Salinity Recorders
Salinity in the SE is a primary stressor of many of the organisms that historically inhabited this area. This stressor may be extreme low or extreme high salinity due to too much or too little fresh water. The desired condition is to reduce the intensity, frequency, duration, and spatial extent of high salinity events, reestablish common mesohaline to oligohaline conditions in mainland nearshore zones, and reduce the frequency and rapidity of salinity fluctuations resulting from pulse releases of fresh water from canals. The effect of water management on salinity is manifested in different ways throughout different regions in the SE. In Florida Bay, extended periods of hypersalinity in NCFB due to decreased freshwater runoff have been identified as a potential stressor to benthic seagrasses. In fact, the highest salinities observed in Florida Bay were concurrent with the massive seagrass die-off that sparked much of the public interest in Florida Bay (Fourqurean and Robblee 1999). Historically, flow through the Buttonwood embankment into this sub-region would decrease salinities. Currently, this flow is only observed after the passing of tropical cyclones with associated high precipitation events (Kelble et al. 2007).

In Biscayne Bay, runoff has been diverted from creeks and coastal wetlands to point source canals (Meeder et al. 1999, Meeder et al. 2001). As a consequence, large volume releases of fresh water from canal mouths cause sudden declines in salinity, while cessation of flows during the dry season may result in nearshore hypersalinity. These unstable salinity regimes stress estuarine biota, negatively affect their life cycles and decrease reproductive potential (Serafy et al. 2003). Historically, the Biscayne Bay coastal wetlands and nearshore areas supported a diverse assemblage of estuarine faunal communities, including oyster reefs, estuarine fish and crocodiles. Redfish and other species that relied on sustained estuarine condition were “abundant at all seasons” (Smith 1896), and Miami-Dade County was at the core of the American crocodile geographic range in the United States (Kushlan and Mazzotti 1989). Historic oyster beds are presently inactive due to changed salinity patterns resulting from the loss of freshwater discharge into the wetlands through creek systems. Estuarine fishes and shellfish have precipitously declined in abundance due to the loss of estuarine habitat along the Biscayne Bay’s southwestern edge (Serafy at al. 2001). Efforts to restock red drum have failed due to the release of juveniles into areas that were no longer consistently estuarine (Serafy et al. 1996). It is anticipated that redirecting canal flows will provide sustained mesohaline salinity patterns in the nearshore environment and lower salinity in the mouths of tidal creeks.

Biscayne Bay Continuous Salinity Recorder Data
The average bottom salinity measured in BNP between June 2005 and October 2006 was 26 ppt (SD 1.8). The lowest average monthly salinity for the time period was 11 (SD 5.7) at Site 32 (a bottom recorder), and the highest average monthly salinity was 39 (SD 2.5) at Site 20 (also a bottom recorder) (Site locations are depicted in Figure 7-12). As expected, lower salinities were measured closer to shore, and in particular between canals C-1 and C-103. Sites with the highest salinities were located offshore, with salinities approaching oceanic as proximity to the Atlantic Ocean increased.

Average wet season salinity for the 2005-2006 WY was 23 ppt, based on the average monthly values from June 1, 2005 to October 31, 2005. Thirteen of the sites had average wet season salinities less than 20 ppt. The zone of salinity under 20 ppt extends from the shoreline during the wet season into the nearshore areas south of Mowry Canal and north of
Black Point (*Figure 7-13*). Surprisingly, the lowest salinities were found around Fender Point, which is furthest from any canal outfall. This is likely due to existing groundwater flow through the porous Biscayne aquifer since there are no other adjacent sources from canals or overland flow. Although salinity is somewhat higher just south of Black Point, low salinities persist further offshore in this area. Salinity slowly increases with distance offshore and to the north and south. In these areas SFWMD employees studying groundwater flux into the bay found extensive groundwater flow (Kruppa, pers. com., 2007).

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**Figure 7-12: Numbered Sites for the Biscayne Bay Continuous Salinity Recorders**
Average dry season salinity for the 2005-2006 WY was 28 ppt. Salinity ranged from a high of 36 ppt at Site 10 (Caesar’s Creek, an ocean outflow point) to a low of 22 ppt at Site 40 (benthic mangrove site). Sites 22, 24, 28, 30, 40, and 42 had average dry season salinity below 25 ppt, but no sites exhibited mean salinity less than 20 ppt during the dry season. Salinity was lowest in the area between Princeton and Military Canals (Figure 7-13).

Site 40 maintained the lowest salinity in both the wet and dry season and is located far from any direct canal discharge (Figure 7-12). The consistently lower salinity at this site reflects groundwater flow. Past analyses have indicated that sites 62 and 64 showed lower salinity during dry conditions, an observation also indicative of significant groundwater inflow. Histograms (Figure 7-14) show the wet and dry season distribution of salinity at sites from Manatee Bay to Black Point. All sites show the late onset of wet season flows and their delayed effects on salinity. Site 44 at the mouth of Black Creek (C-1 canal) shows the effect of canal discharges on salinity.

A complete analysis of available data is contained in annual reports submitted by Biscayne National Park to the Corps, Jacksonville District, as part of their contractual agreement for MAP monitoring.
Figure 7-14: Distribution of salinity patterns by site arranged south (top) to north (bottom) and by dry season (left side) versus wet season (right side)
Operational Effects on Salinity

Salinity in the SE will likely be significantly affected by any CERP activities that would alter the quantity or distribution of freshwater runoff. The large degree of natural variability, both spatially and temporally, in SE salinity amplifies the importance of developing a capability to adequately assess the impact of water management on salinity in the SE. Current salinity monitoring activities appear sufficient to assess the effect of CERP on the SE in both Biscayne and Florida Bay; however, increased effort is necessary on the SWFS where there are only a few continuous salinity recorders and quarterly synoptic cruises (Table 7-3 and Table 7-4). High-resolution spatial variability is provided by the periodic synoptic water quality/salinity monitoring (currently underway), whereas high-resolution temporal variability is provided by continuous monitoring at fixed stations. These are supplemented and enhanced by other periodic monitoring. The spatial resolution is greatly enhanced with the flow-through observations (currently underway) resulting in an increased ability to accurately measure the distribution of salinity in the SE (Figure 7-15). Accurate measurement of spatial salinity distributions is required to quantify the effect of CERP on the salinity regime of the SE. The spatial salinity distributions allow for quantification of the spatial extent of the mesohaline region before and after CERP projects, comparison of salinity distributions in nearshore areas where non-point source wetlands have replaced historical canal discharges, and determination of the extent to which operational activities (e.g. large scale water releases) may disrupt the natural salinity regime in downstream communities. In Florida Bay, there is a good understanding of salinity and the physical processes that affect it including the relative contribution of runoff, precipitation, and evaporation to salinity (Nuttle et al. 2000, Lee et al. 2006 and 2007, Kelble et al. 2007, and Nuttle et al. 2007). Thus, the effect of CERP activities on these relationships will be quantifiable.

The continuous-recording fixed-station array needed to better describe salinity patterns and salinity variability on the short time scales most relevant to the flora and fauna has only recently been established in the shallow nearshore waters of SBB; this is where CERP will have its greatest effects on salinity and the ecosystem. This nearshore array is essential to connecting biological changes to salinity and salinity to CERP via freshwater inflow.

For the next assessment, methods will be employed to quantify the effect of operations on salinity. This will include determining if management actions or precipitation changes have resulted in increased runoff, if the spatial extent of the mesohaline region has been extended, and/or if reductions in the extent, duration and magnitude of hypersalinity have occurred versus similar baseline periods. A comparison can be made of observed salinity distributions versus modeled distributions whereby the model is run with the observed precipitation and evaporation, but based on the baseline hydrology. In Biscayne Bay it is unclear if there are adequate models to carry out a similar assessment; moreover, a detailed analysis of observed salinities has yet to be completed particularly with respect to partitioning the relative contribution of runoff, precipitation, and evaporation. This effort is currently underway and should be completed for inclusion in the next biennial assessment.
Samples Illustrate that Discrete Sampling Alone Misses Significant Spatial Variation in Salinity and Chlorophyll $a$

**Figure 7-15: Plots of Continuous Synoptic Underway Flow-Through Data Overlayed on Discrete Station**

The largest operational water management effect on salinity during the current assessment period was the opening of the C-111 canal prior to Hurricane Katrina’s landfall on August 25, 2005. The result was a large water release out of the C-111 canal (**Figure 7-16**). The time series of flow rates at S197 also illustrates the highly sporadic nature of freshwater runoff from the C-111 canal which undoubtedly increases stress to the organisms living downstream. This large release of freshwater destabilized the natural salinity regime in a large area of the adjacent coastal embayment (**Figure 7-18**). The proof that this decrease was due to the increased runoff in adjacent areas with similar depths, but no runoff source experienced as dramatic a salinity decrease, which would be expected if the freshwater source was primarily precipitation. The lack of a similar decrease indicates the decrease was largely a result of runoff. The affected region included all of Manatee Bay and part of Barnes Sound, where the surface salinity dropped from over 30 ppt to below 10 ppt within one week of Hurricane Katrina making landfall. The bottom salinities from the continuous salinity recorders in this area did not display as dramatic a response to the freshwater pulse, but did have their largest decrease to date. Although they were not as large as the surface salinity decreases, a decrease of 13 ppt in 4 days was observed at Station 00 followed by a quick recovery which returned bottom salinities to greater than the pre-hurricane condition before the synoptic sampling was conducted on August 31, 2005 (**Figure 7-17**). This dramatic change in salinity could have a large effect on the biota living in this region. For example, seagrasses have shown large physiological responses to less drastic salinity variation (Lirman and Cropper 2003). This type of operational activity may have in part contributed to the previously discussed extensive synechococcus bloom in this region that began shortly after the water release and still persists.
Figure 7-16: Time Series of Daily Water Discharge Through the C-111 Canal at S197

Figure 7-17: Time Series of Mean Daily Bottom Salinity
Figure 7-18: Salinity Before and After Hurricane Katrina Depicts the Large Effect of the Managed Water Release Down the C-111 Canal

The current continuous salinity monitoring network clearly demonstrates the instability of the existing (pre-restoration) salinity regime along the western coastline in southern Biscayne Bay. These conditions make it difficult for a variety of estuarine faunal communities to either colonize or optimally utilize these regions. 

Table 7-5 indicates the estimated benthic estuarine area (i.e., area ≤ 20 ppt) relative to PM targets. The benthic estuarine area was calculated by ArcGIS interpolation of the monthly mean salinities from the continuous benthic salinity recorders (see examples in Figure 7-19). Note the seasonal differences in both Table 7-5 and Figure 7-19). Only when the estimated ≤20 ppt area (Figure 7-19) extends to or beyond the PM contour line is the PM target being met. ArcGIS interpolation creates data that is artificially smoothed and thus is likely to result in an overestimate of the estuarine salinity area, because the recorders are not randomly distributed, but rather are strategically located in areas with high salinity variability and thus a significant source of freshwater. Only the months where there was at least one station with a monthly mean salinity less than 20 ppt are listed. During the wet season and the beginning of the dry season, there is an extensive amount of freshwater available for restoration, yet rarely was the PM target met. The area of salinity that meets the PM targets appears to be controlled by the practice of seasonal drawdown where groundwater levels are dropped 0.8 feet between October and November. This results in an increase in canal discharge and decrease in groundwater discharge. Therefore, it appears that if the practice of seasonal draw-downs was
ceased, larger areas of estuarine salinity would persist well into the dry season. Appropriate redistribution of available fresh water should lead to restoration of more biologically amenable salinity regimes, which in turn holds promise for dramatic improvement in biological diversity and productivity. The current network appears adequate to detect and track CERP-induced changes in this area, although additional sites in key areas may be warranted. An important revelation provided by these data is the documented importance of groundwater flow, which should be taken into consideration in the design of CERP features for the purpose of improving salinity regimes particularly given current conditions. Raising the groundwater earlier in the wet season and holding it as high and as long as possible into the dry season could greatly benefit Biscayne Bay and its biological communities.

Table 7-5: Estuarine Areas by Month for the Period of Record
Area Expressed in Acres Was Derived from ArcGIS Interpolation (only months and locations with salinity<20 ppt are included)

<table>
<thead>
<tr>
<th>Month</th>
<th>Est. Area of Salinity &lt;20 ppt (acres)</th>
<th>Difference Between Observed Area and Performance Target</th>
<th>Location of Area with Salinity &lt;20</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept +</td>
<td>204</td>
<td>-3,568</td>
<td>Fender Point</td>
</tr>
<tr>
<td>Oct +</td>
<td>2,738</td>
<td>-1,034</td>
<td>Black point to Convoy Point</td>
</tr>
<tr>
<td>Nov *</td>
<td>1,841</td>
<td>-1,931</td>
<td>Black Point to Convoy Point</td>
</tr>
<tr>
<td>Dec *</td>
<td>247</td>
<td>-3,525</td>
<td>Fender Point</td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June +</td>
<td>4,186</td>
<td>414</td>
<td>C-100 to C-103 (Mowry Canal)</td>
</tr>
<tr>
<td>July +</td>
<td>3,406</td>
<td>-366</td>
<td>~Shoma Homes Property to C-103 (Mowry Canal)</td>
</tr>
<tr>
<td>Aug +</td>
<td>3,214</td>
<td>-558</td>
<td>South of Shoma Property to C-103</td>
</tr>
<tr>
<td>Sept +</td>
<td>3,335</td>
<td>-437</td>
<td>South of Shoma Homes Property to Turkey Point</td>
</tr>
<tr>
<td>Oct +</td>
<td>5,368</td>
<td>1,596</td>
<td>Shoma Homes Property to south of Turkey Point</td>
</tr>
<tr>
<td>Nov *</td>
<td>1,481</td>
<td>-2,291</td>
<td>Slightly north of C-102 to south of Turkey Point</td>
</tr>
<tr>
<td>Dec *</td>
<td>110</td>
<td>-3,662</td>
<td>Fender Point</td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan *</td>
<td>91</td>
<td>-3,681</td>
<td>Fender Point</td>
</tr>
<tr>
<td>July +</td>
<td>2,255</td>
<td>-1,517</td>
<td>North of Black Point to C-103</td>
</tr>
<tr>
<td>Aug +</td>
<td>1,960</td>
<td>-1,812</td>
<td>Just north of Black Point to just north of Military Canal</td>
</tr>
<tr>
<td>Sept +</td>
<td>2,036</td>
<td>-1,736</td>
<td>Just north of Black Point to just north of Military Canal</td>
</tr>
<tr>
<td>Oct +</td>
<td>1,013</td>
<td>-2,759</td>
<td>South of Black Point to north of C-103</td>
</tr>
</tbody>
</table>

dry season PM = 2017 acres; wet season = 3772 acres

Salinity Conclusions
Salinity will be the primary parameter in the SE directly altered by CERP and changes to salinity regimes in the SE will have significant effects on water quality and biota in the SE. Given this, in future SSRs there will be a separate salinity section with distinct, testable hypotheses. The primary goal of this section will be to quantify how operational activities (and eventually newly constructed system features) have altered the salinity regime of the SE. The desired condition is to reduce the intensity, frequency, duration, and spatial extent...
of high salinity events, reestablish common mesohaline to oligohaline conditions in mainland nearshore zones, and reduce the frequency and rapidity of salinity fluctuations resulting from pulse releases of fresh water from canals.
Figure 7-19: Southern Estuarine Performance Measures for Dry Season (250m) and Wet Season (500 m) from BNP Continuous Salinity Data
Salinity Conclusions
Salinity will be the primary parameter in the SE directly altered by CERP and changes to salinity regimes in the SE will have significant effects on water quality and biota in the SE. Given this, in future SSRs there will be a separate salinity section with distinct, testable hypotheses. The primary goal of this section will be to quantify how operational activities (and eventually newly constructed system features) have altered the salinity regime of the SE. The desired condition is to reduce the intensity, frequency, duration, and spatial extent of high salinity events, reestablish common mesohaline to oligohaline conditions in mainland nearshore zones, and reduce the frequency and rapidity of salinity fluctuations resulting from pulse releases of fresh water from canals. By altering freshwater flow, CERP will almost certainly affect salinity distributions in the SE, which will in turn result in changes to water quality and all other PMs. Thus, it is logical and necessary to have a separate salinity hypothesis cluster and PMs that can be rigorously assessed to ensure we are capable of detecting any changes that may occur as a result of CERP.

Conclusions
This approach to assessing water quality has proven to be quite capable of detecting changes as it did in the BMB sub-region for 2006. There is precedence for the criteria development and the graphical representations can be easily understood by all audiences. The one weakness is with respect to sampling frequency. It has been recommended by the Advisory Committee on Water Information and the National Water Quality Monitoring Council that water quality be measured monthly to assess the condition of specific estuaries (ACWI and NWQMC 2006) and this is equally true on the SWFS given the intermittency of freshwater inflows. The current sampling frequency is simply not sufficient on the southwest Florida shelf; moreover, FIU is now scheduled to discontinue its SFWMD supported shelf monitoring. Maintaining and indeed increasing, the sampling frequency in this sub-region is of particular importance, because CERP is likely to significantly increase freshwater discharge in this sub-region.

7.3 Southern Estuaries Hypothesis Cluster-Submerged Aquatic Vegetation

7.3.1 Abstract
Seagrasses are the dominant biological communities in the coastal region to be affected by CERP and they provide the majority of the fisheries habitat in this system. The goal of the South Florida Fisheries Habitat Assessment Program (FHAP-SF) is to provide information for the spatial assessment and resolution of inter-annual variability in seagrass communities, and to establish a baseline to monitor responses of seagrass communities to water management alterations associated with CERP activities. FHAP-SF is documenting the status and trends of seagrass distribution, abundance, reproductive, and physiological status (ecoindicators), as well as providing process-oriented data such as photosynthetic quantum yields and epiphyte loads. Resource managers will be able to use these data to address ecosystem-response issues on a real-time basis and to weigh alternative restoration options. Specific objectives of FHAP-SF are to: (1) develop a basic understanding of the relationships among water quality parameters (e.g. salinity, water clarity, nutrient levels) and seagrass species distribution and abundance in south Florida, (2) provide baseline data in
in order to separate anthropogenically induced changes from natural system variation, and (3) assist in verifying model predictions on species and ecosystem-level responses to water quality changes associated with CERP. Results of the 2007 SSR suggest that the methods adopted can detect changes in SAV from pre-CERP conditions when there are sufficient reference data, and that the present trends are consistent with hypothesized causal relationships.

7.3.2 Background Description

Seagrasses (e.g., SAV) are characteristic of shallow coastal waters worldwide; however, few areas contain meadows as extensive as those found in the south Florida region (Fourqurean et al. 2002). SAV communities provide key ecological services, including organic carbon production, nutrient cycling, sediment stabilization, and enhanced biodiversity (Orth et al. 2006). These plants are not only a highly productive base of the food web, but are also a principal habitat for higher trophic levels.

Because seagrasses live in close proximity to the land-sea interface, they are subject to physical disturbances and water quality changes associated with human population growth. As perennial plant species, seagrasses integrate net changes in water quality parameters (e.g. salinity, light availability, nutrient levels) which tend to exhibit rapid and wide fluctuations when measured directly. As such, seagrasses serve as biological sentinels of increasing anthropogenic influence in coastal ecosystems (Orth et al. 2006). To a large extent, seagrass abundance determines public perception regarding the health of the coastal waters of Florida (Goerte 1994, Boesch et al. 1995). Thus, the recent changes in the distribution and abundance of seagrasses within south Florida estuaries have been perceived as an especially significant change in the overall ecosystem health. For these reasons, seagrasses have been deemed one of the best indicators of change in the SE module (Fourqurean et al. 1992).

Submerged Aquatic Vegetation Conceptual Ecological Model

The hypotheses described below are derived from a heuristic conceptual model (Figure 7-20) of the factors that influence SAV community structure (e.g., water management, land use and episodic events), and the interaction of SAV with estuarine organisms and the physical environment. CERP implementation will alter the volume, timing, and spatial distribution of freshwater inflow into the SE. SAV field data and concomitant water quality information are being collected to establish baselines (i.e., reference conditions) against which the extent of system change will be measured once CERP is implemented. Analysis of this pre-CERP data is needed to determine the extent of ecosystem change that will be detectible (and how long that might take) once CERP is implemented. At an early stage, it will also reveal systematic problems in the monitoring or analysis and highlight areas where significant improvements can be made.
Major CERP Relevant Hypotheses

- **Hypothesis 1**: 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 though the combined and interrelated effects of light penetration, epiphyte load, nutrient availability, sediment depth, salinity, temperature, hypoxia/anoxia, sulfide toxicity, and disease.

- **Hypothesis 2**: Changes related to CERP implementation will include an expansion of areas with *Halodule wrightii* and *Ruppia maritima* cover and a reduction in areas of *Thalassia testudinum* 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 and the eastern half of Biscayne Bay are not expected to change.

- **Hypothesis 3**: Changes in both salinity and water quality resulting from CERP implementation are expected to change benthic algal cover, biomass, distribution, species composition, and diversity though the combined and interrelated effects of light penetration, nutrient availability, salinity, temperature, and changes in seagrass density and species composition.

- **Hypothesis 4**: Significant changes in benthic algae and seagrass distribution can affect susceptibility of sediments to become resuspended and the stability of mudbanks as well as nutrient availability to other primary producers.
Interim Goals
Submerged aquatic vegetation distribution and abundance are central ecological indicators of ecosystem health in the south Florida region, and as such are PMs throughout the SE domain. However, based on the indicator selection criteria (i.e., predictability [including adequate existing monitoring data], ecosystem restoration effect, ease of recognition and understanding by the intended audience, and manageable total number of indicators), the IGs for SAV in the SE module are currently limited to several locations within Florida Bay. Water management has dramatically altered the natural freshwater flow patterns (quantity, timing, and distribution) to Florida Bay. These changes, including reduced volume of freshwater inflow, are thought to have affected SAV in the Florida Bay ecosystem (McIvor et al. 1994, Durako et al. 2003, Rudnick 2004). The IGs for Florida Bay seagrass are based on an estimate of ecosystem conditions prior to major human interventions. These conditions (i.e., Florida Bay ecosystem history) were determined from paleoecological research and historical accounts (Brewster-Wingaard et al., 2003; Zieman et al., 1999; Cronin et al., 2001). It is likely that the Florida Bay of the 1970s and early 1980s, with lush *T. testudinum* and clear water, was probably a temporary and atypical condition. Additional ecosystem history research and increased SAV and water quality monitoring will help refine the IGs for SE SAV.

Presently, seagrass meadows in northeastern Florida Bay consist primarily of sparse *T. testudinum* communities. Central and western Florida Bay are dominated by sparse *T. testudinum* to dense *T. testudinum* meadows, but *H. wrightii*, and to a lesser extent *Syringodium filiforme* are also common. The occurrence and relative abundance of these community types vary by basin. From an ecological perspective, restoration targets are established that envision a more diverse seagrass community with lower *T. testudinum* density and biomass than during that anomalous period. A diversity of seagrass habitat is expected to be beneficial to many upper trophic level species (Thayer et al. 1999). CERP implementation should affect SAV in the north shore mangrove zone lakes and coastal embayments (closer to freshwater source) more than offshore areas in the Florida Bay ecosystem. However, central Florida Bay should also be a primary focus area. Spatially explicit SAV restoration targets for the Florida Bay ecosystem are discussed in detail in the Florida Bay and Florida Keys Feasibility Study Draft PMs (USACE and SFWMD 1999) and to a lesser extent in the Florida Bay and Everglades Mangrove Estuaries CEMs (Rudnick et al. 2005, Davis et al. 2005).

7.3.3 Methods and Analyses
SAV species have been monitored at ten Florida Bay locations since 1995 by the Florida Bay Fisheries Habitat Assessment Program (FHAP-FB). As a component of MAP, the geographic scope of FHAP-FB was expanded in 2005 to a total of 22 locations extending from the Lostman’s River to northern Biscayne Bay (*Figure 7-20*), and the program was renamed the FHAPSF. Monitoring stations are determined using a systematic random-sampling design. Each location is divided into approximately 30 tessellated hexagonal grid cells (*Figure 7-21*), and a single station position is randomly chosen from within each grid cell during each monitoring event. Sampling grids were generated using algorithms developed by the EPA’s Environmental Monitoring and Assessment Program (EMAP).
Monitoring is conducted once per year at the end of the dry season (May-June). Salinity stress on seagrasses is typically highest at this time, and this is also the period when the dominant seagrass of the region, *T. testudinum* approaches its maximum leaf biomass,
increasing the team’s ability to detect changes in cover. Reproductive effort (flowering and fruit development) can also be assessed at this time. SAV community structure at each station is visually quantified using a modified Braun-Blanquet (BB) technique (Fourqurean et al. 2002). A series of 0.25 m² quadrats are placed on the bottom at each sampling station. The number of individual BB quadrats examined in each location during each year is provided below in Table 7-6.

| Species occurring within the quadrats are assigned a cover/abundance value according to the following scale: 0 = absent; 0.1 = solitary with small cover; 0.5 = few with small cover, 1 = numerous but < 5% cover; 2 = any number with 5-25% cover; 3 = any number with 26-50% cover; 4 = any number with 51-75% cover; 5 = any number with 76-100% cover. The average BB score for each species is computed for the quadrats within a site to yield an average BB density estimate for each location. Epiphyte loads are also determined for each site. Most recently PAM fluorometry has been used to estimate quantum yield/photosynthetic efficiency. Concomitant with the SAV sampling, physical data are also collected including at least depth, temperature, salinity, pH, dissolved oxygen, and PAR.

Most Florida Bay seagrass reports to date have qualitatively compared maps of BB estimates per species among different years (e.g., Durako et al. 2002). While these maps are extremely informative, it is felt that a more quantitative procedure would also be required for CERP assessment purposes. However, the distribution of the BB data raised concerns because of the large number of zero observations in the quadrats surveyed, as well as many cases where even the positive values were distributed in a highly non-normal manner (Figure 7-22). A procedure known as the delta approach, which has been useful in other contexts where data are positively skewed and zero values predominate (Fletcher et al. 2005), was chosen for

<table>
<thead>
<tr>
<th>Table 7-6: Number of Sampling Quadrats Surveyed in Each Basin for Each Year during the Spring Florida Bay Fisheries Habitat (FHAP) Monitoring Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Loxahatchee River</td>
</tr>
<tr>
<td>Oyster Bay</td>
</tr>
<tr>
<td>Whiskey Bay</td>
</tr>
<tr>
<td>Cool Bay</td>
</tr>
<tr>
<td>Rabbit Key Basin</td>
</tr>
<tr>
<td>Twin Key Basin</td>
</tr>
<tr>
<td>Loxahatchee River</td>
</tr>
<tr>
<td>Matlacha Key Basin</td>
</tr>
<tr>
<td>Cape Key Basin</td>
</tr>
<tr>
<td>Duck Key Basin</td>
</tr>
<tr>
<td>Blackwater Sound</td>
</tr>
<tr>
<td>Manatee Bay</td>
</tr>
<tr>
<td>Barnes Sound</td>
</tr>
<tr>
<td>Card Sound</td>
</tr>
<tr>
<td>South Black Point</td>
</tr>
<tr>
<td>North Black Point</td>
</tr>
<tr>
<td>Port of Miami</td>
</tr>
<tr>
<td>North Biscayne Bay</td>
</tr>
</tbody>
</table>

testing. The delta approach as applied here involves generating two data sets from the original: the first indicating the species presence (occurrence or frequency proportion of quadrats positive for the species in question), and the second abundance when present (concentration, mean BB abundance per quadrat, when present). The product of frequency and mean abundance values yields an index of relative density. Such a statistic is considered more representative of the data than a mean density estimate calculated in the conventional way, where the data set has a large number of zeros (Seber 1982). Separate analysis of the two components not only results in more robust estimation and understanding of the variance associated with each but typically reduces variability around the (composite) delta-mean value (Lo et al. 1992). Herein the term “delta-mean” will be used for the average delta-density values calculated. Note that in the application using nontransformed data, the means calculated are identical to conventional means and only the variance changes. This approach was employed and proved successful in an analysis of spatio-temporal trends in shoreline fish species in southern Biscayne Bay (Serafy et al., 2007). It is also being employed in other MAP monitoring components such as the Juvenile Seatrout Monitoring for similar reasons (the large number of zero observations).

![Figure 7-22: Frequency Distribution of BB Estimates for Representative Seagrass Species](image)

Since all data collected thus far reflect pre-CERP conditions, the current assessment is simply the exercise of comparing the available baseline (pre-2006) data to the 2006 data with respect to the summary statistics discussed above. This exercise was confined to two Florida Bay locations, Johnson Key Basin and Blackwater Sound (Figure 7-22). These locations have substantially different environmental conditions (e.g., salinity patterns, sediment depth), and the seagrass in these areas have been monitored since 1995. For each of these basins, the 2006 values were compared to the means of the prior observations for that basin with respect to delta-mean and its constituent terms, frequency and concentration, and for predominant SAV taxa. A statistically significant difference occurred when the 2006 values fell outside the 95 percent confidence interval for the means of prior values (1995-2005). While not a power (or sensitivity) analysis in the formal sense, such an exercise is relatively free of assumptions about the data and yields a quantitative appreciation for the underlying baseline data and its inherent variability (i.e., the context against which CERP induced changes will have to be discerned). In essence, a new tool to explore aspects of the data not usually considered is being added to the assessment toolbox, which will improve the SE module...
team’s ability to detect CERP related changes beyond just comparing the spatial distribution of BB scores at different points in time.

**Johnson Key Basin**

**Brief History**—In 1987, extensive areas of *T. testudinum* began dying rapidly in central and western Florida Bay (including Johnson Key Basin). Factors that may have contributed to the die-off were physiological stressors such as elevated water temperature and prolonged hypersalinity, excessive seagrass biomass leading to increased respiratory demands, hypoxia and sulfide toxicity, and disease (Hall et al. 1999). Although *T. testudinum* mortality slowed substantially after several years, seagrass abundance in the central and western bay continued to decline due to an extended period of water column turbidity which began in 1991 and lasted until the late 1990s. Reduced water clarity was caused by resuspended sediments and phytoplankton blooms, most likely associated with the *T. testudinum* die-off (Durako et al. 2007). After water clarity improved, seagrass communities in Johnson Key Basin began to recover.

**Results of Analysis**—The 2006 Johnson Key Basin SAV community was composed of a variety of taxa, including substantial representation by *T. testudinum*, *H. wrightii* and *S. filiforme*, and occasional macroalgal species. With respect to *T. testudinum*, delta-density significantly differed in 2006 from the baseline condition (*Figure 7-23*), and did so with respect to both its components (frequency and concentration). In contrast, the 2006 *H. wrightii* delta-density was not significantly different from the baseline condition, although it declined substantially as a result of decreasing concentration with no change in occurrence.

![Figure 7-23: Comparison of 2006 spring SAV observations with mean spring observations and 95% confidence intervals from 1995-2005 (n=11) in Johnson Key Basin for (a) Thalassia testudinum and (b) Halodule wrightii](image)

An analysis of longer term trends (*Figure 7-24*) indicates that while *T. testudinum* has been increasing in both concentration and occurrence, the relative contribution of *H. wrightii* peaked approximately five years earlier in 2000.
Figure 7-24: (a) Frequency, (b) Concentration, and (c) Delta-density values for *Thalassia testudinum* and *Halodule wrightii* in Johnson Key Basin from spring 1995 to 2006 (open symbols indicate 2006 values). Contour plots illustrate the distribution and abundance of (d) *Thalassia* and (e) *Halodule* in 1995, 1999, 2005, and 2006 in Johnson Key Basin.

Comparing these temporal trends to Johnson Key Basin water quality (*Figure 7-25*), it was determined that the water quality trends are consistent with increasing light availability (lowered turbidity and water column chlorophyll $a$), increasing salinity, and decreasing water column nutrients (and one of the team’s CERP hypotheses). The decreases in water column nutrients, turbidity, and chlorophyll $a$ are also consistent with an overall increase in sediment stability, representing a positive feedback loop (another CERP hypothesis). In any case,
there is little question that Johnson Key Basin is continuing to change as fish and invertebrate habitat in conjunction with water quality changes, and is doing so in a direction consistent with the SE module team’s general hypotheses.

![Graphs showing time-series plots in Johnson Key Basin](image)

Data provided by the FIU SERC Water Quality Monitoring Network

**Figure 7-25:** Time-series plots in Johnson Key Basin for (a) salinity, (b) turbidity, (c) chlorophyll $a$, (d) TP, (e) dissolved inorganic nitrogen, and (f) nitrate plus nitrite

**Blackwater Sound**

**Brief History**-A highly unusual algal bloom has persisted in northeastern Florida Bay and southern Biscayne Bay since fall 2005. Similar algal blooms have been observed in central and western Florida Bay, but never in eastern Florida Bay (Rudnick et al. 2006). Chlorophyll $a$ concentrations (an indicator of the amount of algae in the water column) greatly exceeded values recorded during the previous fifteen years of water quality monitoring in this region (SFWMD/FIU Coastal Water Quality Monitoring Program). The algae bloom has been found to be mostly composed of blue-green algae, which are photosynthetic bacteria.
Causes of the bloom are not certain, but may be related to at least two factors: 1) disturbance associated with road construction activity along U.S. Highway 1 between the Florida mainland and Key Largo (eighteen mile stretch); and 2) hurricane impacts from August through October 2005 (Hurricanes Katrina, Rita, Wilma). Highway construction has entailed the cutting and mulching of mangrove trees and soil tilling (mixing fresh mulch into the peat soil) and soil stabilization with injection of cement since May 2005. Hurricane disturbances included a large discharge of fresh water and P from the C-111 canal and the impact of high winds, waves, storm surge and abrupt salinity change on plants, soils, sediments, and ground water. The proximity of the blooms to both sides of U.S. Highway 1 (an area where blooms have not been previously recorded) indicates the likelihood that the unique disturbance of road construction is involved as a cause of the bloom (see Rudnick et al. 2006 for complete summary).

Results of Analysis-The 2006 Blackwater Sound SAV community was composed of sparse to moderate *T. testudinum*, sparse *H. wrightii*, and sparse *Syringodium* communities, and occasional macroalgal taxa (e.g., *Batophora*). Results of delta-mean analyses for *T. testudinum*, *H. wrightii*, and *Batophora* are illustrated in Figure 7-26. Delta-density of all three taxa significantly differed in 2006 from the “baseline” condition, primarily as a result of significant declines in concentration.

![Figure 7-26](image)


**Figure 7-26:** Comparison of 2006 spring SAV observations with mean spring observations and 95% confidence intervals from 1995-2005 (n=11) in Blackwater Sound for a) *Thalassia testudinum*, b) *Halodule wrightii*, and c) *Batophora*
These declines are consistent with recent decreases light availability in Blackwater Sound due to substantial increases in both turbidity and chlorophyll $a$ levels (Figure 7-27).

Data provided by the FIU SERC Water Quality Monitoring Network

**Figure 7-27:** Time-Series Plots in Blackwater Sound for (a) Salinity, (b) Turbidity, and (c) Chlorophyll $a$

### 7.3.4 Discussion

Results of the 2007 SSR suggest that the methods adopted can detect changes in SAV from pre-CERP conditions when there is sufficient reference data, and that the present trends are consistent with hypothesized causal relationships. Partitioning the relative contribution of the causal factors will require judicious application of the mechanistic SAV model currently being developed for the SE module, as well as some sensitivity analyses. It will also require a considerable time series of data after CERP is implemented. Implicit is the quantitative understanding of the relationship between water management changes and both salinity and water quality. Developing these relationships throughout the SE module will almost certainly depend upon integrated water quality monitoring and modeling (including hydrodynamic and hydrologic). The present analysis suggests that it will require a decade or more of monitoring to obtain an adequate amount of data to detect and interpret ecosystem change related to CERP activities. Fortunately given the present implementation schedule, such a time series will be available if MAP monitoring is sustained as planned.

There is a relatively close relationship between the SAV monitoring (and assessment) and the present IGs with respect to the SE but it is far from perfect. In fact the current MAP monitoring will not in itself be sufficient (unless modified and supplemented) to address some of the refined spatial goals discussed above. Explicit targeted transect sampling will be required, but a more troubling concern may be the need for modeling purposes to accurately
assess biomass (rather than estimating it indirectly from regression relationships based on limited data). The SE module team has begun to address these concerns by establishing 15 permanent SAV monitoring transects in Florida Bay. These transects are co-located with long-term water quality monitoring stations of the FIU/SERC Coastal Water Quality Monitoring Network, and will be sampled twice each year. Cores for seagrass biomass will be collected in addition to BB cover estimates and seagrass shoot counts. Depending upon model sensitivity, additional permanent transects may be required. It is probable that the IGs for SAV in the SE module will change in its next iteration. As a consequence, the MAP sampling will be updated in relatively short (two-four year) contract renewal intervals. The SE module team will have this opportunity, and will clearly need to take full advantage of the opportunity to, improve the match between the processes of model prediction and assessment.

7.4 Southern Estuaries Hypothesis Cluster-Nursery Habitat

7.4.1 Abstract

Three concurrent field efforts are providing substantial, long-term data that are relevant to assessing the suite of nursery hypotheses. In the 2007 SSR, the spatio-temporal extent, quantity, and quality of these data for four species that use the SE as nursery habitat will be illustrated: gray snapper (*Lutjanus griseus*), spotted seatrout (*Cynoscion nebulosus*), pink shrimp (*Farfantepenaeus duorarum*), and rainwater killifish (*Lucania parva*). The first three species: (1) are among the most ecologically and economically important species in the SE; and (2) display responses to salinity (and therefore, to changes in freshwater flow) in terms of their distribution and/or abundance. The rainwater killifish, while of no direct economic importance, is the most abundant benthic fish in northern Florida Bay and western nearshore Biscayne Bay. Note that the three monitoring efforts (visual survey, trawl, and throw trap) collect data on many more species than are illustrated in this report. Ongoing fieldwork is also quantifying the abundance, distribution, size-structure, and salinity relationships for various species of mojarras, grunts, killifishes, barracuda, gobies, pipefishes, and caridean shrimps. Furthermore, the data from the shoreline visual assessment and Fish and Invertebrate Assessment Network (FIAN) are being used in concert to characterize species assemblages, their variation in space and time, and relationships with habitat.

7.4.2 Background Description

South Florida estuaries provide critical nearshore nursery habitat for many species of fish and invertebrates that support ecological food webs and fisheries (*Figure 7-28*). These include pink shrimp, spotted seatrout, gray snapper, and small forage fishes and invertebrates, such as rainwater killifish, caridean shrimp, and crabs. The abundance and distribution of the various species and resultant faunal community dynamics, including prey-predator relationships, are largely determined by the area of overlap of favorable salinities with favorable bottom and shoreline features (Browder and Moore 1981). Salinity patterns in the SE are established and maintained by mixing with offshore marine waters and the volume and timing of freshwater inputs, which are controlled not only by tide and weather, but also by water management. Human modification of freshwater inflow over the past 100 years has severely altered salinity patterns and salinity fluctuations, resulting in deterioration or elimination of estuarine habitat and a decline in both species abundance and community
richness. The implementation of CERP is expected to increase the distribution and abundance of fishes and invertebrates in the SE as well as community richness by increasing the area of overlap of mesohaline salinities with bottom and shoreline features that are favorable for the most species, especially those species characteristic of estuaries. Specific nursery hypotheses are depicted in Figure 7-28.

Figure 7-28: SE Module Nursery Habitat Hypothesis CEM

Major CERP Relevant Hypotheses

- Hypothesis 1: CERP will expand the gradient of salinities from near fresh to polyhaline to cover a larger nearshore zone and will reduce salinity fluctuation to a range and frequency characteristic of natural estuarine conditions, increasing the area of optimum habitat for many species and, as a result, expanding local distribution, increasing abundance, and allowing a richer species assemblage.

- Hypothesis 2: CERP will reduce the intensity, duration, and area of coverage of hypersaline conditions, thereby increasing the area of optimum habitat for nearshore fish and invertebrates.

- Hypothesis 3: CERP will increase the area covered by patchy or heterogeneous seagrass habitat, thereby increasing the area of optimum habitat for seagrass-associated fish and invertebrate species.

- Hypothesis 4: CERP will increase the length of shoreline receiving direct freshwater inflow and establish more persistent salinity gradients thereby, increasing the area of
optimum habitat for fish species spending all or a part of their life cycle along the shoreline.

- Hypothesis 5: CERP will increase the area of overlap of favorable salinities with favorable bottom habitats and shoreline features, thereby increasing the distribution and abundance of a richer species assemblage, especially those species characteristic of estuaries.

Interim Goals

**Juvenile Shrimp Densities in Florida and Biscayne Bays**

The nursery habitat hypothesis cluster is presently represented in IG/IT by pink shrimp. The desired condition for juvenile shrimp densities in Florida and Biscayne Bay is an increase to peak abundance in juvenile pink shrimp density during the August-October period in optimal habitat (seagrass) in three regions of Florida Bay - in Ponce de Leon Bay, on the lower southwestern mangrove coast, and in southwestern nearshore Biscayne Bay.

Current IG/ITs focus on four locations: Johnson Key Basin and Whipray Basin in Florida Bay, Ponce de Leon Bay on the southwest coast, and nearshore Biscayne Bay (from Shoal Point to Turkey Point). Johnson Key Basin, located in western Florida Bay, site of a systematic long-term throw trap study (Robblee et al. 1991), has the highest densities of juvenile pink shrimp measured in south Florida estuaries. Salinities are moderated by mixing with oceanic waters, but are influenced by the outflow of lower southwest Florida coastal rivers (e.g., Shark River, Lostman’s River) (Kelble et al. 2007). Nursery grounds in Johnson Key Basin lie relatively short distance from Florida Bay’s western boundary, the boundary crossed most frequently by postlarval pink shrimp ready to settle (Criales et al. 2006). An almost solid cover of seagrass, consisting of a mixture of *T. testudinum, H. wrightii* and *S. filiforme* enhances the value of this area as a nursery ground for pink shrimp. The optimum density stated in IG/ITs is 17 pink shrimp per square meter. Whipray Basin, located in NCFB, although not as well sampled, is known to contain fewer juvenile shrimp than Johnson Key Basin. Extreme hypersalinity frequently occurs in this area and can persist for months or even years, spreading to cover large parts of the bay. A simulation model by Browder et al. (2002) suggested that the production of young pink shrimp in Whipray Basin and other central interior basins varies from year to year and that suitability of this area as pink shrimp nursery habitat might be enhanced by restoration of a more natural regime of freshwater inflow. Optimum densities in Whipray Basin are expected to be five shrimp per square meter. Rabbit Key Basin is located in the south-central bay and is another rich seagrass area on the edge of Florida Bay where salinity is moderated by oceanic exchange. Ponce de Leon Bay opens to the southwest coast and receives the direct inflow of the Shark River. The Everglades estuaries of the lower southwest mangrove coast have been identified as important nursery habitat for pink shrimp. The little sampling conducted there suggests that pink shrimp density is lower there than in Johnson Key Basin. It is unclear if lower pink shrimp densities result from salinity conditions or postlarval access to the region or both.

Nearshore southern Biscayne Bay from Shoal Point to Turkey Point also supports lower pink shrimp densities than western Florida Bay basins. This area has substantial areas of hard-bottom and fluctuating salinities due to canals with control gates that make automatic water...
releases relative to water levels. The present IG/IT for Johnson Key Basin is 17 pink shrimp. Targets for the other four areas are set as expected in relation to the Johnson Key Basin target, and they are seven, five, seven and two pink shrimp per square meter, respectively, whenever Johnson Key Basin reaches 17 shrimp per square meter. The other locations are expected to achieve their maxima when Johnson Key Basin achieves its maximum; thus Johnson Key Basin serves as a yard-stick that might more strongly express seasonal and year-to-year variation in postlarval recruits as well as the influence of freshwater inflows.

The MAP FIAN monitoring component currently measures pink shrimp density, frequency, and concentration at 19 locations, including all locations with stated IG/ITs. FIAN will be described in the section below.

7.4.3 Methods and Analysis

The pink shrimp is one of many members of the nearshore faunal assemblage. The faunal assemblage is being monitored using three main sampling methods: (1) visual belt-transects (60 square meters [m²]), (2) otter trawls (~3.6 meter [m]-wide mouth, 6 millimeter [mm] mesh), and (3) throw traps (1m², 3 mm mesh). The visual belt-transect technique is used to survey fishes in mangrove fringe habitats. The otter trawl and throw trap are used in shallow, open water seagrass habitats to quantify juvenile spotted seatrout and SAV-associated fish, shrimp and crabs, respectively. A suite of habitat measurements is collected in conjunction with each faunal sample, including at least salinity, temperature, and water depth, as well as other physicochemical and biological habitat features, such as the taxonomic composition and coverage of benthic flora. Details of each method are provided in Serafy et al. (2003), Powell et al. (2007) and Robblee and Browder (2007), respectively. Prior use of the same visual, trawl and throw trap methods in the study domain dates back as far as 1984 (e.g., throw trap). In each project this allows the inclusion of considerable historical data for establishing pre-CERP conditions, variability, and trends in nearshore faunal abundance, diversity, and size-structure. Sampling design and effort specifics for the three programs are provided below.

Species-specific analyses are clearly required to assess nursery habitat condition in relation to salinity. Such analyses are not without difficulties because, at the species-specific level, abundances are often positively skewed and dominated by zeros (LO et al. 1992). This reflects patchiness in the environment and in the distribution of the species concerned (Gaston 1994). Consequently, following Serafy et al (2007) and Serafy and Valle (2006), the SE module team examined species-specific abundance and its variation with salinity using the delta approach. The delta approach entails separate consideration, over time and along gradients, of occurrence (frequency of samples in which a species is present), concentration (density of a species in a collection considering only samples where that species is present) and delta-density (product of occurrence and concentration, which, in the absence of any data transformation, is simply the mean). The delta-density can be more representative of the data than a density estimate calculated in the conventional way, where the data set has a large number of zeros (Seber 1982). Separate analysis of the two constituents not only results in more robust estimation and understanding of the variance associated with each, but also typically reduces variance around the delta-density value (LO et al. 1992). To better clarify patterns in an estuarine environment in which species have broad salinity tolerances, salinity
data are, in most cases, organized into five-psu salinity bins for summarization and analysis of abundance in relation to salinity.

Submerged aquatic vegetation, especially seagrass, is distributed widely in south Florida coastal waters and is thought to play an important ecological role in shaping nearshore epibenthic fish and invertebrate communities. Because animals associate with benthic vegetation for food and shelter, animal abundance is thought to reflect the structure and complexity of benthic vegetation; an understanding of faunal relationships to benthic vegetation is necessary to understand faunal relationships with salinity. For this reason, extensive data on bottom vegetation are taken in both the spotted seatrout and the epibenthic fish and invertebrate MAP monitoring components, and a project exploring the relationship of between shoreline fish communities in southern Biscayne Bay in ongoing. The spotted seatrout monitoring component uses a harvest-based method to describe seagrass, and the FIAN uses both a harvest-based and a visual-based (BB) method. In addition to collection of SAV as an integral part of FIAN, the sampling design of FIAN is closely linked to that of the MAP FHAP-SF project. Although extensive, the SAV data of the two faunal monitoring components have not yet been fully incorporated into analyses of MAP faunal data and are discussed only briefly in this report.

The purpose of this section of the SSR is to: (1) present results of efforts to date; (2) incorporate pre-MAP and MAP data thus far processed; and (3) develop a characterization of pre-CERP biological conditions (i.e., baseline) with which to assess CERP as it seeks to restore the desired ecological state of south Florida estuarine communities. Sampling design and effort specifics for the visual belt-transect, trawl, and throw trap monitoring components are provided below.

**Shoreline Fish Survey**

Following a stratified random sampling design, visual monitoring of shoreline fishes has focused on the western and eastern margins of southern Biscayne Bay, Card Sound, and Barnes Sound (Figure 7-29). Since 1998, visual fish surveys have been conducted twice annually, during the wet season (July to September) and the dry season (January to March). To date, the survey spans 18 consecutive seasons (nine years) along four shoreline segments, and the sampling effort has grown consistently over the years, especially along the mainland shoreline (Figure 7-29). The number of samples, by year and season, for each shoreline stretch has increased since the project has been incorporated into MAP (Figure 7-29). Sampling is along belt transects at randomly sited locations of the shoreline. Currently, there are 20 to 50 belt transects in each shoreline segment. Details of the survey design and methodology are given in Serafy et al. (2003, 2006) and Serafy et al. (2007).
Spotted Seatrout Monitoring in Florida Bay
Trawl sampling for juvenile spotted seatrout is conducted in four areas in western and NCFB: West area, Rankin Lake, Whipray Basin, and Crocodile Dragover (Figure 7-30). These are the four areas, out of all in the bay sampled historically (1984-2000), where juvenile spotted seatrout have previously been collected. Sampling is conducted from June through November each year. These are the months when juvenile spotted seatrout are most available (Powell et al. 2007). The MAP sampling design locates samples randomly in space in each of the four areas, while avoiding islands and exposed banks. Each area is divided into cells measuring 1800 meters on a side, which are further divided into four smaller cells (microcells). Larger cells are randomly selected and one sample is taken at the center of each microcell (900 meters on a side). Hence, there are four potential sites per cell. There are roughly 50 trawlable cells in the West area, 23 in Rankin, 19 in Whipray, and 20 in Crocodile Dragover. Based on the number of trawlable sites per area and monthly sampling from June through November, results would yield a collection of approximately 360 samples annually, 156 in the West area, 84 in Rankin, and 60 each in both Whipray and Crocodile Dragover (Figure 7-31). A power analysis based on the historical data collected between 1984 and 2000 was used to help establish the original sampling design. Sampling effort may be reallocated among areas upon completion of a new power analysis based on the MAP data collected from 2004 through 2006.
Figure 7-30: MAP Spotted Seatrout Monitoring Sites

Sampling was conducted with a small otter trawl with a 3.4-m head rope, 3.8-m foot rope equipped with a 3-mm galvanized tickler chain, which was towed for two minutes at a speed of approximately 2.0 meters per second (m/s). Details of the sampling gear and deployment are given in Powell (2007). Concentration and delta-density are presented in terms of number of fish 1,000 m$^{-2}$. Trout > 100mm standard lengths were excluded from the analysis because of observed changes in behavior beyond that size that affect catchability. Temperature and salinity were measured with a Hydrolab Scout 2 Water Quality Data System and a H$2$O sensor. Turbidity (nephelometric turbidity units [NTU units]) was measured using a Hach 2100P Turbidimeter. An historical database dating back to 1984 is available to MAP for developing a pre-CERP baseline (Figure 7-31). The MAP has greatly increased the sampling effort.
In certain cases, data from two calendar years had to be combined to obtain a complete set of months (i.e., Oct.-Nov., 1984, with June-September, 1985. Sampling was incomplete in 2004 due to a late start in funding and in 2005 because of hurricanes. A non-parametric, Kruskal-Wallis test (Sokal and Rohlf, 1981) with alpha = 0.05 was used to test differences in spotted seatrout densities among years and areas.

Fish and Invertebrate Assessment Network
In FIAN, seagrass-associated fish and invertebrates are sampled with the 1 m$^2$ throw trap at 19 locations within three south Florida regions: Biscayne Bay, Florida Bay, and the southwest mangrove coast including Whitewater Bay (Figure 7-32). Collections are made biannually at the end of the dry (April-May) and wet seasons (September-October). At each monitoring location, sampling occurs within a randomly-sited grid of 30 equal-sized, tessellated hexagonal cells established in coordination with the MAP seagrass monitoring component (FHAP-SF). Eighteen of the 19 FIAN monitoring locations and grids coincide with those used in FHAP-SF; Ponce de Leon is the only FIAN monitoring location not a FHAP-SF location. For each collection, one throw trap sample is taken at a randomly
located site within each of the 30 grid-cells at each of the 19 monitoring locations, resulting in 570 samples collected each season. An advantage of this sampling design is that it ensures that sampling encompasses gradients of environment or habitat present in the monitoring location.

Sampling effort in FIAN is reflected in Table 7-7 for 2005 and 2006 when 60 samples were collected each year from each of the 19 locations (30 spring years and 30 fall years). Ninety-five percent or more of penaeid and caridean shrimps and small fishes are removed from the throw trap with the five sweeps of a sweep net (Robblee and Browder 2006). The throw trap can be used in shallow water and, using scuba, water more than 75 centimeters deep. Details of the sampling method using the throw trap are given in Robblee and Browder (2006 and 2007). Surface and bottom temperature and salinity, water depth, and sediment depth are measured with each sample. The Mann-Whitney U Rank Sum test was used to compare distributions of occurrence, concentration, and delta-density in MAP and pre-MAP data. Simple linear regression was used to explore the relationship between annual values of each abundance metric and salinity in the pre-MAP data from Johnson Key Basin.

Note: locations are shaded in green

Figure 7-32: Locations of the 19 Sampling Locations that Comprise FIAN
Table 7-7: Annual Throw-trap Samples for POR 1984-2006

| Location                  | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 |
|---------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| North Biscayne            |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |
| Port of Miami             |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |
| North Black Point         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 126|
| South Black Point         |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 258|
| Card Sound                |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 258|
| Barnes Sound              |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 258|
| Manatee Bay               |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 258|
| Duck Key Basin            |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Eagle Key Basin           |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Calusa Key Basin          |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Crane Key Basin           |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Rankin Lake               |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| WIlkprag Basin            |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Johnson Key Basin         | 72 | 288| 280|108 | 72 | 212| 144|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |132|
| Rabbit Key Basin          |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Lostmans River            |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Ponce de Leon Bag         |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Oyster Bay                |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |
| Whitewater Bag            |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 60 |    |    |    |    |    |    |    |    | 60 |

Summarized for each FIAN sampling location are annual total throw-trap samples available in the period-of-record. Included in 2005 and 2006 are the current samples available from MAP (60 annually; 30 spring years and 30 fall years)
7.4.4 Discussion

Three concurrent field efforts provide substantial, long-term data that are relevant to assessing the suite of nursery hypotheses listed in Section 7-4. The spatio-temporal extent, quantity, and quality of these data for three species that use the SE as nursery habitat (gray snapper, spotted seatrout, and pink shrimp) are illustrated here as well as one species that occurs in estuaries throughout its life cycle (rainwater killifish). The first three species (1) are among the most ecologically and economically important species in the SE system and (2) display responses to salinity; therefore, to changes in freshwater flow) in terms of their distribution and/or abundance. The rainwater killifish, while of no direct economic importance, is the most abundant fish in northern Florida Bay and western nearshore Biscayne Bay. Note that the three monitoring efforts (visual survey, trawl, and throw trap) collect data on many more species than are illustrated in this report. Ongoing fieldwork is also quantifying the abundance, distribution, size-structure, and salinity relationships of such species as mojarras, great barracuda, and various species of gobies, pipefishes, and caridean shrimps. Furthermore, the data from the shoreline visual assessment and FIAN are being used to characterize species assemblages, their variation in space and time, and relationships with habitat.

Shoreline Fish Visual Assessment

The visual fish monitoring effort provides a pre-restoration time series of abundance and size information for a variety of mangrove-fish species. One prominent species is the gray snapper, *L. griseus*, a fish of high ecological and economic value throughout south Florida coastal bays. Shown in Figure 7-33 are three abundance metric time series for gray snapper, which inhabit mangrove shoreline habitats of Biscayne Bay.

![Figure 7-33: Time Series of Abundance Metrics for Gray Snapper](based on data collected as part of the shoreline fish visual assessment)
In Figure 7-34, the delta approach is applied to reveal relationships with salinity. It is important to note that several species have been examined using the same approach as illustrated in Figure 7-34 and several strong relationships with salinity have been found. The reader is referred to Serafy and Valle (2006) for further details. Finally, Figure 7-34 illustrates seasonal size-frequency distributions for gray snapper, which is another species-specific metric (i.e., size structure) that may respond to CERP-related salinity regime changes. Greater habitat utilization by juveniles post-CERP, for example, would be reflected in pre- versus post-CERP length-frequency plots. Such before-after comparisons of size structure could then be tested using the Kolmogorov-Smirnov statistic, or similar distribution test.
Juvenile Spotted Seatrout Monitoring in Florida Bay

The objectives of the juvenile spotted seatrout program are to (1) develop a time series from pre-MAP (1984-85; 1996-2000) and MAP (starting in 2004) data that can be used to form a baseline characterization of juvenile spotted seatrout populations; (2) perform power analysis to evaluate the sampling design for change detection capability and use results to refine the design, (3) develop abundance indices to compare spatial patterns and temporal trends; and (4) determine the factors that influence juvenile spotted seatrout abundance.

Pre-MAP data (1984-85; 1994 through 2000) were used to initially establish reference conditions for assessing responses of juvenile spotted seatrout to CERP. Collection methods are detailed in Thayer et al. (1987), Thayer and Chester (1989), and Powell et al. (2007). For the pre-MAP time series, only data from June through November and only data from the stations that coincided with MAP sampling (Figure 7-30) were selected for this study. A total of 164 collections were included (Figure 7-31). The historical data for 1984 through 2000 are shown by year with the 2004 through 2006 MAP data in Figure 7-36 and combined for comparison with the MAP data in Figure 7-37. There was considerable year-to-year variability in the historic data, but the sample size was small. Therefore, the pre-MAP years were combined for comparison with the MAP years (Figure 7-37).

Spotted seatrout occurrence and density were low in all areas in 2004, but varied differently among years in the four areas in 2005 and 2006 (Table 7-6, Figure 7-37). The density in western Florida Bay was very low in 2004 and 2005 compared to historical density, but very high in 2006 compared to all previous periods. In 2004 and 2005 juvenile spotted seatrout were collected at only about ten percent of the stations sampled, whereas in 2006 they were collected at about 50 percent of the stations sampled. Thus, variation in occurrence among years mirrored that of density.
Figure 7-36: Spotted Seatrout Density and Frequency, by Year, from Pre-MAP and MAP Databases
Table 7-8: Summary of Kruskal-Wallis Test P-values

<table>
<thead>
<tr>
<th>Year</th>
<th>1984-2000</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>West</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>0.011</td>
<td>0.65</td>
<td>&lt;0.011</td>
</tr>
<tr>
<td>2005</td>
<td>0.011</td>
<td>-</td>
<td>&lt;0.011</td>
</tr>
<tr>
<td>2006</td>
<td>0.011</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rankin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>&lt;0.011</td>
<td>&lt;0.011</td>
<td>&lt;0.031</td>
</tr>
<tr>
<td>2005</td>
<td>0.23</td>
<td>-</td>
<td>&lt;0.01†</td>
</tr>
<tr>
<td>2006</td>
<td>0.13</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Whipray</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>0.25</td>
<td>0.041</td>
<td>0.011</td>
</tr>
<tr>
<td>2005</td>
<td>0.19</td>
<td>-</td>
<td>&lt;0.011</td>
</tr>
<tr>
<td>2006</td>
<td>0.01†</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Crocodile Dragover</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>0.81</td>
<td>0.53</td>
<td>0.05†</td>
</tr>
<tr>
<td>2005</td>
<td>0.36</td>
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<tr>
<td>2006</td>
<td>0.08</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(Probability > Chi-square; % = 0.05) comparing spotted seatrout densities among years, by area. Arrows indicate a significant increase (8) or decrease (9) in values. For example, densities in 2004 were less than 1984-2000, not different than 2005, less than 2006.
A-D: Density (numbers 1000 m$^{-2}$ + SD) of spotted seatrout. E-H: Frequency of occurrence of spotted seatrout. Data for 1984-2000 are combined. For the years sampled during 1984-2000, see Figure 7-36 and text. Values in parentheses indicate the number of stations sampled (sample size), which was the same for both density and frequency.

**Figure 7-37: Density and Frequency of Occurrence of Spotted Seatrout in Florida Bay, by Area and Year**

Mean salinities in the West monitoring area of Florida Bay during the 2004-2006 sampling period were moderate and only slightly depressed in the fall of 2005 following the passage of hurricanes (**Figure 7-38** and **Figure 7-39**), which indicates the influence of Gulf of Mexico waters on western Florida Bay salinity patterns. A trend toward increasing salinities in
western Florida Bay (i.e., Johnson Key Basin) (clear in the data from 1995 through 2006) was accompanied by a decreasing trend in turbidity, chlorophyll \textit{a}, and nutrients (RECOVER 2007). The decreasing trend in chlorophyll \textit{a} might indicate a decrease in zooplankton, a valuable food source for larval spotted seatrout and other larval fishes.

The pattern of juvenile spotted seatrout density and frequency in 2005 and 2006 differed markedly in Whipray and Rankin (\textit{Table 7-6, Figure 7-37}) despite their close spatial proximity (\textit{Figure 7-37}). Density and frequency were high in Rankin in 2005 and high in Whipray in 2006. In Rankin in 2005 and Whipray in 2006, spotted seatrout were collected at almost half of the stations sampled (\textit{Table 7-6, Figure 7-37}). Salinity was similar in Rankin and Whipray in 2005 and 2006 and was lower than in the previous two years (\textit{Figure 7-38}). Whipray Basin waters have long residence times with a greater tendency towards hypersaline conditions (RECOVER 2007).

Marked differences in juvenile spotted seatrout density and frequency also occurred between Whipray and adjacent Crocodile Dragover. Whipray Basin appears to be the eastern limit of juvenile spotted seatrout habitat, as they are rarely collected in Crocodile Dragover (\textit{Figure 7-37}). Salinity patterns in Whipray and Crocodile Dragover are slightly lower and more variable (\textit{Figure 7-38}).

Differences in seagrass biomass or species composition among areas might partially explain the differences. Recent seagrass collections (2005) during the spotted seatrout monitoring indicate that above-ground biomass of \textit{H. wrightii} and \textit{S. filiforme}, but not \textit{T. testudinum}, is higher in Rankin than Whipray (Powell 2007). Seagrass data collected during spotted seatrout monitoring (2004 and 2005) indicate that \textit{H. wrightii} and \textit{T. testudinum} above-ground biomass is greater in Whipray than Crocodile Dragover. Further analysis and additional data are needed to determine the basis for the differences between Rankin and Whipray and the reversal in relative dominance of the two areas between years.
Figure 7-38: Salinity Mean and Standard Deviation in the Four Spotted Seatrout Monitoring Areas
(by year)
Mean density (number m$^{-2}$ + SD) of spotted seatrout, and mean salinity (+SD) by area and month (September 2004-November 2005). Values in parentheses indicate the number of stations sampled and are the same for salinity.

**Figure 7-39: Spotted Seatrout Mean Density and Mean Salinity-September 2004-November 2005**

Notable increases in spotted seatrout density in NCFB occurred in the fall of 2005 following a considerable decrease in salinities as a result of hurricanes (**Figure 7-39**). Densities of about ten juvenile spotted seatrout 1000 m$^{-2}$ in the Rankin area in October 2005 were the second highest mean densities observed in Florida Bay, only surpassed by mean densities in West in 1999-2000 (**Figure 7-36**). Perspectives on relationships of spotted seatrout indices of abundance with salinity are given in **Figure 7-40** and **Figure 7-41**. Note in **Figure 7-41**,
that the relationship with salinity is negative in the three interior basins, but positive in West area basin. This may be related to the more prevalent hypersaline conditions in the interior basins.

Concentration (density where present, + SD) and occurrence (proportion of stations where trout were collected) of spotted seatout, by area and salinity, in Florida Bay. Values in parentheses indicate the number of stations sampled and also apply to salinity.

**Figure 7-40: Spotted Seatout Concentration and Occurrence in Florida Bay**
Figure 7-41: The Relationship Between the Occurrence of Spotted Seatrout Juveniles and Salinity, by area, in Florida Bay

Fish and Invertebrate Assessment Network
A pre-CERP database for characterizing baseline conditions of nearshore seagrass-associated fish and invertebrates is being developed by accumulating MAP monitoring data and, where it exists, comparable data from pre-MAP projects. The 1-m$^2$ throw trap has been used to sample epibenthic fauna in shallow nearshore waters of south Florida since 1984 (Powell et al 1987; Sogard 1989, Robblee et al., 1991). Long-term records exist from two locations: (1) Johnson Key Basin in western Florida Bay and (2) the FIAN monitoring location-South Black Point in southern Biscayne Bay (Browder et al 2005, 2006). Collectively, these data form the beginning for a seagrass-associated fish and invertebrate data set defining pre-CERP conditions. A goal of FIAN is to extend and expand this baseline to track the impact of CERP implementation on the nearshore seagrass-associated fish and invertebrate communities. The number of throw trap samples available from each FIAN sampling location since 1984 is given in Table 7-5.

Comparing and reconciling data collected with the same gear, but with somewhat different sampling designs, is essential to combining MAP and pre-MAP data in order to create long-term baseline datasets. Previous sampling in Johnson Key Basin followed a repeated measures design; four replicate 1-m$^2$ throw trap samples were collected at each of nine sites.
distributed evenly among three macrohabitats: basin, bank and near-key. In southern Biscayne Bay (South Black Point) a single throw trap sample was collected from each of 33 randomly-located stations; stations were distributed on an areal-basis among three hydrologic-model-predicted salinity zones; low, medium, and high frequency of occurrence of salinity ≤12 psu. A strength of the FIAN sampling design (after FHAP-SF) is that habitat gradients present at a sampling location are sampled according to their areal coverage with results reflecting differences at the scale of sampling location rather than differences by macro-habitat type, which can differ greatly in faunal density. FIAN is addressing the impact of sampling design on faunal abundance and community characterizations by sampling both Johnson Key Basin and South Black Point concurrently using both the original and the FIAN sampling design and directly comparing the results.

Some differences in species composition, size frequency, and abundance have been observed in previous comparisons of data from the two methods, and these differences were attributed to the fact that macrohabitat types (i.e., bank, basin, and near-key) were sampled disproportionately to the area they covered (Robblee and Browder 2007). Among the 12 comparisons, only a single difference in the estimated sample density median (Figure 7-42 and Figure 7-43), was observed, and that difference only at a significance of p<0.1. Comparing delta-density and its constituents (i.e., occurrence and concentration) (Figure 7-49 and Figure 7-51), six comparisons of pink shrimp and rainwater killifish occurrence differed only once each (22 percent of total) and no difference in concentration occurred. The delta-density differed in seven of 12 comparisons (58 percent), four for the rainwater killifish and three for the pink shrimp; a difference was assumed if the FIAN sample mean fell outside the 95 percent confidence interval. These results suggest that no systematic error is operating on abundance estimation, and therefore, it is appropriate to merge the pre-MAP and MAP time-series. Estimate variance often is larger in FIAN than in the historical, long-term data, which might impact change detection. Additional comparative data are needed to determine if the results of these comparisons are robust and if change detection can be improved by appropriate adjustment of the long-term data sets.
Comparison is based on the original and FIAN sampling designs. A Mann-Whitney U-Rank Sum test found no difference in the median among the six comparisons, n = 17 density intervals.

**Figure 7-42: Comparison of the Sample-density Frequency of Pink Shrimp and Rainwater Killifish at South Black Point**
Comparison is based on the original and FIAN sampling designs. A Mann-Whitney U-Rank Sum test found a single difference (p<0.1) in the median among the six comparisons, n = 17 density intervals.

**Figure 7-43:** Comparison of the Sample-density Frequency of Pink Shrimp and Rainwater Killifish at Johnson Key Basin

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**Sample-Density Distribution**

Comparison is based on the original and FIAN sampling designs. A Mann-Whitney U-Rank Sum test found a single difference (p<0.1) in the median among the six comparisons, n = 17 density intervals.
Regional Perspective

FIAN provides the unique opportunity to observe shallow, seagrass-associated epibenthic fish and invertebrate communities on a regional scale. The pink shrimp, *F. duorarum*, and *L. parva*, the rainwater killifish, are examples of abundant species that exhibit distinct regional distribution patterns and are used here to illustrate the capability of FIAN to provide a region-wide view of the SE. To date, 156 species of fish, shrimp and crabs have been collected in FIAN. The pink shrimp is the dominant penaeid shrimp observed in shallow waters of south Florida and is an important commercial species. Western Florida Bay, typified by Johnson Key Basin, is the principal inshore nursery habitat supporting the offshore Tortugas pink shrimp fishery (*Figure 7-44*). Pink shrimp are most abundant where well-developed SAV (*Figure 7-46*, included for reference) coincide with ready access to the Gulf of Mexico (i.e., Johnson Key Basin, and, less so Rabbit Key Basin and Whitewater Bay). In contrast, pink shrimp are least abundant in northeastern Florida Bay and Manatee Bay and Barnes and Card Sounds where only relatively sparse benthic vegetation occurs and contact with the Gulf of Mexico and Atlantic Ocean is remote. The rainwater killifish is the numerically dominant seagrass-associated fish in both pre-MAP studies and current FIAN collections. In FIAN collections, this fish is abundant where the grass canopy is well developed (compare *Figure 7-45* to *Figure 7-46*). It is absent from sampling-locations along the southwest coast and in Whitewater Bay, even though it is abundant in upstream rivers (Bill Loftus, USGS, pers. comm.).
Figure 7-45: Seasonal Abundance Patterns of Rainwater Killifish in FIAN Sampling Locations
Temporal Patterns

Increases in occurrence and concentration of killifish in spring 2005 and spring 2006 collections from South Black Point accounted for significantly higher killifish delta-densities compared to available historical data (i.e., FIAN estimates fell outside the 95 percent confidence intervals of long-term data) (Figure 7-47). A distinct positive trend in abundance of the killifish since the mid-1990s is evident in Johnson Key Basin (Figure 7-50). The killifish virtually disappeared from this basin following a series of disturbances: seagrass die-off, hypersaline conditions, and persistent turbidity/algal blooms. Recovery of the rainwater killifish, a grass-canopy dependent species, has been following the recovery of the seagrass community (Figure 7-24) and more moderate environmental conditions; this is particularly evident in a strong increasing trend in occurrence in Johnson Key Basin (Figure 7-48). No such trend is apparent in killifish abundance in southern Biscayne Bay (Figure 7-49).

FIAN estimates of pink shrimp delta-density in 2005 and 2006 are not significantly different from the long-term record in either South Black Point or Johnson Key Basin (Figure 7-47 and Figure 7-50). Differences in dry and wet season abundance result from strong seasonal recruitment of pink shrimp into nearshore nursery habitats in the fall. With inter-annual variation high, long-term changes in relation to seagrass community recovery are not as evident in pink shrimp as in rainwater killifish in Johnson Key Basin (Figure 7-48).
Comparison of Long-term Pink Shrimp and Rainwater Killifish Abundance at South Black Point (2002-2006; 95% CIs) with FIAN Spring 2005 and 2006 and Fall 2005 collections. Black symbols = occurrence, blue = concentration and red = delta-density; BL = long-term data set, FIAN collections: S5 = spring 2005, S6 = spring 2006, F5 = fall 2005. Sample size is five for dry season and four for wet season sample in BL. Sample size is two for dry season and one for wet season in FIAN.

**Figure 7-47: Comparison of Long-term Pink Shrimp and Rainwater Killifish Abundance at South Black Point**
Comparison of Long-term Pink Shrimp and Rainwater Killifish Abundance in Johnson Key Basin (1984-2006; 95% CIs) with FIAN Spring 2005 and 2006 and Fall 2005 Collections. Black symbols = occurrence, blue = concentration and red = delta-density; BL = long-term data set, FIAN collections: S5 = spring 2005, S6 = spring 2006, F5 = fall 2005. Sample size is 17 for dry season and 18 for wet season in BL, and two for dry season and one for wet season in FIAN.

Figure 7-48: Comparison of Long-term Pink Shrimp and Rainwater Killifish Abundance in Johnson Key Basin
Historic (black with 95% CI), and concurrent FIAN (red with 95% CI) collections

**Figure 7-49: Comparison of the Baseline Rainwater Killifish and Pink Shrimp Time Series Available from South Black Point**
Historic (black with 95% CI) and concurrent FIAN (red with 95% CI)

**Figure 7-50: Comparison of the Dry and Wet Season Baseline Rainwater Killifish and Pink Shrimp Time Series Available from Johnson Key Basin**

The FIAN monitoring component has reviewed its period-of-record (1984-2005) pre-CERP data from Johnson Key Basin for a salinity relationship. Data from the fall of each year were selected because this is the period of peak abundance of pink shrimp and some other species. Fall rainwater killifish and juvenile pink shrimp occurrence, concentration, and delta-density are plotted in relation to salinity measured at the site and date of sampling in **Figure 7-51**. Simple linear regression revealed that within the range of the salinity data (~31-46 psu), pink shrimp concentration and delta density had a significant (p=0.032 and p=0.036, respectively) negative relationship with salinity that translates into a 0.8 shrimp per square meter decrease in shrimp density with each 1-psu increase in salinity. This result supports Nursery Hypotheses 1 and 2 and is consistent with laboratory studies of growth and survivorship for young pink shrimp from Florida Bay within this salinity range (Browder et al. 2002). Conversely, concentration, and delta-density of rainwater killifish were significantly positively related to salinity (p=0.0034 and p=0.0053, respectively) within the range of the
salinity data, which is contrary to Hypotheses 1 and 2. Further analyses are being pursued especially in relation to seasonal timing. Occurrence, a presence/absence measure of abundance, was not significantly related to salinity for either species. In the case of pink shrimp, the lack of a significant relationship of occurrence with salinity might reflect the relatively few samples without at least one pink shrimp during peak abundance in the fall; however, this does not explain the lack of a significant relationship of rainwater killifish occurrence with salinity. Occurrence may be a less sensitive measure of abundance than either concentration or density.

![Pink Shrimp and Rainwater Killifish graphs](image)

Occurrence, concentration, and delta-density of rainwater killifish and pink shrimp, as a function of salinity at the site and time of sampling, Johnson Key Basin, fall (September or October) of each year within period 1984-2005. P-values for the regression equations are, for rainwater killifish, p=0.1146, 0.0034, and 0.0053, for occurrence, concentration, and delta-density, respectively; for pink shrimp, 0.1686, 0.0320, and 0.0361, respectively.

**Figure 7-51: Occurrence, Concentration and Delta-density of Rainwater Killifish and Pink Shrimp**

Overview of Nursery Habitat Monitoring and Assessment
Relating the abundance of estuarine fauna to salinity is a challenge. The issue is confounded by the complicated ecology of each species, with varying physiological needs and ecological responses of different age/size groups, acclimation of individuals to prior salinity conditions, and possibly the presence of different phenotypic or genetic types in the same or different locations. Quinn and Dunham (1983) proposed that distributional limits could be set by: (1) physiological limits that affect survival; (2) lack of recruitment in certain areas; (3) limits set by competition; and (4) limits set by predation. Even physiological limits might be due to a variety of factors, acting singly or in interaction. Results to date suggest that, with MAP monitoring and their predecessors, the tools to adequately evaluate CERP biological effects can be developed.
As presented above, nine years of pre-CERP data from the shoreline fish community project has seen gray snapper seemingly increasing as a function of salinity, although gray snapper of all ages are common in the shoreline waters of Biscayne Bay, where salinity is often low and highly variable. This phenomenon may illustrate the difficulty of separating effects of salinity magnitude from salinity variability, which usually vary together. For example, it may be high variability of salinity along the shoreline, rather than low salinity, per se, that affects gray snapper distribution and abundance.

In another example of seemingly contradictory information, pre-CERP data from the juvenile spotted seatrout monitoring illustrates spotted seatrout occurrence decreasing as a function of salinity in its three interior basins of Florida Bay (although the fit was poor in Rankin Lake) while increasing as a function of salinity in its western Florida Bay region. As part of this relationship, juvenile spotted seatrout abundances reached a record high in Rankin Lake in 2005, whereas, in 2006, another long-term record high was set in Whipray Basin. The Rankin Lake high occurred in October 2005, immediately following a series of hurricanes that both mixed the waters of the interior bay and introduced large volumes of fresh water that caused salinity to plunge. Salinity was substantially lower in both 2005 and 2006 than in previous years in all three interior basins. It was lower and more variable in 2005 than in 2006 and more variable in Whipray and Crocodile Dragover than Rankin.

Interestingly, 1999, a year of substantially lower and more variable salinities in Crocodile Dragover, was a record high year for this location (although based on very few data points). Decreases in salinity associated with dilution of mineral salts may be more favorable to juvenile seatrout in areas prone to hypersalinity that experience poor mixing than in a well-mixed area closer to oceanic waters such as western Florida Bay. Acclimation of individuals to the salinity present in an area when they arrive might also explain the differing responses of the same species among areas where different salinity conditions prevail. On the other hand, the contrasting relationships with salinity may reflect an underlying relationship with some covariate such as nutrients, chlorophyll \(a\), or turbidity, which might vary differently in relation to salinity in the western and interior regions. Chlorophyll \(a\) often is linked to food supply for postlarval fishes. Additional data and coordination of the juvenile spotted seatrout monitoring with other MAP monitoring components that measure chlorophyll \(a\) and nutrients, as well as salinity and turbidity, may be needed to sort this out. General linear models are presently under development with juvenile spotted seatrout data and will include habitat, salinity, and other potential explanatory variables.

The FIAN project showed a significant negative relationship of pink shrimp abundance with salinity in Johnson Key Basin between 1984 and present (several years in the series are not represented), consistent with laboratory studies and an associated simulation model of pink shrimp survival and growth as functions of salinity and temperature (Browder et al. 2002). FIAN monitoring is also finding pink shrimp in the lower-salinity waters of Whitewater and Oyster Bays, although density there is less than half that in Johnson Key Basin. On the other hand, the rainwater killifish demonstrated a significant positive relationship with salinity in Johnson Key Basin, although it is the most abundant fish species in the shallow, often low-salinity waters of western nearshore Biscayne Bay. These new observations need to be evaluated in the context of other information, such as size-frequency distributions, also
available from the FIAN data. A species such as pink shrimp or rainwater killifish may not necessarily have the same relationship with salinity at all locations, and there may be sound biological or ecological reasons underlying this. Mixed-effects models presently are being developed with FIAN-MAP data to explore relationships of abundance to salinity and bottom vegetation as they vary in space and time. The treatment and data are particularly suited and promise to provide greater insight on faunal habitat relationships; however, with only one fall season and two spring seasons available for analysis at this time, the data are too sparse, especially at the extremes of the salinity range, to be confident in the patterns.

Establishing baseline levels of abundance of these estuarine species and detecting the impacts of CERP requires longer time series than currently possessed. It is critical to associate abundance with habitat and environmental conditions. Salinity variation over time needs to be quantified for the sampling domain, and variation, itself, needs to be tested as a factor influencing faunal abundance. Ideally, monitoring for the MAP should be supported by laboratory salinity/temperature tolerance, growth and preference experiments with species and life stages of interest. Other species in the pre-CERP database should be examined for relationships with salinity and habitat.

7.5 Southern Estuaries Module Conclusions

Florida’s Southern Estuaries (SE) are of enormous ecological and economic value and are operating at less than their full potential, largely due to anthropogenic changes to freshwater flow that began more than a century ago. CERP aims to restore more natural salinity regimes to nearshore environments, which, in turn, will have positive consequences for the region’s flora, fauna, and fisheries.

The SE component of the SSR concluded that the approaches and methods used for assessing water quality, salinity regimes, SAV and nursery functions are appropriate and efficient relative to the size, complexity, and value of the systems in question. Therefore, data obtained from SE sampling will prove critical, not only in a monitoring and assessment context, but also for advancing the understanding of how subtropical ecosystems respond to incremental reductions in anthropogenic stress. Some of the most important scientific conclusions in the SE are listed below:

**Water Quality and Salinity:** Baseline conditions indicate that most of the SE are oligotrophic with median Chlorophyll a concentrations of less than or approximately 1 ppb. These baseline data were used as the reference condition to assess the 2006 data, and only the Barnes, Manatee, and Blackwater Sound sub-region was found to have chlorophyll a biomass significantly higher than the baseline. This test case demonstrates that the approach and methods used are sensitive to water quality changes now and into the future as CERP is implemented.

Understanding how CERP affects water quality in the SE will facilitate adaptively managing and guiding restoration efforts. The current continuous salinity monitoring network clearly demonstrates the instability of the existing (pre-restoration) salinity regime along the western coastline in southern Biscayne Bay. These conditions make it difficult for a variety of estuarine floral and faunal communities to either colonize or optimally utilize these regions.
Submerged Aquatic Vegetation: Results of the present assessment suggest that the methods adopted can detect changes in SAV from pre-CERP conditions when there are sufficient reference data, and that the present trends are consistent with hypothesized causal relationships. Results of the present assessment suggest that the methods adopted can detect changes in SAV from pre-CERP conditions when there is sufficient reference data, and that the present trends are consistent with hypothesized causal relationships. Partitioning the relative contribution of the causal factors will require judicious application of the mechanistic SAV model currently being developed for the SE module, as well as some sensitivity analyses. It will also require a considerable time series of data after CERP is implemented. Implicit is the quantitative understanding of the relationship between water management changes and both salinity and water quality. Developing these relationships throughout the SE module will almost certainly depend upon integrated water quality monitoring and modeling (including hydrodynamic and hydrological). The present analysis suggests that it will require a decade or more of monitoring to obtain an adequate amount of data to detect and interpret ecosystem change related to CERP activities. Fortunately given the present implementation schedule, such a time series will be available if MAP monitoring is sustained as planned.

Nursery Function: Three concurrent field efforts are providing substantial, long-term data that are relevant to assessing the suite of nursery hypotheses. The species under examination: (1) are among the most ecologically and economically important species in the SE system; and (2) display responses to salinity (and therefore, to changes in freshwater flow) in terms of their distribution and/or abundance.

Establishing baseline levels of abundance of these estuarine species and detecting the impacts of CERP requires longer time series than currently possessed. It is critical to associate abundance with habitat and environmental conditions. Salinity variation over time needs to be quantified for the sampling domain, and variation, itself, needs to be tested as a factor influencing faunal abundance. Ideally, monitoring for MAP should be supported by laboratory salinity/temperature tolerance, growth and preference experiments with species and life stages of interest. Other species in the pre-CERP database should be examined for relationships with salinity and habitat.

7.6 Status of Monitoring in the Southern Estuaries Module

The following table provides an abbreviated status of monitoring in the SE Module. The table includes a list of monitoring components, links them to the associated hypothesis cluster(s) and performance measures, and provides a brief description of the monitoring itself as well as its status. The table is not meant to be exhaustively comprehensive and represents the most current information to date when the table was developed.
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<td>Biscayne Bay Salinity Monitoring Network</td>
<td>SE Salinity</td>
<td>BNP measures salinity gradients in a series of east-west transects that radiate outward from canals or other prominent hydrological features in Biscayne Bay to document a progression of estuarine conditions near shore to marine conditions offshore</td>
<td>Pre-CERP condition monitoring ongoing, began in 2004.</td>
</tr>
<tr>
<td>Nursery Habitat</td>
<td>3.2.3.7</td>
<td>Juvenile Spotted Seatrout Monitoring in Florida Bay</td>
<td>SE Fish Community</td>
<td>Spatial and temporal patterns in juvenile spotted seatrout populations in Florida Bay are determined by NOAA in order to describe baseline reference conditions and develop a juvenile abundance index (mean densities) for evaluating CERP effects and making predictions.</td>
<td>Pre-CERP condition monitoring ongoing, began in 2004.</td>
</tr>
<tr>
<td>Nursery Habitat</td>
<td>3.2.3.6</td>
<td>Shoreline Fish Communities Visual Assessment</td>
<td>SE Fish Community</td>
<td>Visual surveys by NOAA collect community and species-specific abundance and size-structure information from mangrove-lined shorelines of Biscayne Bay, Card Sound and Barnes Sound.</td>
<td>Pre-CERP condition monitoring ongoing, uninterrupted, biannual (wet &amp; dry season) data set spans from 1998 to present</td>
</tr>
<tr>
<td>Nursery Habitat and Submerged Aquatic Vegetation</td>
<td>3.2.3.5 &amp; 3.2.4.5</td>
<td>South Florida Seagrass Fish &amp; Invertebrate Assessment Network</td>
<td>SE Fish Community</td>
<td>In FIAN, USGS and NOAA quantify change and trends in epibenthic fish, shrimp, and crab communities in relation to bottom habitat and salinity in estuarine to marine waters of Florida Bay, Biscayne Bay, and the lower SW coast.</td>
<td>Pre-CERP condition monitoring ongoing, began in 2004.</td>
</tr>
<tr>
<td>Nursery Habitat</td>
<td>3.2.3.3</td>
<td>Coastal Wetlands Fishes</td>
<td>SE Fish Community</td>
<td>This NOAA and TSC project provides a comprehensive, spatially-explicit baseline</td>
<td>Pre-CERP condition monitoring ongoing, began</td>
</tr>
<tr>
<td>Habitat Category</td>
<td>Study Areas</td>
<td>Description</td>
<td>Monitoring Period</td>
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<tr>
<td>Nursery Habitat</td>
<td>3.2.3.5 &amp; 3.2.4.7 Epifauna Relationships in Nearshore Biscayne Bay</td>
<td>Epifauna Relationships in Nearshore Biscayne Bay, SE Fish Community (previously SE-12-13), SE Juvenile Pink Shrimp and Associated Epifauna (previously SE-11) In this project, NOAA and USGS are developing a baseline characterization of the fish, shrimp, and crabs of the very shallow open-water area immediately adjacent to South Biscayne Bay’s mainland shoreline, relating species occurrence, concentration, and density and community metrics to salinity regime and habitat, and examining potential functional relationships between open-water epifauna and shoreline fishes</td>
<td>Pre-CERP condition monitoring ongoing, began in 2007.</td>
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</tr>
<tr>
<td>Nursery Habitat and Submerged Aquatic Vegetation</td>
<td>3.2.3.3 &amp; 3.2.4.7 Survey of Benthic Habitat in Biscayne Bay</td>
<td>Survey of Benthic Habitat in Biscayne Bay, SE Fish Community (previously SE-12-13), SE Submerged Aquatic Vegetation (previously SE-10) This NOAA project provides a comprehensive, spatially-explicit baseline database on the seasonal species composition, distribution, diversity, and abundance of benthic organisms that constitute the nearshore seagrass, macroalgal, and hardbottom communities of Biscayne Bay; and provide environmental data (i.e., light, DO, temperature, salinity) that are essential to relate the current status and future changes of benthic communities to these physical parameters at a scale commensurate with the benthic surveys</td>
<td>Pre-CERP condition monitoring ongoing, began in 2007.</td>
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<tr>
<td>Nursery Habitat and Submerged Aquatic Vegetation</td>
<td>3.2.3.3 South Florida Fish Habitat Assessment Program</td>
<td>South Florida Fish Habitat Assessment Program, SE Fish Community (previously SE-10) Using BB analysis to estimate macrophyte cover/abundance, and coring to measure seagrass shoot densities and Pre-CERP condition monitoring ongoing, began in 2004.</td>
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<tr>
<td>Water Quality</td>
<td>3.2.3.1 Water Quality and Phytoplankton Monitoring Network</td>
<td>SE Salinity (previously SE-1, SE-2, SE-4-9)</td>
<td>From South Biscayne Bay to the SW coast, continuous underway and moored synoptic sampling bimonthly by NOAA/AOML measures sea surface temperature, salinity, and chlorophyll $a$ fluorescence (for biomass estimation). At moored sites, NOAA estimates Total Suspended Solids, CDOM fluorescence, light attenuation, and pH. At fixed stations, FIU/SERC samples Total Organic Carbon, Total Phosphorous, APA, and Total Nitrogen monthly. DERM monitors salinity and other parameters in parts of coastal Miami-Dade County not covered by the other monitoring.</td>
<td>Pre-CERP condition monitoring ongoing, began in 2004.</td>
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<tr>
<td>Submerged Aquatic Vegetation</td>
<td>3.2.3.4 Large-Scale Remote Sensed SAV Monitoring Program</td>
<td>SE Submerged Aquatic Vegetation (previously SE-10)</td>
<td>FWC/FMRI acquires and interprets aerial photography on a schedule of every 5 years to characterize the large-scale patterns of bottom vegetation cover in Biscayne Bay.</td>
<td>Pre-CERP condition monitoring began in 2004, and the first part of the project was completed in 2007. Phase 2 will be completed when funds become available.</td>
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<tr>
<td>Water Quality</td>
<td>Biological Availability of Organic Nitrogen in Florida Bay</td>
<td>SE Water Quality (previously SE-14-18)</td>
<td>This SFWMD project addresses the bioavailability of allochthonous dissolved organic matter as a source of nitrogen to Florida Bay.</td>
<td>The first phase was completed, and the second phase has not been initiated.</td>
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<tr>
<td>Nursery Habitat</td>
<td>Present and Past Distribution of Oysters in South Florida Coastal Complex</td>
<td>SE Juvenile Pink Shrimp and Associated Epifauna (previously SE-11)</td>
<td>This project by FGCU determines the distribution and nature of oyster buildups, both predrainage (late Holocene) and current; provides basic biological information on living oysters (i.e., adult mortality, CI, and juvenile recruitment); characterizes the estuarine conditions under which historical oyster beds grew and the approximate date of their establishment and maintenance; and makes projections on where and how habitat suitable for oysters could be re-established under different Everglades flow restoration conditions. Area of focus is from Chatham River to Whitewater Bay.</td>
<td>Pre-CERP condition monitoring ongoing, began in 2006.</td>
<td></td>
</tr>
<tr>
<td>Nursery Habitat and Water Quality</td>
<td>Salinity Relationships in Epifaunal Species – Oysters in Biscayne Bay</td>
<td>SE Juvenile Pink Shrimp and Associated Epifauna (previously SE-11)</td>
<td>Conducted by FWCC/FWRI, this project’s purpose was to locate and monitor existing oyster reefs in Biscayne Bay and determine the availability and viability of oyster spat for colonization. The project was suspended after 3 years but may be reinstated later (after more information is available on salinity patterns along the shoreline) to help monitor the progress of CERP.</td>
<td>This project began in 2004 and is suspended while supporting information is acquired or until conditions become more favorable to the development of oyster build-ups.</td>
<td></td>
</tr>
<tr>
<td>Nursery Habitat and Water Quality</td>
<td>Salinity Relationships in Epifaunal Species – Pink Shrimp in Biscayne Bay</td>
<td>SE Juvenile Pink Shrimp and Associated Epifauna</td>
<td>The FIU project planned to investigate the effects of different salinity and temperature exposure scenarios on pink shrimp (<em>Farfantepenaeus duorarum</em>) collected from Biscayne Bay and to</td>
<td>This project began in 2007 but was unable to grow or otherwise acquire, for use as test organisms, pink shrimp postlarvae</td>
<td></td>
</tr>
</tbody>
</table>

2007 System Status Report Final 7-84 November 2007
| (previously SE-11) SE Salinity (previously SE-1, SE-2, SE-4-9) | define optimum salinity and temperature conditions for survival, development, and growth. | originating from known Biscayne Bay stock. The project was suspended after 1 year. |
7.7 References


DERM. 2005. Biscayne Bay water quality wtatus and trends (C-15864), Final Report to the South Florida Water Management District, Miami-Dade County Department of Environmental Resources Management, Miami, FL, USA.


McIvor, C.C., J.A. Ley, and R.D. Bjork. 1994. Changes in the freshwater inflow from the Everglades to Florida Bay including effects on biota and biotic processes: a review. In:


University of Miami and SFWMD. 1995. The South Dade Watershed Project planning and support documents. South Florida Water Management District, West Palm Beach, FL, USA.


Wanless, H., D. Cottrell, R. Parkinson, and E. Burton. 1984. Sources and circulation of turbidity in Biscayne Bay, Florida. Florida Sea Grant and Miami-Dade County, Miami, FL USA.


7.8 Acknowledgements

This report is a collective work. The data summarized in this report is the result of field and laboratory work conducted by a long list of dedicated individuals. Chris Kelble, Penny Hall and Joan Browder, respectively, had leading roles in organizing and writing the water quality, SAV and nursery hypothesis cluster sections. Other report co-authors (in alphabetical order) were: Sarah Bellmund, Joe Boyer, Penny Hall, Peter Ortner, Allyn Powell, Mike Robblee, and Joe Serafy. A special thanks to Greg Graves for volunteering his writing, editing and organizational skills when and where they were needed most.
APPENDIX 7A–MAP METADATA

All maps appearing in this document meet the standards and guidelines as defined in the CERP GIS Standard Operating Procedures (SOP) Manual. These maps are NOT to be used as Stand Alone Documents. To utilize a map as a stand alone hand out, please contact the map creator for additional map elements.

Disclaimer: These maps/data are a conceptual tool utilized for project development and implementation only. These maps/data are not self executing or binding, and do not otherwise affect the interests of any person including any vested rights or existing uses of real property. Any information, including but not limited to maps and data, received from CERP is provided as is without any warranty and CERP expressly disclaims all express and implied warranties of merchantability and fitness for a particular purpose. CERP does not make any representations regarding the use, or the results of the use of the information provide by CERP.

Southern Estuaries Boundaries
  Map Author: Laura Biddison, CERP GIS Map Technician
  Map Created: March 28, 2007
  Map Location: \cerp\projects\GIS\PRGM_03\map_docs\cmn4598_SSRS_07Maps\SE_Site_cmn4598.mxd
  Base Imagery: Land Sat Imagery 2004
  Datasets used:
  SE MAP Module Boundary- \cerp\projects\GIS\PRGM_03\spatial\shp\cmn4598\SE_Bndy_cmn4598.shp
  SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD
  Urban Areas–CERP SDE; GISLIB.BDDEP_MUNICIPAL_BOUNDARY
  CERP SDE; GISLIB. MIAMIDADE_BDJUR_MUNICIPAL

National Oceanic and Atmospheric Administration and Florida International University Water Quality Monitoring Stations
  Map Author: Laura Biddison, CERP GIS Map Technician
  Map Created: May 23, 2007
  Map Location: \cerp\projects\GIS\PRGM_03\map_docs\cmn4598_SSRS_07Maps\SE_WQ_NOAA_FIU_cmn4598.mxd
  Base Imagery: Land Sat Imagery 2004
  Datasets used:
  Water Quality Monitoring Stations-CERP SDE; RECOVER_MONITORING;
  SE_WQ_SALINITY_Kelble
  SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

National Park Service Continuous Salinity Stations in Biscayne Bay
  Map Author: Laura Biddison, CERP GIS Map Technician
  Map Created: June 8, 2007
Map Location:  
\cerp\projects\GIS\PRGM_03\map_docs\cmn4598_SSR_07Maps\SE_WQ_NOAA_Bellmund_BBay_cmn4598.mxd  
Base Imagery:  Land Sat Imagery 2004  
Datasets used:  
NPS Continuous Salinity Stations-CERP SDE; RECOVER_MONITORING;  
SE_BBAY_SALINITY_Bellmund  
Biscayne Bay National Park Boundary-CERP SDE; GISLIB.NPS_BISCAYNE_BND  
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Florida Bay Fisheries Habitat Sample Monitoring Design  
Map Author:  Laura Biddison, CERP GIS Map Technician  
Map Created:  June 25, 2007  
Map Location:  
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Base Imagery:  Land Sat Imagery 2004  
Datasets used:  
FHAP Transect Head Locations-CERP SDE; RECOVER_MONITORING;  
SE_FHAP_TRANSECT_HEAD  
FHAP Sampling Basins-CERP SDE; RECOVER_MONITORING;  
SE_FHAP_BASINS  
FHAP 2006 Random Sampling Locations-CERP SDE; RECOVER_MONITORING;  
SE_FHAP_RANDOMSAMP_06  
FHAP Sampling Hexagons-CERP SDE; RECOVER_MONITORING;  
SE_FHAP_HEXAGON  
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

National Park Service Continuous Salinity Stations and National Oceanic and Atmospheric Administration Underway Tract (not used)  
Map Author:  Laura Biddison, CERP GIS Map Technician  
Map Created:  May 22, 2007  
Map Location:  
\cerp\projects\GIS\PRGM_03\map_docs\cmn4598_SSR_07Maps\SE_WQ_NOAA_Bellmund_cmn4598.mxd  
Base Imagery:  Land Sat Imagery 2004  
Datasets used:  
NPS Continuous Salinity Stations-CERP SDE; RECOVER_MONITORING;  
SE_BBAY_SALINITY_Bellmund  
NOAA Underway Salinity-CERP SDE; RECOVER_MONITORING;  
SE_NOAA_UNDERWAY_SALINITY  
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

National Oceanic and Atmospheric Administration Fish and Invertebrate Assessment Monitoring Stations (not used)  
Map Author:  Laura Biddison, CERP GIS Map Technician
Map Created: June 13, 2007
Map Location:
\cerp\projects\GIS\PRGM_03\map_docs\map_docs\cmn4598_SSR_07Maps\SE_NOAA_FishInvert_cmn4598.mxd
Base Imagery:  Land Sat Imagery 2004
Datasets used:
Fish and Invertabrate Monitoring Stations-CERP SDE; RECOVER_MONITORING;
SE_NOAA_FISH_INVERT
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

National Oceanic and Atmospheric Administration Spotted Seatrout Monitoring Stations (not used)
Map Author:  Laura Biddison, CERP GIS Map Technician
Map Created:  June 13, 2007
Map Location:
\cerp\projects\GIS\PRGM_03\map_docs\cmn4598_SSR_07Maps\SE_NOAA_SpottedTrout_cmn4598.mxd
Base Imagery:  Land Sat Imagery 2004
Datasets used:
Spotted Seatrout Monitoring Stations-CERP SDE; RECOVER_MONITORING;
SE_SEATROUT
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD

Shoreline Fish Visual Assessment (SFVA) Belt Transect Monitoring Stations (not used)
Map Author:  Laura Biddison, CERP GIS Map Technician
Map Created:  June 12, 2007
Map Location:
\cerp\projects\GIS\PRGM_03\map_docs\cmn4598_SSR_07Maps\SE_NOAA_VisualBelt_cmn4598.mxd
Base Imagery:  Land Sat Imagery 2004
Datasets used:
SFVA Visual Belt Transects since 1998-CERP SDE; RECOVER_MONITORING;
SE_SFVA_VISUALBELT
SFWMD Canals–CERP SDE; HYSUR_CANAL_CRL_SFWMD
### Comment/Response Table

<table>
<thead>
<tr>
<th>Name</th>
<th>Section</th>
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<th>How is the Comment Resolved</th>
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<tbody>
<tr>
<td>Eric Bush - Corps Planning</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>Part 1 - 1) From an individual project formulation and justification perspective, this compilation of information is very useful to help inform non-scientists about key aspects and attributes of the sub-regions in which individual projects are located. Integrating this kind of basic science information into CERP project implementation reports recommending approval and subsequent funding actions is essential. However, project implementation reports sometimes do not adequately reflect the basic information and data and associated scientific thought underlying alternative plan development and evaluation. As a result, approval and subsequent budgeting decisions typically default to water budget-type information (e.g., average annual storage volume, dry season deliveries, etc.).</td>
<td>No response to this comment is required.</td>
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<td>(Part 1)</td>
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<td>Eric Bush - Corps Planning</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>Part 2 - This Draft Report should serve as a catalyst to better integrate scientific information into CERP PIRs, including justification analyses. To that end, RECOVER or agency scientists must be more actively involved in the evaluation and documentation of alternative plan effects, using the attributes and aspects described in this system status report as the basis for that evaluation and documentation work.</td>
<td>RECOVER scientists and the Integrative Assessment Sub-team (IAT) are available to support evaluation and documentation of alternative plans effects.</td>
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<tr>
<td>(Part 2)</td>
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<td>Eric Bush - Corps Planning</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>Part 3 - 2) The hypotheses addressed in the report will be valuable for incremental project implementation recommendations. Many CERP projects will be implemented incrementally, but agency leadership and decision-makers are asking what will be gained from such incremental implementation. The hypotheses will be useful for addressing these concerns from a scientific perspective. 3) The report focuses on primary aspects and attributes of key sub-regions of S FL ecosystem. A compilation of the status of higher-level attributes (apex &quot;charismatic&quot; organisms, such as manatees, snail kites, cape-sable sparrows, panthers, etc.) would be useful.</td>
<td>While the reports are divided and presented as subregions, the key ecological attributes being assessed include &quot;charismatic&quot; apex organisms such as the wading birds, crocodiles, apex organisms, such as the wading birds, crocodiles, oysters, and important habitats such as sea grasses. While apex charismatic organisms are important not all may be critical indicators of the successful return to pre-drainage conditions.</td>
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<td>Eric Bush - Corps Planning</td>
<td>ALL</td>
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<td>4) The probability based sampling efforts in the Greater Everglades Wetlands may provide extremely useful information. Monitoring efforts should include measurement of appropriate aspects of flow, particularly at minimally impacted or unimpacted sites (if there are any) to help inform future restoration efforts. Flow is an essential aspect of the Ridge and Slough community, and it is often stated that &quot;more flow is desirable&quot;. However, there is much basic information about flow and flow targets in the Everglades that is lacking. Compiling flow information on the current system should help to inform future restoration planning efforts, especially when target depths and target stages may present competing priorities.</td>
<td>The comment has been noted.</td>
</tr>
<tr>
<td>Eric Bush - Corps Planning</td>
<td>ALL</td>
<td>ALL</td>
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<td>The results from the 2007 SSR provide the following information that would be beneficial to CERP Planning Technical Leaders:</td>
<td>No response to this comment is required.</td>
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<td>- Detailed pre-CERP ecological conditions, which in turn would provide data for projecting future without-project conditions.</td>
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<td>- There is plenty of hydrologic information for problems and opportunities for CERP projects as well as other ecosystem restoration projects.</td>
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<td>- There is enough data in the report that would assist in developing hydrologic as well as ecological models for CERP projects.</td>
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<td>- The hypotheses that the SSR provide would be beneficial to providing improved PMs, and quantifying ecological benefits.</td>
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<td>- The hypotheses would all so assist in developing project level monitoring plans for CERP projects as well as other ecosystem restoration projects.</td>
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<tr>
<td>Kevin Whelan</td>
<td>ALL</td>
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<td>It would suggest that a number of these research programs have longer term datasets that would allow the investigation of trends in addition to the snap shot type of investigation of the 2005 or 2006 dataset. This report fluctuates between the two types of analysis.</td>
<td>The comment has been noted and will be addressed to the extent that the data allows.</td>
</tr>
<tr>
<td>Bruce Sharfstein</td>
<td>ALL</td>
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<td>ALL</td>
<td>It is unclear whether the order of the document on the FTP site reflects the final order of the document, but I would suggest that the document sections be organized North to South (i.e. starting with Lake O and ending with the SE estuaries).</td>
<td>The comment has been noted and the SSR will be reorganized from North to South.</td>
</tr>
<tr>
<td>Bruce Sharfstein</td>
<td>ALL</td>
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<td>Two items which I think need to be addressed in the SSR are the topics of MAP sustainability and the challenge to the MAP of adjusting monitoring priorities to a changing implementation schedule. Similarly, the challenge of responding to CGL 12/06 needs to be addressed as the three issues may be the key drivers to the ongoing revision of the MAP.</td>
<td>RECOVER and the Integrative Assessment Sub-team (IAT) are currently in the process of refining the MAP based upon findings from the 2006-2007 SSR reports. This will include examining changing implementation schedules and responding to the CERP Guidance Letter (CGL) dated December 2006.</td>
</tr>
<tr>
<td>Bruce Sharfstein</td>
<td>ALL</td>
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<td>ALL</td>
<td>Although I believe that it is part of our mandate under the Pro Regs, there is no section in the SSR that addresses water supply issues. I realize that we still don't have assessment performance measures in place for these items but feel that we should at least include an explanatory paragraph or two relating why this is so and committing to resolve the omission by the next SSR.</td>
<td>The IAT has altered the 2007 SSR to include a section on System Synthesis that will have specific recommendations on how Water Supply and Flood Protection will be addressed in future reports.</td>
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<tr>
<td>Bruce Sharfstein</td>
<td>ALL</td>
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<td>ALL</td>
<td>I believe that we should edit out statements in the SSR that advocate for more, or different monitoring, or changes in operational performance unless they reflect a consensus view of RECOVER. Examples include statements about seasonal draw downs towards the end of section 2.2 of the SE section, line 40 in the NE section (re: planting clutch) and various similar comments, particularly in the NE and GEW module sections.</td>
<td>Where appropriate to the success of Everglades restoration, the Integrative Assessment Sub-team (IAT) will identify additional monitoring or a shift in monitoring priorities - this additional monitoring and/or shift in monitoring will represent a consensus by the MAP module making the recommendations (with input from the PIs). These shifts in monitoring and recommendations will be delineated further during the MAP refinement process. Any statements advocating for more or different monitoring will be included in a new section entitled &quot;Lessons Learned.&quot;</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
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<td>ALL</td>
<td>It is abundantly clear that a great deal of effort went into preparation of the 2007 SSR, the first full-blown, system-wide assessment report following the development of the assessment strategy. Those that were involved with the preparation of this document should receive strong applause for their work. This is especially appropriate as the South Florida community continues to hear the full spectrum of discussion about how this was the first, and last complete assessment given the large MAP budget cuts coming, the pending revision to the Monitoring and Assessment Plan, and the absorption of project-level monitoring into the MAP without additional funding.</td>
<td>No response to this comment is required.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>A global technical edit will vastly improve the document</td>
<td>A technical edit will be done.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>An Executive Summary or Global Synthesis or something up front would be valuable to the reader, rather than just the summary section at the end of this long report. A notable chunk of the Summary section should be ported up into the Executive Summary (i.e., the Exec. Summary should be more than a couple graphics.)</td>
<td>An Executive Summary will be included in the 2007 SSR.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>What would really aid this document is a matrix table for each module that presents hypothesis clusters (or components) as rows, and the decision framework (Fig 6-2) as columns. Then, the table could be populated on the outcome of the assessments (see attached separate diagram).</td>
<td>Matrices have been developed and included at the end of each MAP module section (labeled &quot;work plans&quot; in the SSR) that specifically links the hypothesis clusters to the performance measures and status of associated monitoring. However, the IAT has not linked this information to performance outcome because it was felt that this was more appropriate for assessments once CERP had been implemented.</td>
</tr>
<tr>
<td>Eliza Hines</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>I agree with the inclusion of a matrix table for each module that presents the hypothesis clusters as rows and indicates status of each at some specific wave points - I think we have the makings for this already for each module, but I think in a lot of cases, simpler is better. I think we’ve even discussed this before. I keep trying to envision myself as a manager and simply wanting both an overview of a module (conclusions/exec summary) and some idea of what had been done or not done for a module. It might be a useful tool for the PDTs too as they try to figure out what the MAP is monitoring and in what stage of that monitoring they are. I think that is half the battle the PDTs face - they have no idea what RECOVER monitors and if what they would like monitored as even been initiated or is planned.</td>
<td>No response to this comment is required.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>Between 5 and 10% of the people reading this report will have extensive problems reading the color figures. Therefore, this report should be able to be entirely legible in black and white (how I reviewed it).</td>
<td>The comment has been noted and the necessary changes will be implemented where feasible.</td>
</tr>
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<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>The &quot;Summary&quot; section for each module piece was intended to tie the overall information from the module to the hypothesis clusters and provide the reader a quick synopsis of where each cluster is in the assessment process, including the three-prong interpretation framework diagram from the MAP II. This was not done.</td>
<td>The IAT has modified the format of the report to address this comment.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>MAP modules should be presented in some sort of geographical orientation, either from North to South or South to North. Summary section not in same sequence as report.</td>
<td>The comment has been noted and the SSR will be reorganized from North to South.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>Graphics had extensive problems throughout the report, including: - not being legible because shrunk too small - inadequate captions or legends - inability to discern between lines in black-white format</td>
<td>This comment has been addressed. Graphics will be altered to ensure they are readable, of adequate size, and include legends that are complete.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>The intent of the consistent maps was good; however, several major changes will make them much more valuable: - displaying the aerial imagery in the background made labels virtually impossible to read - inset map of Florida had labels that could not be read - the outline of SFWMD boundary was of no value - this is not a SFWMD map, nor is the SFWMD boundary the same as the CERP boundary</td>
<td>This comment has been addressed. The maps used consistently will be revised to include the listed revisions.</td>
</tr>
<tr>
<td>Matt Harwell (Part 1)</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>There is a critical need for the module sections to provide module-level recommendations for changes (more, less, different) in monitoring. This would be valuable in both how it the document continues to aim for presenting science in the context of what is needed to understand – and therefore make changes to – the system as a whole, and as a launching place for the Assessment Team as a whole to examine as part of the MAP refinement process.</td>
<td>Comment is being addressed by the addition of a lessons learned section of the SSR.</td>
</tr>
<tr>
<td>Matt Harwell (Part 2)</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>There are some instances of this already in the report, but more is warranted. Remember that this is not an agency document, or a document of the sponsoring agencies, merely the consensus findings and interpretations of modules that are compiled together in one place. Therefore, recommendations are not ill-advised here, and are encouraged. Even generic statements like the one from the Southern Estuaries, &quot;Without question, reducing the current monitoring effort will diminish the ability to: (1) detect change; (2) distinguish CERP-impacts from non-CERP impacts; (3) make realistic assessments and predictions of system status; and (4) perform adaptive management. Given the size, complexity and high value of southern estuaries, directing more, not less, resources towards monitoring system responses is key to tracking restoration progress and thus guiding restoration towards success&quot; is appropriate.</td>
<td>Comment is being addressed by the addition of a lessons learned section of the SSR.</td>
</tr>
<tr>
<td>Carol Mitchell</td>
<td>Exec Summary &amp;</td>
<td>ALL</td>
<td>ALL</td>
<td>I would caution against making causality statements where the only available data is correlation. There may be one instance of this in the executive summary where disease in oyster colonies is stated to be a &quot;result&quot; of higher salinities. If this is only a correlation (i.e. no lab work done etc) then need to state as such.</td>
<td>The IAT will review the SSR and use caution regarding statements of causation. If the causation is determined to be warranted, the IAT will ensure to include additional references and data to support the claim.</td>
</tr>
<tr>
<td>Bruce Sharfstein</td>
<td>Executive</td>
<td>ALL</td>
<td>ALL</td>
<td>There are two formatting errors which may be related to lines containing URLs. These are in the executive summary pp xvii line 39 and in the System Wide Synthesis pp 2-7 line 19.</td>
<td>These errors will be corrected.</td>
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<tr>
<td>Bruce Sharfstein</td>
<td>Exec Summary &amp; System Synthesis</td>
<td>ALL</td>
<td>ALL</td>
<td>I have some concerns regarding the text on human ecology (dimension science) in both the Executive Summary and the System Wide Synthesis. While I believe that there is agreement that human dimension science (HDS) is a potentially important component of CERP/RECOVER, despite the Ad Hoc sub-teams recommendations, the RLG has decided not to move forward on any aspect of HDS at this time or in the immediate future (beyond looking at water supply and flood control issues) and this should be clearly conveyed in these sections.</td>
<td>The language regarding human ecology in the SSR will be revised to ensure that it does not give the false impression that RECOVER is pursuing human ecology efforts at this time. It will however still recognize formation of the RECOVER ad hoc group and the subsequent set of recommendations presented to the RLG.</td>
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<tr>
<td>Agnes McLean</td>
<td>1</td>
<td>2</td>
<td>25</td>
<td>&quot;4) a discussion of why the goals and hypotheses are not being achieved&quot; hypotheses are either proven or disproven, not achieved.</td>
<td>Text was revised to address this comment.</td>
</tr>
<tr>
<td>Agnes McLean</td>
<td>1</td>
<td>2</td>
<td>39</td>
<td>I found the dates very confusing, please recheck</td>
<td>Tables have been checked and modified as necessary.</td>
</tr>
<tr>
<td>Agnes McLean</td>
<td>1</td>
<td>3</td>
<td>5 &amp; 6</td>
<td>Which year is being referred to, 2004 or 05?</td>
<td>The Water Year for this report is 2006-2007. The text in the draft 2007 SSR report was for 2005-2006 and there simply as a &quot;place holder.&quot;</td>
</tr>
<tr>
<td>Agnes McLean</td>
<td>1</td>
<td>3</td>
<td>21</td>
<td>I must be missing the point with this discussion of long-term climate variability. Much of it reads like a rah-rah for how the SFWMD does water resources planning. If the point is to explain how climate variability confounds the ability to detect change from CERP v change from climate, it should be so stated. Right now I can only infer this is what’s meant.</td>
<td>The text has been revised in response to this comment. The challenge is that climate variability can confound our ability to detect change from CERP from climate change itself.</td>
</tr>
<tr>
<td>Sue Sofia</td>
<td>1</td>
<td>2</td>
<td>40</td>
<td>&quot;WY 2007&quot; be &quot;WY 2006&quot;?</td>
<td>Water Year for the 2007 SSR is 2006-2007.</td>
</tr>
<tr>
<td>Sue Sofia</td>
<td>1</td>
<td>2 &amp; 3</td>
<td>45 &amp; 1</td>
<td>Is the &quot;24&quot; supposed to be there?</td>
<td>The typographical error has been corrected.</td>
</tr>
<tr>
<td>Sue Sofia</td>
<td>1</td>
<td>2</td>
<td>18</td>
<td>I realize that &quot;IG&quot; means Interim Goals, but I’m not sure what the &quot;IG/IGs&quot; stands for. Clarify.</td>
<td>The typographical error has been corrected. Should read IG/IT.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>1.3</td>
<td>3</td>
<td>ALL</td>
<td>Need to rearrange the order of how these listed documents feed into one another. As stated, the order does not make the most sense.</td>
<td>The comment was noted and the order of the documents rearranged accordingly.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>1.3</td>
<td>4</td>
<td>19-36</td>
<td>Same comment applies as above - other agencies other than the SFWMD are contemplating these climatic topics. Additionally, in Line 22, &quot;The SFWMD is proceeding cautiously to address long-term climatic change in its planning process through an adaptive management approach, collecting data and periodically reviewing project designs and operation based on new information.&quot; Is this a documented method? Is the SFWMD referring to the AM Strategy for CERP? If RECOVER and the AM process as it interfaces with the SSR is interagency, it should be treated and detailed as interagency not simply as a SFWMD process.</td>
<td>Comment noted and changes to the text expanded to include the contributions of other agencies.</td>
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SECTION 1.0 - INTRODUCTION

30 October 2007
## SECTION 2.0 - SOUTHERN ESTUARIES

### Chris Kelble (Part 1)

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<tr>
<td>Chris Kelble</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>In reviewing the southern estuaries system status report for 2007, I noticed a rather significant omission that I hope will be addressed prior to its finalization. The primary goal of CERP is to alter the quantity, timing, and distribution of freshwater flow throughout the Greater Everglades. For the southern estuaries this alteration will manifest itself primarily via altered salinity distributions and possibly to a lesser extent altered circulation. The end-result is that salinity will likely be the primary driver of CERP related changes to the biotic components of the SE. This fact is acknowledged throughout the SSR as evidenced by the identification of salinity modifications by CERP, as a primary driver in all of the conceptual ecological models. Based on this, it is my strong suggestion that a separate section should be included which addresses the current state of salinity variation and circulation throughout the southern estuaries. There was a separate salinity hypothesis cluster in MAP Part 1 that was not included in MAP Part 2.</td>
<td>This is a good point and a strong endorsement of a separate salinity section in future reports. However, it was not possible to produce a separate section for this SSR given the timeframe for completion of the document.</td>
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### Chris Kelble (Part 2)

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<tr>
<td>Chris Kelble</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>The salinity section in the 2007 SSR should focus on our current ability to distinguish the effect of operations, e.g. canal releases, from natural salinity variability in the southern estuaries. In the future, this section should address how CERP projects have altered the physical environment (salinity) of the southern estuaries which drive changes in the other hypothesis clusters. The hypothesis clusters focus on the distribution of their parameters versus the independent variable of salinity. This is a good method to examine the effect of CERP; however, the ability to attribute altered salinity patterns to CERP implementation is a requirement to be able to attribute altered SAV, water quality, and nursery habitat functioning to CERP. In the current SSR version, there is minimal discussion on the current status of salinity variation and distribution in the SE. The brief discussion of salinity is in the water quality section and focuses on data collected by continuous salinity recorders in a very limited nearshore area of Biscayne Bay.</td>
<td>This is a good point and the impact of operations on salinity in the SSR is addressed in an added Fig. 2-12 and text in the &quot;Discussion Section&quot; of the water quality section.</td>
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### Chris Kelble (Part 3)

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<tr>
<td>Chris Kelble</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>The inclusion of this data in the water quality section disrupts the flow of this section and weakens the ability of this section to address the changes observed in water quality. This section does not make an attempt to delineate natural salinity variability from operational activities, which is the central premise of CERP’s effect on the SE. Moreover, the reference to salinity as an indicator of water quality is inappropriate, because salinity is unaffected by many of the processes which influence many of the other water quality parameters.</td>
<td>The discussion of salinity unless directly related to water quality has been quarantined under the salinity sub-title in the discussion area and a brief discussion of the impact of operations on salinity is now included. Furthermore, the discussion on water quality has been greatly expanded and now is complete and coherent.</td>
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### Chris Kelble (Part 4)

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<tr>
<td>Chris Kelble</td>
<td>ALL</td>
<td>ALL</td>
<td>ALL</td>
<td>In the future, I would recommend that the SAV and nursery habitat hypothesis clusters utilize the extensive salinity database in the SE to further the analysis of their data. In the current SSR, these hypothesis clusters acknowledge that their components are integrators of water quality and salinity variation, yet most rely on their single grab salinity samples at time of collection to analyze their data which may or may not be the best approach. Furthermore, the intrabasin spatial distributions in SAV in Fig. 2-20 may benefit with a comparison to intrabasin spatial distributions of salinity and chlorophyll a.</td>
<td>We intend to compare intrabasin spatial distributions of SAV in some Florida Bay basins with those of water quality parameters in the near future. However, the majority of locations where we anticipate the most dramatic changes in SAV species composition, distribution, and abundance with CERP implementation (e.g. NE Florida Bay) have only been sampled since 2005.</td>
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### Greg Graves

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<tr>
<td>Greg Graves</td>
<td>2</td>
<td>7</td>
<td>16</td>
<td>“No recent hurricane has hit Fla Bay” is not correct usage of word “recent” within geologic description of formation. There were numerous hurricanes pre 1960 and on back.</td>
<td>Text was revised to address this comment.</td>
</tr>
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</tr>
<tr>
<td>Greg Graves</td>
<td>2</td>
<td>7</td>
<td>30-34</td>
<td>Incorrect statement - It is unlikely that the phosphate industry significantly impacts the Bay. This should be rephrased from “Contributions of nutrients from atmospheric deposition and from the Gulf of Mexico, which may include nutrients from the phosphate fertilizer industry of the Tampa-Port Charlotte area and residential development from Tampa to Naples, are significant external nutrient sources (Rudnick et al. 1999)” to “Contributions of nutrients from atmospheric deposition and from the Gulf of Mexico are significant external nutrient sources (Rudnick et al. 1999), and include inputs from Florida’s large geologic deposits of phosphate and urban development from Tampa to Naples.”</td>
<td>Text was revised to address this comment.</td>
</tr>
<tr>
<td>Greg Graves</td>
<td>2</td>
<td>22</td>
<td>5-12</td>
<td>Should be rewritten as it gives wrong impression and is improperly worded: “If the annual median chlorophyll <em>a</em> concentration is greater than the reference median, but lower than the 75th percentile, the sub-region is marked yellow, and if greater than the 75th percentile it is marked red. In the end that a stoplight map is produced to display the status of chlorophyll <em>a</em> water quality in each sub-region (Figure 2-11). The physical environment of the southern estuaries, particularly salinity, responds to meteorological events, such as tropical cyclones and El Niño (Figure 2-12). Thus, water quality responds to these natural events and any change due to CERP must be detected against a widely varying natural condition.</td>
<td>The SE Module Lead, all SE PIs and two SSR reviewers strongly agree with (and recommend retaining) the generic statements provided at the end of the SE section.</td>
</tr>
<tr>
<td>Greg Graves</td>
<td>2</td>
<td>22</td>
<td>13</td>
<td>Conveys wrong impression; figure title should read, “Figure 2-11: The circle in each sub-region displays the relative status of chlorophyll <em>a</em>, where yellow circles denote median concentration greater than the regional median yet less than the 75th percentile, and red denotes median concentration greater than the 75th percentile. All concentration medians were well below the State regulatory maximum of 11 ug/l.” This caption was changed as suggested with the exception of the final sentence, because if median chlorophyll <em>a</em> values ever approached the state regulatory maximum of 11 ug/l, there would be serious environmental degradation. This regulation is not appropriate for the oligotrophic SE.</td>
<td></td>
</tr>
<tr>
<td>Greg Graves</td>
<td>2</td>
<td>24</td>
<td>7-10</td>
<td>Wrong idea being conveyed; should read: “The desired condition is sustained good water quality in Florida Bay, which is realized by minimizing the magnitude, duration, and spatial extent of algal blooms in the bay sufficient as to maintain adequate light penetration sufficient to sustain healthy and productive seagrass habitat.” Good point. This statement was altered to reflect the comment.</td>
<td></td>
</tr>
<tr>
<td>Greg Graves</td>
<td>2</td>
<td>46</td>
<td>12</td>
<td>Recommend a global replace of arcane “delta-density(ies)” with plain-English “changes in density(ies)” as follows here in line 12 “was used to compare distributions of occurrence, concentration, and changes in density in...” The authors agree and the text has been revised.</td>
<td></td>
</tr>
<tr>
<td>Greg Graves</td>
<td>2</td>
<td>69</td>
<td>7-12</td>
<td>Delete soapbox comment “Without question, reducing the current monitoring effort will diminish the ability to (1) detect changes, (2) distinguish CERP impacts from non-CERP impacts, (3) make realistic assessments and predictions of system status, and (4) guide adaptive management. Given the size, complexity, and high value of southern estuaries, directing more, not less, resources toward monitoring system responses is key to tracking restoration progress and thus guiding restoration towards success.” This is important, highly relevant, and should be stated. The authors disagree that this statement should be removed.</td>
<td></td>
</tr>
<tr>
<td>Bill Perry</td>
<td>General</td>
<td>General</td>
<td>General</td>
<td>It is clear a great deal of work went into this section and it was written by multiple authors. It does a good job of describing the general approach, metrics, and methods used. A good deal of variation exists, however, in level of detail, the treatment of the two bays, and among the biological indicators. For the most part, ‘status’ was difficult to determine after reading the discussion sections. I suggest development of a qualitative scale on which the status of the various indicators can be placed and a clear statement of what that status is on the scale. If status is not known due to lack of information – not enough years, for example - that should be stated.</td>
<td>Given how early we are in the faunal monitoring process, the reader should not expect an assessment of system status per se. Rather this report indicates what monitoring plans are being implemented, the types of data being tracked and levels and variability in various metrics that have been observed thus far.</td>
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<tr>
<td>Bill Perry</td>
<td>General</td>
<td>General</td>
<td>General</td>
<td>The 'impact zone' for Florida Bay is 1) northeast Florida Bay and 2) north central Florida Bay. These are the most estuarine areas and the ones that are most affected by changes in inflows. Unfortunately, except for water quality and SAV, there are no upper trophic level indicators. This has been an existing problem, but I am not sure we can adequately evaluate the Southern Estuaries system without including indicators from these areas.</td>
<td>The authors agree with this statement and would like to see funding, if available, directed towards greater monitoring of upper trophic levels.</td>
</tr>
<tr>
<td>Bill Perry</td>
<td>General</td>
<td>General</td>
<td>General</td>
<td>There is a large amount of existing data that has yet to be analyzed and reported; this draft acknowledges that. I would make clear at the beginning of the section there is ongoing work to analyze and incorporate existing data that did not make it into this report. The authors agree with this statement and would like to see funding, if available, directed towards greater monitoring of upper trophic levels.</td>
<td></td>
</tr>
<tr>
<td>Bill Perry</td>
<td>General</td>
<td>General</td>
<td>General</td>
<td>It is also clear that the status of the ‘system’ will not be reliably assessed using the current scale of monitoring. Unless one makes very large assumptions that the small areas examined a few times are representative of the larger landscape, the current level of monitoring will likely not permit a valid test of hypotheses. At the level of monitoring described and the annual variation exhibited, only catastrophic or significant system-wide change will permit a conclusion that one year’s indicators are significantly different from another year. Given our current experience with the momentum the southern Everglades ecosystem exhibits in terms of seagrass die-off and algae blooms, it will not be useful to merely verify that a significant change has occurred. In addition to providing a CERP scorecard, it will be very important to detect changes that identify trends before such events occur and be prepared to provide a sound basis on which sound adaptive management decisions can be made.</td>
<td>The authors share the concern about adequacy of monitoring. This is stated in no uncertain terms in the conclusion section of the SE Module. Regarding annual comparisons - because, for all intents and purposes, CERP impacts have not yet been realized, comparison of year to year changes here are primarily for illustrative purposes. In practice, we will be comparing values derived from multiple years versus multiple years worth of data post-CERP. We fully agree with the second point about the need to examine the trends - this report contains several cases of this.</td>
</tr>
<tr>
<td>Bill Perry</td>
<td>Part 1</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>This statement is frequently made in describing salinity dynamics, but sea-level rise is important to coastal and near-shore salinity, and on 100- and 1,000-year time scales. Over the longer term (i.e. centuries), it is a key factor in determining where the tidal interface is geographically. A coastal salinity gradient may not change with sea-level rise except for moving inland. Assuming, of course, that quantity, timing, and distribution of the inflows is not significantly changed. In the context of CERP, which is on a decadal time scale, sea-level rise is not nearly as important a factor as the effect that changing fresh water deliveries to the estuaries currently has on coastal salinities. The paragraph reconstructs the historical salinities of the Bay on a millennial scale but does not include recent paleoecological information that provides good clues about salinities in the Bay in the last 150-200 years. I suggest that a slightly more detailed account of the Bay and the salinity conditions that helped trigger authorization of CERP would be more balanced and informative.</td>
</tr>
<tr>
<td>Bill Perry</td>
<td>Part 2</td>
<td>2</td>
<td>7</td>
<td>6</td>
<td>I also suggest that the focus be the stressors on the Bay, as identified by the conceptual ecological model for the Bay. In a manner similar to that of the section following that describes Biscayne Bay and its status. For Biscayne Bay, the emphasis is on nearshore salinity, which is a stressor, but inflow water quality is not mentioned. Nutrient loading to Biscayne Bay should be mentioned, and to be complete, a description of contaminant issues is also needed.</td>
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<tr>
<td>Bill Perry</td>
<td>2</td>
<td>15</td>
<td>ALL</td>
<td>This section is somewhat superficial, in that data on important stressors is either missing or sparse. There is a discussion of salinity for Biscayne Bay, but very little for Florida Bay, where hypersaline conditions in several of the basins has persisted for years. A significant algal bloom that occurred initially in Barnes Sound was described, but the fact that it persists even today (two years later) and has spread all along the bayside of the upper Keys is not clear (the Blackwater Sound bloom is mentioned in later sections). There have likely been benthic community impacts from light attenuation, but that topic was not included; it should at least be mentioned. A great deal has been written about the problems in Florida Bay; I suggest this section be revised to reflect what we now as stressors that have adversely affected the Bay for the last 50 years.</td>
<td>Another sentence was added concerning hypersalinity in north-central Florida Bay.</td>
</tr>
<tr>
<td>Bill Perry</td>
<td>2</td>
<td>24</td>
<td>6</td>
<td>This section first addresses Florida Bay water quality in terms of description of an eastern algal bloom and then Biscayne Bay in terms of salinity impacts. I suggest a clear statement of status: good, fair, poor, bad for water quality (Florida Bay) and salinity (Biscayne Bay). I also suggest that salinity condition status in Florida Bay be addressed (i.e., how it took two hurricanes in 2005 to break up hypersaline conditions in the central Bay). The prescription provided for Biscayne Bay in this section (cease the practice of 'seasonal draw downs' and holding groundwater levels high into the dry season) would also greatly benefit Florida Bay.</td>
<td>Another sentence was added concerning hypersalinity in north-central Florida Bay.</td>
</tr>
<tr>
<td>Bill Perry</td>
<td>2</td>
<td>29</td>
<td>14</td>
<td>I could not find this citation (USACE and SFWMD 2004). Should have been 1999 not 2004 (page 29, line 14 in pdf). Text has been revised to reflect this comment.</td>
<td>Should have been 1999 not 2004 (page 29, line 14 in pdf). Text has been revised to reflect this comment.</td>
</tr>
<tr>
<td>Bill Perry - Part 1</td>
<td>2</td>
<td>40</td>
<td>6</td>
<td>Pink shrimp is an extremely ecologically important species in both bays. Part of the forage base, they link primary production (and detritus) to the fisheries that make the bays economically important. Their life cycle complicates the use of densities as a biological indicator metric, however, since recruitment is governed by offshore reproduction and current-assisted immigration into rearing habitats. For areas in eastern Florida Bay, where fresh water effects have the most direct effects, lack of tidal inflows precludes the use of pink shrimp as an indicator species. For the central bay, where some larval transport exists, densities may be as much a function of the quality of larval transport as they are of benthic conditions. I suggest that in future evaluations of the status of pink shrimp that transport potential be factored into the conclusions about density.</td>
<td>This is a good suggestion that will be included in future analyses.</td>
</tr>
<tr>
<td>Bill Perry - Part 2</td>
<td>2</td>
<td>40</td>
<td>6</td>
<td>Predation rate is obviously also a factor, but that information is much more difficult to obtain. Rates likely vary depending on benthic structure; for example, predation rate in high SAV densities are probably lower that in low or sparse SAV densities. And SAV densities vary widely within and among basins/bays, so reaction to salinities are only a part of the ecology of the species. Or one could avoid the complication of interpreting juvenile shrimp density and use seasonal growth rate as a metric of salinity response instead (after factoring in temperature).</td>
<td>This is a good suggestion that will be included in future analyses.</td>
</tr>
<tr>
<td>Bill Perry</td>
<td>2</td>
<td>50</td>
<td>1</td>
<td>Juvenile Spotted Seatrout Comment: I suggest that like pink shrimp, juvenile seatrout in the western part of Fl Bay are more influenced by factors other than salinity (depth, bottom condition, predation rate), since that part of the Bay has relatively little salinity change (on average, a few psu). So I am not sure use of 'West' Bay data is kosher in comparison to central bay data.</td>
<td>Western Florida Bay data is included as it will be used to develop a General Linear Model, and because it typifies &quot;good&quot; spotted seatrout habitat, it serves as a control for analyzing trends in the central Bay.</td>
</tr>
<tr>
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</tr>
<tr>
<td>Bill Perry</td>
<td>2</td>
<td>Table 2-6</td>
<td>Table 2-6</td>
<td>Table 2-6 is very difficult to understand.</td>
<td>Table 2-6 - arrows were lost in word-to-pdf conversion. The arrows will be added back into the table.</td>
</tr>
<tr>
<td>Bill Perry</td>
<td>2</td>
<td>58</td>
<td>ALL</td>
<td>This is a fairly well-developed section that could also benefit from additional analyses of collection results.</td>
<td>Analyses are ongoing.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>8</td>
<td>23</td>
<td>Missing Kinne 1971 from citations</td>
<td>Kinne was added to references cited section.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>10-11</td>
<td>24-33</td>
<td>At the end of this section it is not clear how the above described data will be analyzed. Was the analysis a compiling of data for the multiple sources and have analysis across the multiple programs or is the discussion just being done by each research program? See comment below on how this un-clarity affects the product.</td>
<td>The methods has been greatly expanded to more fully address these issues and text has been added which states &quot;The data from both NOAA/AOML and FIU/SERC were combined and the grab samples collected at all of the stations in Fig. 2-3 were utilized to determine the status of chlorophyll a in the SE for this assessment. &quot;</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>15</td>
<td>22-24</td>
<td>The data was divided.... &quot; What data was divided - the fixed station and the monthly samples or only the grab samples.</td>
<td>The methods has been greatly expanded to more fully address these issues and text has been added which states &quot;The data from both NOAA/AOML and FIU/SERC were combined and the grab samples collected at all of the stations in Fig. 2-3 were utilized to determine the status of chlorophyll a in the SE for this assessment. &quot;</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>19</td>
<td>32-35</td>
<td>Surprisingly , the lowest ..... If this statement is to be made then there needs to be much more clearer data presented so that the reader can make an informed decision. This statement figures prominently in the conclusion and I do not feel that it is really all that clear that these finding are only due to ground water. Particularly because you can not locate the sampling site on the map (fig 2-9) and there are no values presented to back up this statement.</td>
<td>Good point. The authors agree and this statement has been removed.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>20</td>
<td>Figure 2-9</td>
<td>Must make this figure much larger and add site identification since the writing on pages 19 and 20 relate to position of these sampling locations.</td>
<td>The figure and text have been removed because it is merely a snap shot at two periods in time and thus is not a true measure of the current status.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>21</td>
<td>Figure 2-10</td>
<td>Must add error bars or SD to the graphics. Why are the values binned at 2 ppt here and the krigged figure (fig 2-9) is binned at 5 ppt. Are there biological reasons for this binning? Also the y-axis should have similar values for easier comparison across sites.</td>
<td>This figure has been removed because this section now focuses on water quality with only a brief mention of salinity; salinity is desperately in need of its own separate section as its status cannot be adequately addressed in the water quality section without both being detrimentally affected.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>22</td>
<td>3-4</td>
<td>What happen there is no transition here?</td>
<td>This has been corrected and the section now has none of the abrupt disconnects which were associated with the merging of water quality and salinity.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>22</td>
<td>Figure 2-11</td>
<td>No legend for symbols presented.</td>
<td>This figure is now better supported with an improved legend that states &quot;The Circle in Each Sub-region Displays the Current Status of Chlorophyll a, Where Yellow Circles Denote Median Concentration is Greater Than the Sub-regional Baseline Median Yet Less Than the 75th Percentile, and Red Denotes Median Concentration is Greater Than the 75th Percentile of the Baseline&quot; and there is an additional table 2-2 which displays the criteria for this analysis and a figure 2-8 which depicts the analysis for this figure.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>2</td>
<td>25</td>
<td>19-25</td>
<td>Need stronger evidence if this is going to be a conclusion of this section of the report.</td>
<td>Good point, this conclusion has been removed due to its lack of support.</td>
</tr>
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<tr>
<td>Libby Johns</td>
<td>2</td>
<td>General</td>
<td>General</td>
<td>I have looked over the Southern Estuaries Module portion of the Draft 2007 SSR, and my impression is that this is a nearly complete, comprehensive, and potentially very useful documentation of the status of the CERP restoration hypotheses for the MAP modules.</td>
<td>There is no response needed to this comment.</td>
</tr>
<tr>
<td>Libby Johns</td>
<td>2</td>
<td>General</td>
<td>General</td>
<td>My primary concern is that there does not appear to be sufficient emphasis placed on the role of salinity in the documentation of the pre-CERP condition and any potential CERP-related changes to the Southern Estuaries system. Salinity is of concern not only as an indicator of natural and/or man-made changes to the freshwater/saltwater balance of these estuaries, but it is also of great importance to virtually all of the other components of the system, including water quality and the biota. Given this important role, I recommend that salinity should be singled out from the water quality hypothesis for the next iteration of this document, form its own SE Hypothesis Cluster, and be the subject of a more careful and detailed analysis of pre-CERP conditions, and a comprehensive analysis of natural sources of change as well as CERP-related changes to this key indicator of the health of the SE ecosystem.</td>
<td>The authors completely agree with this statement and in the future, there will be a separate SE module salinity section addressing how operational activities altered the salinity.</td>
</tr>
<tr>
<td>Patrick Pitts (Part 1)</td>
<td>2</td>
<td>General</td>
<td>General</td>
<td>Although not clearly specified in the report, there are inferences that the statistical determination of change detection will rely mostly on the delta approach and that a given test year will be deemed a &quot;change&quot; if the delta-mean falls outside the 95% CI of the baseline data. Although I believe this approach can determine if a given &quot;test&quot; year is statistically different from other years, I'm still skeptical that the approach can determine if change due to CERP is occurring. I believe that the detection of change caused by CERP will probably end up being more of a qualitative assessment of ecological and physical patterns that is supported by monitoring data such as was presented in the report.</td>
<td>The authors share the concern about adequacy of monitoring. This is stated in no uncertain terms in the conclusion section of the SE Module. Regarding annual comparisons - because, for all intents and purposes, CERP impacts have not yet been realized, comparison of year to year changes here are primarily for illustrative purposes. In practice, we will be comparing values derived from multiple years versus multiple years worth of data post-CERP. We fully agree with the second point about the need to examine trends - this report contains several cases of this.</td>
</tr>
<tr>
<td>Patrick Pitts (Part 2)</td>
<td>2</td>
<td>General</td>
<td>General</td>
<td>I think it will be very difficult to use biometrics and well-defined thresholds to conclusively determine whether or not changes observed in the southern estuaries are a result of CERP. With that said, the report does integrate the delta approach statistics with biological trends and physical data, all of which is needed to help determine change. However, judgement calls (i.e., qualitative assessments) will have to be made over whether or not CERP is responsible for the change. This may be specified elsewhere in the report; if not, perhaps it should be.</td>
<td>The authors share the concern about adequacy of monitoring. This is stated in no uncertain terms in the conclusion section of the SE Module. Regarding annual comparisons - because, for all intents and purposes, CERP impacts have not yet been realized, comparison of year to year changes here are primarily for illustrative purposes. In practice, we will be comparing values derived from multiple years versus multiple years worth of data post-CERP. We fully agree with the second point about the need to examine trends - this report contains several cases of this.</td>
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</tbody>
</table>

30 October 2007
<table>
<thead>
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<tbody>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>15</td>
<td>2-3</td>
<td>How does monitoring only chl a indicate what nutrient might be problematic? Isn’t that important?</td>
<td>Yes, it is important. The proposed methodology uses chlorophyll a merely as an indicator of water quality. When chlorophyll a is above baseline a more detailed analysis is undertaken which incorporates the use of nutrient data. This enhanced detail is now included in the text and depicted in figure 2-11.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>16</td>
<td>2-5</td>
<td>It would be much easier to make sub-region comparisons if the same scale was used for all plots in the figure.</td>
<td>I agree and this change has been made to figure which is now fig. 2-4</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>18</td>
<td>2-8</td>
<td>What are the units?</td>
<td>The legend was changed to indicate that the units are parts per billion (ppb)</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>20, 25</td>
<td>ALL</td>
<td>Section 2.2 describes salinity regimes in the SE using available monitoring data but I cannot find where the report describes how the data will be used to detect changes in salinity due to CERP.</td>
<td>This was not mentioned because salinity was haphazardly included in the water quality section. This has changed so now the brief salinity discussion is in the water quality section discussion and this question is addressed. In the future, there will be a separate salinity section with the primary goal of answering how CERP has altered the salinity regime.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>22</td>
<td>4-11</td>
<td>Shouldn’t this be part of Section 2.2.3 since it is the chl a methods and analysis? Why is it in the salinity section?</td>
<td>The authors agree and the text was revised.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>24 and 25</td>
<td>21 (page 24) and line 1 (page 25)</td>
<td>So, how will we know what might drive future blooms if we only monitor or analyze chl a?</td>
<td>Chlorophyll a analysis is emphasized because it is an indicator of water quality. The monitoring of other water quality variables is essential to explain why these blooms occur and we utilize this data when chlorophyll a is significantly elevated from background. The authors are in no way suggesting only chlorophyll a is being monitored.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>25</td>
<td>11-16</td>
<td>I don’t see where the data in the table supports these statements, even though I agree with them.</td>
<td>The authors agreed and this statement has been removed.</td>
</tr>
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<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>25</td>
<td>20-21</td>
<td>The report does not specify how salinity data will be used to detect change.</td>
<td>This was not mentioned because salinity was haphazardly included in the water quality section. This has changed so now the brief salinity discussion is in the water quality section discussion and this question is addressed. In the future, there will be a separate salinity section with the primary goal of answering how CERP has altered the salinity regime.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>25</td>
<td>25-26</td>
<td>I agree, but how will this be tested?</td>
<td>The text has been revised because it was too speculative in nature.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>25</td>
<td>Figure 2-3</td>
<td>This table is very confusing. How was the analysis conducted to produce the table? Why was one area chosen for evaluation on a given month and a different area chosen for evaluation on another month (this makes comparisons impossible)? How does average monthly discharges for all canals relate to a given location (e.g., wouldn’t September discharges through only S-21A and S-20G be relevant for Fender Point)? How is this used in the big picture of detecting change?</td>
<td>This comment is confusing because it refers to a figure but talks about a table. More clarification from the reviewer is needed before the comment can be considered.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>33</td>
<td>12-16</td>
<td>The graphs in Figure 2-18 do not show the statistics necessary to warrant the statement that “the delta-mean significantly differed in 2006?”. Also, 2006 may differ from the mean, but it follows or is consistent with the trend for both species.</td>
<td>The text in this section actually referred to figure 2-17, not 2-18. The text has been revised to reflect this change.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>33</td>
<td>12-15</td>
<td>So, is change detection for SAV determined by the &quot;test&quot; year being outside the 95% CI of the baseline? Do all 3 delta parameters (concentration, occurrence, delta-density) have to fall outside the 95% CI for change to be deemed to have occurred or can only one or two of those parameters suffice?</td>
<td>Change in SAV is considered statistically significant when the delta-density for the &quot;test&quot; year is outside the 95% CI of the delta-mean (i.e. average delta-density values) for the &quot;baseline&quot; years. The authors have tried to clarify this issue by editing the text in several locations as well as editing the symbol legends in figures 2-17 and 2-20, and the y-axis title in figure 2-18 c to reflect the definitions of delta-density and delta-mean described in the text. These figures are on the FWRI FTP site which can be accessed at: ftp://ftp.floridamarine.org/users/har/Penny/</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>33</td>
<td>15-16</td>
<td>The interpretation seems flawed. The 2006 concentration for Halodule is numerically greater than the previous 2 years.</td>
<td>The text in this section was actually referring to figure 2-17, not 2-18. The text has been revised to reflect this change.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>34</td>
<td>2-18</td>
<td>Although the report does not indicate that 2006 is statistically significantly different from the baseline, it appears to be the case from the figure. An important consideration that was not addressed is: Why is this occurring? CERP is not a factor yet.</td>
<td>Change in SAV is considered statistically significant when the delta-density for the &quot;test&quot; year is outside the 95% CI of the delta-mean (i.e. average delta-density values) for the &quot;baseline&quot; years. The authors have addressed possible causes for the changes in SAV on page 34 (lines 7-15) in the pdf.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>34</td>
<td>12-15</td>
<td>But what, if anything, is the threshold for whether or not change is occurring?</td>
<td>For this exercise, the threshold for determining change is when the delta-density of the &quot;test&quot; year exceeds the 95% CI for delta-mean of the &quot;baseline&quot; years.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>36</td>
<td>Figure 2-20</td>
<td>The statistics panels seem appropriate and I'm wondering why these statistics were not shown for Johnson Key Basin?</td>
<td>The authors feel that figures 2-20 and 2-21 sufficiently illustrate the data and support the conclusions regarding Blackwater Sound.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>36</td>
<td>Figure 2-20</td>
<td>The panels need to be larger; it is impossible to read the legends on my hardcopy.</td>
<td>The authors agree with this statement with regards to the SEM SAV section. The authors have placed a file with original figures on the FWRI FTP site which can be accessed at: ftp://ftp.floridamarine.org/users/har/Penny/</td>
</tr>
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</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>37</td>
<td>6-7</td>
<td>So, if a given year delta-mean falls outside the 95% confidence level. does that mean change has occurred?</td>
<td>In practice, we will be comparing values derived from multiple years versus multiple years after CERP-related changes have occurred. Post-CERP values that fall outside 80% CIs will be deemed significantly different.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>37</td>
<td>6-7</td>
<td>Can more than 1 &quot;test&quot; year be used in the analysis (e.g., 1995-96 tests years compared to 1995-2004 baseline)?</td>
<td>Yes, in practice, we will be comparing values derived from multiple years versus multiple years after CERP-related changes have occurred. Post-CERP values that fall outside 80% CIs will be deemed significantly different.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>41</td>
<td>5-6</td>
<td>It seems unrealistic to think that pink shrimp maxima in Biscayne Bay or SW Florida will coincide in time with the maximum occurring in Johnson Key Basin. What is the rationale for that belief?</td>
<td>All nursery locations reflect the seasonal variation in spawning and recruitment of post-larvae. Sampling in Florida Bay, SW FL, and Biscayne Bay indicate that the seasonal patterns of abundance of small pink shrimp is the same in all these areas. The late summer-fall peak of abundance is the same across all of South Florida.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>48</td>
<td>4-5</td>
<td>The text refers to “three” species that use the SE as nursery habitat, although 4 are listed. I believe rainwater killifish uses the SE for its entire life cycle, so it isn’t really a nursery species.</td>
<td>This revision has been made (change from 3 to 4 species).</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>48</td>
<td>2-16</td>
<td>This is repeated almost verbatim from Section 2.4.1. Perhaps is could be deleted.</td>
<td>The repetition text/phrasing between the Abstract at the beginning of Section 2.4.1 and this section (beginning of section 2.4.4) is not inappropriate.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>48</td>
<td>Figure 2-27</td>
<td>The figure and accompanying text shows an interesting relationship between salinity and gray snapper occurrence/concentration. How does this relate back to the 5 nursery habitat hypotheses?</td>
<td>Text has been inserted to relate the gray snapper abundance-salinity relationship to the nursery hypothesis.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>49</td>
<td>Figure 2-28</td>
<td>The figure included the data included all gray snapper collected (i.e., all size classes). It would be interesting to see how that salinity relationship might look if only the juvenile size classes (e.g., &lt;15 cm TL) were used. Perhaps this might be more relevant to the CERP hypotheses.</td>
<td>This is a good suggestion for future analyses. Because size distributions are derived from visual estimates of minimum, mean and maximum values per sample, the suggested analysis can be conducted, but only with additional assumptions that require further consideration and testing.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>48-49</td>
<td>ALL</td>
<td>Using the visual assessment, it is unclear how change will be detected?</td>
<td>Text has been modified to include: Fish abundance changes will be detected by comparing values (and their variances) for each metric that are derived from multiple years before versus after CERP-related changes.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>51</td>
<td>Figure 2-30</td>
<td>What are numbers in parentheses? Are bars standard deviation or standard error?</td>
<td>A legend was added to Figure 2-30.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>52</td>
<td>Table 2-6</td>
<td>I do not understand this table. Table 2-6 - arrows were lost in word-to-pdf conversion. The arrows will be added back into the table.</td>
<td>Table 2-6 - arrows were lost in word-to-pdf conversion. The arrows will be added back into the table.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>54</td>
<td>6-13</td>
<td>What does this mean for detecting and responding to change in these two sampling areas? Does it mean that monitoring should continue in both because of the 2005 and 2006 differences despite their close proximity?</td>
<td>This graphic illustrates baseline values with variance against which future values can be compared. Monitoring should continue in these two basins as they are ecologically different.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>54</td>
<td>18-19</td>
<td>This sentence needs to be fixed.</td>
<td>Text was revised to address this comment.</td>
</tr>
<tr>
<td>Name</td>
<td>Section</td>
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<td>Line</td>
<td>Comment</td>
<td>How is the Comment Resolved</td>
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</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>Page 56, lines 6-11 and Page 57 lines 1-2, Figures 2-34 and 2-35</td>
<td>see cell to left</td>
<td>Shouldn’t these findings be related back to the CERP hypotheses for Nursery Habitat?</td>
<td>Text has been added to relate findings back to the CERP hypotheses.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>63</td>
<td>2-4</td>
<td>So, is the threshold for change determination reached when the test year falls outside 95% CI of the baseline data? If so, then this should be stated. If not, then how will change detection be determined for pink shrimp and rainwater killifish?</td>
<td>The examples in this report are largely illustrative because CERP-related changes have not transpired.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2</td>
<td>65</td>
<td>Figure 2-44</td>
<td>Panels in the figure should be larger so the x-axis is legible.</td>
<td>The authors have enlarged the fonts and the graphs to make them more readable.</td>
</tr>
<tr>
<td>Patrick Pitts</td>
<td>2.5</td>
<td>68-69</td>
<td>ALL</td>
<td>I agree completely with all the conclusions in this section.</td>
<td>The authors are glad the reviewers agrees with them, as well as the PIs in the SE Module.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>2</td>
<td>ALL</td>
<td>ALL</td>
<td>Big-picture comment is that the majority of figures were not legible - especially those that were shrunk so small that the reader couldn't visualize the information.</td>
<td>The authors have enlarged the fonts and the graphs to make them more readable.</td>
</tr>
<tr>
<td>Name</td>
<td>Section</td>
<td>Page</td>
<td>Line</td>
<td>Comment</td>
<td>How is the Comment Resolved</td>
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</tr>
<tr>
<td>Greg Graves</td>
<td>3</td>
<td>228</td>
<td>41-43</td>
<td>Reword to convey intended meaning – “Since measurements of dissolved oxygen are performed during optimal photosynthetic conditions (i.e., during daylight), the dissolved oxygen levels can be assumed to be lower during periods of the diel cycle when respiration is dominant (i.e., at night).”</td>
<td>Text has been revised.</td>
</tr>
<tr>
<td>Greg Graves</td>
<td>3</td>
<td>256</td>
<td>40-42</td>
<td>Same rewording advised as above</td>
<td>Text has been revised.</td>
</tr>
<tr>
<td>Liberta Scotto</td>
<td>3</td>
<td>103</td>
<td>26-27</td>
<td>&quot;Spat recruitment in all estuaries occurred between March-November months, with peak recruitment occurring between June-November (Figure 3-12).&quot; The statement pertaining to recruitment may only be true for the west coast of Florida. Please check on the east coast recruitment to verify those months. If recruitment in earlier on the east coast, the document must state that so water managers and ecologists make informed decisions.</td>
<td>Data does not indicate earlier recruitment on the east coast. Text as written is accurate and no change was made.</td>
</tr>
<tr>
<td>Liberta Scotto</td>
<td>3</td>
<td>105</td>
<td>Figure 3-13</td>
<td>This is a lot of data and consideration should be given to showing east coast and west coast on different graphs to distinguish sites due to scale.</td>
<td>We intentionally combined east and west coast sites to cut down on the number of tables and to compare the two side by side. No change was made.</td>
</tr>
<tr>
<td>Liberta Scotto</td>
<td>3</td>
<td>109</td>
<td>Figure 3-15</td>
<td>This is also a lot of data and consideration should be given to showing east coast and west coast on different graphs to distinguish sites.</td>
<td>We intentionally combined east and west coast sites to cut down on the number of tables and to compare the two side by side. No change was made.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>137</td>
<td>3-4</td>
<td>Replace the first sentence with “The NE Fish Sub-Team recommended that monitoring of fish populations in the NE begin immediately in order to establish baseline conditions prior to CERP-related changes. Monitoring would be conducted with standard techniques (e.g., seines and trawls) that are currently being used in various systems throughout Florida, with innovative techniques being tested and implemented alongside standard techniques.”</td>
<td>FOR ALL COMMENTS ADDRESSING THE FISH SECTION - modification of text was initially done to reflect comments. During the final revisions by the MAP Module Lead, most comments became obsolete because many of the tables and much of the text was deleted because the section was entirely too lengthy.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>137</td>
<td>8-9</td>
<td>Replace &quot;where seine and trawl nets could not be used with &quot;where salinity was low enough to permit the use of this technique.&quot;</td>
<td>See comment #114. Did not replace text, but added the suggested wording.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>137</td>
<td>26-27</td>
<td>Change item number 3 to &quot;Distribution, abundance, size-frequency, species composition, and general health of juvenile and small-adult fish be monitored in areas affected by CERP-related activities, such as tidal rivers and estuarine areas affected by tidal rivers.** (note: I followed the format of the other items, but it seems awkward to me. Is this an acceptable format for PMs?)</td>
<td>See comment #114. Change made to capture intent of re-wording.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>137</td>
<td>33</td>
<td>Delete &quot;fish can give”; insert after &quot;(PM):&quot; “based on fish communities can be integrated into”; delete “as part of”.</td>
<td>See comment #114. Change made as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>137</td>
<td>39</td>
<td>Delete &quot;cryptic”; after “small” insert “, primarily resident”</td>
<td>See comment #114. Change made as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>137</td>
<td>40</td>
<td>Insert after &quot;larger&quot;: ”, primarily transient”</td>
<td>See comment #114. Change made as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>138</td>
<td>18</td>
<td>Replace sentence beginning with “The state’s…” with: &quot;The Fisheries-Independent Monitoring (FIM) program of the Florida Fish and Wildlife Conservation Commission (FWC) is collecting continuous, long-term (extending back to 1988 or 1989 in some estuaries) data on fish communities in various Florida estuaries, but only a portion of those data collected in southern Indian River Lagoon and southern Charlotte Harbor are directly applicable to CERP.”</td>
<td>See comment #114. Some modification was done based on the comment. Additional details were deleted entirely.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>138</td>
<td>20</td>
<td>Insert before “There is virtually no…”: “Other than the FIM data.”</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Name</td>
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<td>Page</td>
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</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>138</td>
<td>24-25</td>
<td>Delete “associated with Everglades management and restoration efforts”</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>138</td>
<td>25-26</td>
<td>Replace sentence beginning with “It was not until 2003…” with: “Beginning in 2003, the South Florida Water Management District (SFWMDD) and the FWC funded extensive (71 samples per month) juvenile-fish monitoring in the Caloosahatchee River/southern Charlotte Harbor system, and beginning 2005, the these same agencies funded extensive (34 samples per month) monitoring in Estero Bay. However, long-term funding has not been secured for either of these monitoring efforts, and they will both cease in mid-2007 without additional funding.”</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>138</td>
<td>32</td>
<td>Delete “post-larval and”.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>140</td>
<td>5</td>
<td>Insert after “obvious”: “changes in”.</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>140</td>
<td>21-22</td>
<td>Replace sentence beginning with “This work...” with: “This work has shown promise in defining associations between freshwater inflow and the distribution and abundance of fishes.”</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>140</td>
<td>24</td>
<td>Delete “cryptic”.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>140</td>
<td>25</td>
<td>Insert before “often”: “are”, replace “reveal greater sensitivity” with: “more sensitive”.</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>140</td>
<td>26</td>
<td>Replace “such as” to “conditions” with: “than are adults of larger species”.</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>142</td>
<td>16</td>
<td>Delete “burrowing”.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>142</td>
<td>19</td>
<td>Insert after “integrity”: “(IBI)”.</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>143</td>
<td>2-3</td>
<td>Replace with: “An IBI based on pre-CERP data may be used to define the reference state for NE fish communities and to assess CERP-related changes.”</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>143</td>
<td>16-17</td>
<td>Replace with: “3. Distribution, abundance, size-frequency, species composition, and general health of juvenile and small-adult fish be monitored in areas affected by CERP-related activities, such as tidal rivers and estuarine areas affected by tidal rivers.”</td>
<td>See comment #114. Text was changed with minor revision to rewording.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>143</td>
<td>21</td>
<td>Replace “has targeted” with: “estimates that”, delete “(Table 3-12) that”.</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>143</td>
<td>23</td>
<td>Insert after “diversity. “: “These species include numerous planktivores (including planktivorous larvae of some species), substrate-associated predators/detritivores, and top carnivores. At least 36 of these species are of direct economic importance.”</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>143</td>
<td>36</td>
<td>Delete Table 3-12.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>150</td>
<td>Table 6-1</td>
<td>Body of table: 6.1-m trawl did not make it into table; it would sample main river channel, bottom and estuarine channel.</td>
<td>See comment #114. Text has been revised.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>151</td>
<td>4</td>
<td>Delete reference to Table 3-12 if table is deleted as I recommend.</td>
<td>See comment #114. The details have been deleted.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>154</td>
<td>4-5</td>
<td>Delete “randomly selected” from line 4; replace “183-m haul seine” with “183-m, 38-mm-mesh haul seine”; insert after “haul seine.” in line 5: “As in all FIM sampling, sample site selection is based on a stratified-random design.”</td>
<td>See comment #114. The details have been deleted.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>154</td>
<td>7-8</td>
<td>Replace everything after “gear types,” in line 8 with: “21.3-m, 3.2-mm-mesh seines; 183-m haul seines; and 6.3-m otter trawls with 3.2-mm-mesh, cod-end liners.”</td>
<td>See comment #114. The details have been deleted.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>154</td>
<td>9</td>
<td>Replace “The St. Lucie and southern Indian River lagoon FIM collections do not emphasize early life history stage monitoring, but do” with “Because the 183-m haul seine targets larger juvenile and adult fish, the St. Lucie and southern Indian River Lagoon FIM program does not collect smaller juvenile fish, but it does...”</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
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<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>154</td>
<td>11</td>
<td>Replace &quot;data has&quot; with &quot;data have.&quot;</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>154</td>
<td>17-20</td>
<td>Delete entire paragraph</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>157</td>
<td>4</td>
<td>Replace &quot;several juveniles&quot; with &quot;juveniles of several&quot;</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>161</td>
<td>6</td>
<td>A section heading seems to be missing, perhaps &quot;3.5.4.2 Results/Discussion-Juvenile and Small-Adult Fish Communities&quot;</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>161</td>
<td>15</td>
<td>Insert after &quot;responses to flow&quot;: &quot;in some species&quot;.</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>161</td>
<td>29-30</td>
<td>Delete sentence beginning with &quot;Before an exhaustive inflow...&quot;</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>162</td>
<td>10-15</td>
<td>Replace &quot;young-of-the-year and juvenile fishes&quot; with &quot;small-bodied species and juveniles of large-bodied species&quot;</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>162</td>
<td>43</td>
<td>Replace &quot;young-of-the-year, juvenile, and adult fish&quot; with &quot;juveniles to adults of various species&quot;</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>162</td>
<td>44</td>
<td>Replace &quot;sub-adult and adult fish&quot; with &quot;sub-adults to adults of larger species&quot;</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>163</td>
<td>6-7</td>
<td>The &quot;Deployment&quot; column changes from habits sampling to methodology. For the 183-m seine it should read &quot;Bay and River&quot; and for the 6.1-m trawl it should read &quot;Bay and River&quot;</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>163</td>
<td>10-15</td>
<td>Replace first three sentences of paragraph with &quot;Stratification parameters used in the scheme for sample site selection included depth (all gears), presence of overhanging vegetation (seines only), presence of submerged aquatic vegetation (seines only), longitudinal river subzones (all gears), and river main stem versus backwater (small seine only).&quot;</td>
<td>See comment #114. The entire paragraph was deleted because there was too much detail included.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>164</td>
<td>3</td>
<td>Begin new paragraph.</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>164</td>
<td>28-31</td>
<td>Reword sentence beginning with &quot;Sixty-seven...&quot;, it is currently very unclear.</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>164</td>
<td>31</td>
<td>delete (&quot;Tables 3-20, 3-21, 3-22&quot;)</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>164</td>
<td>35-37</td>
<td>Reword sentence because something seems to be askew; three groups are included but the word &quot;both&quot; is used</td>
<td>done</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>165-172</td>
<td>ALL</td>
<td>Delete tables 3-18 and 3-19.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>174-183</td>
<td>ALL</td>
<td>Delete tables 3-20, 3-21, and 3-22 and insert summaries of Table information and reference to report where more detailed information can be found.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
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</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>174</td>
<td>ALL</td>
<td>Body of table: the crested pipefish was not collected and should be deleted (if table is not deleted)</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>176</td>
<td>ALL</td>
<td>Body of table: the crested pipefish was not collected and should be deleted (if table is not deleted)</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>179</td>
<td>ALL</td>
<td>Body of table: the crested pipefish was not collected and should be deleted (if table is not deleted)</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>184</td>
<td>11-12</td>
<td>Something is wrong with the beginning of this sentence, probably needs to begin with &quot;In&quot; or &quot;Based on&quot;.</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>184</td>
<td>11-19</td>
<td>Most of the comparisons in the paragraph have little meaning because sampling effort is not taken into account. All comparisons should be based on density numbers as presented in Table 3-21. Perhaps this entire section could be deleted because the &quot;Seagrass Fish Productivity – Densities&quot; section is more meaningful (but see comments below regarding this section).</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>185</td>
<td>11</td>
<td>Delete reference to Table 3-20 if table is deleted.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>185</td>
<td>7-17</td>
<td>Much of this paragraph will need rewording if tables are eliminated.</td>
<td>See comment #114. Tables have been deleted and rewording completed.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>185</td>
<td>16-17</td>
<td>I am not sure what &quot;Over 44% of these species&quot; refers to; needs rewording.</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>186-187</td>
<td>ALL</td>
<td>Table 3-23 can probably be eliminated, but if it is retained, I would delete the categories in bold type (e.g., &quot;PIPEFISH;SEAHORSES&quot;); they are incomplete, misleading, and unnecessary.</td>
<td>See comment #114. Deleted as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>188</td>
<td>ALL</td>
<td>Entire section: I do not know why acres were used here instead of square meters.</td>
<td>See comment #114. Text was changed as suggested.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>188</td>
<td>3</td>
<td>Delete reference to Table 3-21 if it is deleted.</td>
<td>See comment #114. Table has been deleted.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>188-189</td>
<td>ALL</td>
<td>Although I do not dispute the fact that seagrass loss is a serious problem, the temporal comparisons in this section can be very misleading. The comparisons involving all species combined are very misleading because the three most abundant species captured in 1974 were anchovies, which are distributed in a very patchy manner and are planktivores with little association with seagrass. The remaining comparisons suffer from small sample size and limited geographic coverage. These limitations should at least be acknowledged.</td>
<td>See comment #114. The comparisons and synthesis were performed by the lead PI and thus left as written. No change was made.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>189</td>
<td>20-32</td>
<td>Information in the paragraph appears to conflict with information in Table 3-13, which indicates that DIDSON can be used to identify juvenile fish.</td>
<td>See comment #114. The information included in Table 3-13 was checked and changed as needed.</td>
</tr>
<tr>
<td>Ed Matheson</td>
<td>3</td>
<td>General</td>
<td>General</td>
<td>The names of the following species should be standardized throughout the document. Currently some of them are misspelled, are in the wrong families, or are not standardized among various sections of the document. If some of my recommendations for deletion of tables are implemented, then some of these names may no longer appear in the document. Recommended names are based on the List of Common and Scientific Names published by the American Fisheries Society.</td>
<td>The tables were deleted.</td>
</tr>
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</tr>
<tr>
<td>Patrick Pitts</td>
<td>3</td>
<td>General</td>
<td>General</td>
<td>Generally, the report is well written and the information provided ties directly to the purpose of the report. However, I found a few instances where the data did not support the text or the methods did not seem to relate well to change detection.</td>
<td>This comment has been noted. Where possible, changes were made to ensure that data did support the text and methods related well to change detection. Specific examples would have helped identify these instances.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>3</td>
<td>ALL</td>
<td>ALL</td>
<td>Big-picture comment is that the section is far too long. By dwarfing the other sections, the reader gets lost and misses the big-picture intent of the SSR.</td>
<td>The MAP Module Lead agreed with the comment; many data tables and excessive text were deleted.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>3</td>
<td>ALL</td>
<td>ALL</td>
<td>Presenting raw data was not the intention of the SSR - these types of data (including the appendices) are better suited for PI reports, or some other vehicle.</td>
<td>The MAP Module Lead agreed with the comment; many data tables and excessive text were deleted.</td>
</tr>
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30 October 2007
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Kevin Whelan</td>
<td>4</td>
<td>322-324, also 340</td>
<td>on pg 240, line 1</td>
<td>Overall the information is plausible; however, I would suggest that since the linking of wading bird colony distribution and number of nests to the fish standing crop is a critical goal of CERP, that there actually is some type of analysis besides the graphical rendering from the two datasets. For example, I could see an analysis that looked at the krigged fish crop data from around a bird colony location (some circular distance based on biological data i.e. average flight distance to forage) and determining maximum, mean, variance in fish standing crop and relating this to bird colony metrics.</td>
</tr>
<tr>
<td>Kevin Whelan</td>
<td>4</td>
<td>335</td>
<td>11-15</td>
<td>I would suggest more explanation on how less salt water intrusion translates to greater number of crocodile nests. Is it better nesting area or greater crocodile survival of young from the year previous? In Fig 4-19 there is an increase in crocodilian nest numbers in Everglades National Park for 2006 but this is the sixth year of increases. So there is a positive trend in numbers that can be linked by a BACI type analysis to a management action (I am assuming East Cape canal was plugged in 2000). This is a success that needs to be supported more strongly as a positive reaction to a management decision instead of just citation to an Army Corp report.</td>
</tr>
<tr>
<td>Jed Redwine</td>
<td>4</td>
<td>291</td>
<td>30-31</td>
<td>“Periphyton monitoring also contributes to the working hypothesis that the floating mat comprised of the periphyton complex and various bladderworts provides critical support of the oligohaline Everglades food web,...” could be characterized more clearly. I would phrase it like this: “Research and monitoring of periphyton communities suggests that floating mat formations of periphyton formed around several common submerged aquatic species (particularly Utricularia spp.) are keystone habitats that support the oligotrophic Everglades food web.” The use of the word oligohaline (moderate salinity) is incorrect, oligotrophic (low nutrient levels) is the appropriate word. This correction was confirmed by Evelyn Gaiser who stated: “Oligohaline communities do not support Utricularia spp. because they are freshwater obligate submerged aquatic macrophytes.</td>
</tr>
<tr>
<td>Jed Redwine</td>
<td>4</td>
<td>296</td>
<td>12-13</td>
<td>Should read: “...Ecological processes and attributes in the mangrove coastlines of the southern Everglades are proximately controlled by interactions....”</td>
</tr>
<tr>
<td>Jed Redwine</td>
<td>4</td>
<td>304</td>
<td>45</td>
<td>“Another useful property of the GRTS design is that any subset of samples 1-N is itself spatially balanced.” - for this to be true, N must be a number between 0 and 1. As written, it is unclear what N represents, and therefore difficult to understand what is meant to be communicated by this passage.</td>
</tr>
<tr>
<td>Jed Redwine</td>
<td>4</td>
<td>311</td>
<td>7</td>
<td>Figure 4-7 does not indicate the location of these named regions (L-28, Bear Island, Raccoon Point, Lower Shark, 10 River, Mid-Harney River, Tarpon Bay, and Big Sable Creek).</td>
</tr>
<tr>
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</tr>
<tr>
<td>Jed Redwine</td>
<td>4</td>
<td>331-332</td>
<td>41-43</td>
<td><strong>Initial power analysis showed effects of area on body condition can be detected and additional analyses on the relationship to time and hydrology are underway. While body condition varies across areas and years, the hypothesis states that sustained increases in body condition should occur once the feedback loop of increased alligator populations and alligator holes leads to increased aquatic fauna density.</strong> a. I would substitute the term “marsh location” for “area” in this passage and in the remainder of the document. I wonder whether body condition can be used to detect integrated differences in the quality of the marsh habitat. What are the implications of the lack of difference between canals and marsh habitats in 2005 and 2006? Are canals considered good habitat as a result? This section needs detail and discussion to clarify these issues. I suspect that there are reports or publications available that could support this discussion.</td>
</tr>
<tr>
<td>Jed Redwine</td>
<td>4</td>
<td>331-332</td>
<td>41-43</td>
<td><strong>Initial power analysis showed effects of area on body condition can be detected and additional analyses on the relationship to time and hydrology are underway. While body condition varies across areas and years, the hypothesis states that sustained increases in body condition should occur once the feedback loop of increased alligator populations and alligator holes leads to increased aquatic fauna density.</strong> a. I would substitute the term “marsh location” for “area” in this passage and in the remainder of the document. I wonder whether body condition can be used to detect integrated differences in the quality of the marsh habitat. What are the implications of the lack of difference between canals and marsh habitats in 2005 and 2006? Are canals considered good habitat as a result? This section needs detail and discussion to clarify these issues. I suspect that there are reports or publications available that could support this discussion.</td>
</tr>
<tr>
<td>Jed Redwine</td>
<td>4</td>
<td>General</td>
<td>General</td>
<td>This report needs to provide insight into detectability of alligators and crocodiles. It is OK if we do not yet have a process to estimate a probability distribution around the scores of number of nests (perhaps we believe that all of the nests are found and counted each year), but we need to at least discuss the issue and provide prospective guidance for how we could address it in the future. This would help the discussion of alligator and crocodile monitoring programs match the progress made in the fish, crayfish, periphyton and plant monitoring programs, and is an opportunity to highlight an adaptive management approach.</td>
</tr>
</tbody>
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30 October 2007
### 2007 Assessment Team System Status Report

#### Comment-Response Table for RECOVER RLG Review

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<tr>
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</table>
| Jed Redwine    | 4       | 339  | 7-10 | “It must be recognized that the processes to complete the statistical analysis of this integration are currently undefined and will require an iterative and interactive process between the various scientists and agencies.”  
  a. This statement provides an excellent location in the report to develop a table of the status of statistical analysis and conceptual orientation of each of the hypothesis clusters.  
  Hopefully this table could clearly identify what clusters are in need of what type of analytical facilitation, what is analyzed already, what remains to be done, and what types of adaptive approaches are on the horizon to improve the monitoring program. | A table indicating the status of each hypothesis cluster was located within the Appendix and has been moved to the introduction of the document. The authors believe that along with results, this SSR Update provides the reader with the current status of the analyses.  
Unfortunately, an in-depth assessment of future statistical analytical needs is not probable given the time frame of this update and that RECOVER is currently undergoing a MAP refinement process that could affect this evaluation. |
| Jed Redwine    | 4       | General | General | This report needs a bibliography, and an online library of cited papers in a pdf format to ensure that readers can evaluate for themselves whether the conclusions drawn are appropriate. | A complete list of references cited was provided at the end of the section. The authors regret that they are unable to provide copies of all cited references due to possible copyright infringement |
| Matt Harwell   | 4       | ALL  | ALL  | Big-picture comment is how obvious it is that this section was done differently than the others. The very abbreviated text with figures fell far short of expectations. That being said, this section came the closest to reaching the objectives of the SSR - namely presenting the status of hypothesis clusters. As with the other sections, though, the GE section failed to tie the findings back to the clusters at the end. | We agree with the reviewer that the approach to provide a visual integration of the data was successful in presenting the data as related to the hypothesis clusters and not as results of individual monitoring efforts. The authors respectfully disagree that the text was abbreviated and believe that the discussion of the data adequately describes the finding for each cluster. |
| Matt Harwell   | 4       | ALL  | ALL  | WCA-1 needs to be renamed A.R.M. Loxahatchee National Wildlife Refuge, or LNWR or Refuge. While this appears to be semantic, the distinction is not. The State wants to refer to the area as WCA-1 because of political reasons, whereas LNWR or Refuge is not only technically correct. It provides the appropriate perspective of the presence of federal lands (and their special protection) in the GE correctly. | The authors utilized WCA-1 as opposed to A.R.M Loxahatchee National Wildlife Refuge when referring to the northern most portion of the remnant Everglades in an effort to be consistent with the naming convention used throughout MAP Part 1 and Part 2. However, we agree some recognition to this area's status as a federal refuge is important and have added a sentence to denote this standing. |
| Matt Harwell   | 4       | ALL  | ALL  | This module section had the largest work plan, but the smallest number of pages. A major disappointment to the general reader that waited all the way until p. 280 to learn about the health of the greater Everglades. | The authors respectfully disagree that page number is an appropriate measure of content. Additionally, the overall report format was determined by the Integrative Assessment Team (IAT) and not the module authors. |
## SECTION 5 - LAKE OKEECHOBEE MODULE

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<tr>
<td>Betty Grizzle</td>
<td>5</td>
<td>355</td>
<td>12-21</td>
<td>Some suggestions for a more landscape (and historic) perspective of the lake: Part 1 - Historically, Lake Okeechobee was an important natural hydrologic link between the drainage basin north of the lake and the sawgrass marshes and prairies of the Everglades to the south. The ability of the lake to provide a large volume of water storage allowed for moderation of the effects of wet-dry rainfall cycles on water levels in the Everglades (NRC 2005). Additionally, prior to drainage and other watershed modifications, the ability of the lake to hold large volumes of water was complimented with the natural storage of wetlands in the upper part of the basin and the relatively slow flow of the historic meanders of the Kissimmee River to dampen the effects of the amount and distribution of water within the basin (NRC 2005).</td>
<td>Text has been amended/expanded to address comments as requested.</td>
</tr>
<tr>
<td>Betty Grizzle</td>
<td>5</td>
<td>355</td>
<td>12-21</td>
<td>Part 2 - Research conducted by McVoy supports the idea that sawgrass vegetation occurred in what is now called the Okeechobee marsh and that this plant community directly bordered the lake (C. McVoy, personal communication). Heilprin’s (1887, p. 413) account in 1886 stated that “…for the greater part of the west coast [of the lake], there is necessarily no true shore” and “…the growth of saw-grass or flag terminat[ed] rather abruptly.” The historic presence of this shoreline community has direct relevance to historic lake stages given that water depth requirements to support a sustained sawgrass community represent a constraint on lake levels and strongly suggests an 8- month hydroperiod for this area. McVoy believes that lake stages in the wet season would normally rise up to 2 feet in the wet season (above the ground surface) and fall up to a 1 foot at the end of the dry season since anything higher would have converted the sawgrass community to slough-like vegetation and anything lower would have resulted in a more woody-type community.</td>
<td>Text has been amended/expanded to address comments as requested.</td>
</tr>
<tr>
<td>Betty Grizzle</td>
<td>5</td>
<td>355</td>
<td>12-21</td>
<td>Part 3 - Others have also commented on the development of the current Okeechobee marsh. Pesnell and Brown (1977, p.4) stated that “The vegetation that now exists as the littoral zone of Lake Okeechobee has developed as a response to post drainage lake stages” and that most of this vegetation was located outside the location of the current levee “as a consequence of predrainage hydrological conditions.” Richardson and Harris (1935) also stated that this marsh system developed after the lowering of water levels (due to levee systems, control structures, etc.) in both the Everglades and in the lake over the past 100 years. The relative consistent lake stages since the levee construction and implementation of drainage features have therefore provided the hydrologic conditions for the development of the current littoral zone plant communities, consisting of emergent, floating, and submersed macrophytes.</td>
<td>Text has been amended/expanded to address comments as requested.</td>
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**Comment-Response Table for RECOVER RLG Review**

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<tr>
<td>Betty Grizzle</td>
<td>Part 4</td>
<td>5</td>
<td>355</td>
<td>Part 4-I disagree with the statement that the dike limited the extent of the lake’s “historic” littoral zone. The western and southwestern border of the historic lake was sawgrass vegetation. The Everglades Foundation and others have located historical maps, including one based on 1926 aerial photos, which indicate illustrate this sawgrass marsh zone as does a phytogeographic map from 1913. These maps (which we have geo-rectified to illustrate the location of the current dike) also show that the dike did not, to a significant degree, reduce the size of the lake, though water levels have been maintained at much lower levels than the estimated historic high stage for the lake at around 22.5 feet and a low stage of 19 feet by Wright in 1909 (Wright 1911). Also, the pre-drainage overflow from the lake to the south (up to 70 miles in width in the wet season) was extensive and McCoy and Fennema have calculated the volumes and rate of these flows.</td>
<td>Comment from Wright incorporated. Remainder of comment contradicts comment provided above (Pesnell and Brown “most of vegetation outside location of current levee” being cutoff) and also contradicts other references in same section (Aumen, 1995; Richardson and Harris, Havens and Gawlik, 2005). Peer-reviewed literature, therefore, suggests that dike has limited the historical littoral zone given in the same section. The matter of whether or not the dike reduced or did not reduce the extent of the littoral zone is immaterial to the purposes of the SSR, i.e., restoration proceeds forward from what we have now and what is possible given the current limitations and constraints. The authors respectively decline to address this issue.</td>
</tr>
<tr>
<td>Greg Graves</td>
<td></td>
<td>5</td>
<td>360</td>
<td>This entire line should be deleted: As a real-world check, estimated slopes from significant trends substantially different from zero were conservatively examined in a plot against a backdrop of the time series in question.</td>
<td>Deletion has been made as suggested.</td>
</tr>
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<tr>
<td>Greg Graves</td>
<td>5</td>
<td>374</td>
<td>9-11</td>
<td>It is incorrect, and should read: <strong>Figure 5-15</strong>: Mean monthly stage data (in black) in feet above mean sea level, 1988 through 2006. Desired recession rates from January high of 15.5 to June low of 12.5 (in red) provided as reference to illustrate extent of deviation from ideal.</td>
<td>Text has been changed to reflect the correction in the comment.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>5</td>
<td>ALL</td>
<td>ALL</td>
<td>Big-picture comment is that the conclusions (esp. the summary section) was not tied back to the hypothesis clusters.</td>
<td>Text has been inserted to more clearly tie conclusions to the hypothesis clusters.</td>
</tr>
<tr>
<td>Matt Harwell</td>
<td>5</td>
<td>ALL</td>
<td>ALL</td>
<td>The Future Development section for the SAV cluster (p. 385) was surprisingly valuable to this reader. Other sections of the SSR should consider presenting information in this manner.</td>
<td>This has been noted.</td>
</tr>
<tr>
<td>Bruce Sharfstein</td>
<td>5</td>
<td>Intro</td>
<td>Intro</td>
<td>I applaud the rewrite of the introduction to the Lake Okeechobee chapter which I understand was largely catalyzed by comments from Betty Grizzle. It does a great job of putting the lake’s role and position in Everglades restoration into clear focus.</td>
<td>This has been noted.</td>
</tr>
<tr>
<td>Eric Hughes</td>
<td>5</td>
<td>ALL</td>
<td>ALL</td>
<td>I would encourage the write-up to link Lake O WQ contraints to GE/SE/NE restoration expectations (i.e. until we do better improving Lake O WQ conditions, especially TP), our ecosystem restoration expectations for the GE/NE/SE need to be tempered.</td>
<td>This comment will be addressed (as best is possible) in the 2007 SSR and will also be communicated to the NRC when the final draft is released in November 2007.</td>
</tr>
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### SECTION 6.0 ADAPTIVE MANAGEMENT

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<tr>
<td>Agnes McLean</td>
<td>6</td>
<td>447</td>
<td>14-17</td>
<td>The statement is made in l 16-17 that &quot;addressing the third is often challenging&quot;. Well, is it going to be done? I felt like I was left hanging with no resolution to the challenge. What are the next steps?</td>
<td>The Integrative Assessment Sub-team (IAT) in conjunction with the USACE and RECOVER are completely revising this chapter to address these and other comments resulting from a AM Steering Committee/AT teleconference to discuss AM in the SSR. Changes will include: elimination of examples; shortening of the text, and assuring that there is compatibility between this section and the CERP AM Strategy and Implementation Guidance Manual.</td>
</tr>
<tr>
<td>Bruce Sharfstein</td>
<td>6</td>
<td>ALL</td>
<td>ALL</td>
<td>In my opinion, the adaptive management section would benefit by having the example cases removed. The explanation of the principles espoused is very clear and the examples detract, rather than add to the discussion.</td>
<td>See comment #203 above.</td>
</tr>
<tr>
<td>Sue Sofia</td>
<td>6</td>
<td>447</td>
<td>12</td>
<td>Item (1) is missing some words.</td>
<td>See comment #203 above.</td>
</tr>
<tr>
<td>Steve Traxler</td>
<td>6</td>
<td>ALL</td>
<td>ALL</td>
<td>The section does not go far enough. triggers are mentioned, but very little on decision making or how the information will link back to management actions. When do we start to incorporate this stuff, its been 7 years now.?</td>
<td>See comment #203 above.</td>
</tr>
<tr>
<td>Tom St Clair/Andy LoSchiavo</td>
<td>6</td>
<td>ALL</td>
<td>ALL</td>
<td>See track changes version.</td>
<td>See comment #203 above.</td>
</tr>
<tr>
<td>Eliza Hines/Elmar Kurzbach</td>
<td>6</td>
<td>ALL</td>
<td>ALL</td>
<td>This section must correspond with what is included in AM documents already produced for CERP - the AM Strategy, the AM Implementation Guidance Manual (in process) and any types of presentations/briefings that are being given to PDTs, the Colonel, other management etc. at any agency. We need to present AM (whether in the SSR context or not) in a unified way so that no one gets confused. The project teams are getting bombarded by AM from their own teams, from RECOVER liaisons that attend their PDT meetings, from RECOVER AT staff they ask questions of, and as they try to sort out what types of monitoring and assessment should be done (at the project-level) vs. what is occurring at the system-wide level (SSR). This may require a teleconference with those individuals working on AM for CERP to make sure out the message is clear and consistent and not at all different from what others are presenting.</td>
<td>See comment #203 above.</td>
</tr>
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### SECTION 8.0 CONCLUSIONS

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<tr>
<td>Bruce Sharfein</td>
<td>8</td>
<td>ALL</td>
<td>ALL</td>
<td>The conclusion begins with the following statement of purpose &quot;The focus of the SSRs is to examine the historical and MAP generated data to determine trends in the physical, chemical, and biological/ecological variables that have been determined, from the conceptual ecological models, to be essential for the restoration of the Everglades and South Florida ecosystems&quot; and some sections accomplish this goal very well whereas other sections either report only the last year or two of data (often without clearly stating what the period of record is) or embed the results in so much methodological detail that they are difficult to tease out. In my opinion some reorganization and editing might help a number of sections to more closely adhere to the stated goal.</td>
<td>The Integrative Assessment Sub-team has decided to eliminate this section from the SSR and include module summary material as well as other important <em>system wide</em> topics in both the Executive Summary and in new section at the front of the document entitled &quot;System Synthesis.&quot; The comments within this section will be addressed with this revision.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>8</td>
<td>454</td>
<td>7-8</td>
<td>The last sentence in this paragraph states that it will be necessary to assess whether the changes resulting from implementation of CERP programs are effective in restoring the system to a pre-drainage condition. Are we really aiming for a pre-drainage ecosystem? Aren't we more pointed toward some version of a pre-C&amp;SF system? A goal needs to be decided upon so readers know what to compare results to.</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>8</td>
<td>456</td>
<td>NE Conclusions</td>
<td>The NE Conclusions do not clearly address the hypothesis they assessed - this needs to be made much clearer.</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>8</td>
<td>458</td>
<td>SE Conclusions</td>
<td>For line 37, what type of year is being referenced?</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>8</td>
<td>459</td>
<td>3-14</td>
<td>Paragraph is way too academic for an Executive Summary. Needs to be simplified.</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>8</td>
<td>459</td>
<td>35-38</td>
<td>Does this paragraph hint at MAP Revision/Refinement? The paragraph is very general and not very descriptive as a last paragraph for the SE Module Conclusions.</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Elmar Kurzbach</td>
<td>8</td>
<td>461</td>
<td>Lessons Learned</td>
<td>Need to emphasize the importance of identifying long-term trends and analysis as well as MAP sustainability.</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Eliza Hines</td>
<td>8</td>
<td>ALL</td>
<td>ALL</td>
<td>If I think the module conclusions all need to be similarly written - what did you measure, how does that relate to PMs and IGs/Its, what did you find, what is the status of that hypothesis cluster and what is next for the module. I kind of felt as though the conclusion was &quot;all over the place&quot; in terms of what each module covered. I think the overarching things we found out (i.e., we need MAP sustainability, etc.) should be in the lessons learned so there isn't repetition. Also, I think the module summaries need to be moved up front in each module section. There is an audience out there that would like to know what occurred in the SSR in the NE (for example) but do not want to read the entire section nor do they know all the conclusions are buried in the last 50 pages of the 500 page document.</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Agnes McLean</td>
<td>8</td>
<td>Overall</td>
<td>Overall</td>
<td>I would present the module summaries in the order they are in the document (SE, NE, GE and LO).</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Agnes McLean</td>
<td>8</td>
<td>454</td>
<td>7 &amp; 8</td>
<td>&quot;...programs are effective in restoring the system to its pre-drainage condition&quot;. There are several areas which will not be restored thusly. Suggest &quot;...effective in achieving restoration goals&quot;.</td>
<td>See comment #209 above.</td>
</tr>
<tr>
<td>Agnes McLean</td>
<td>8</td>
<td>456</td>
<td>35</td>
<td>There is no mention in this LO section on hypotheses, whereas the other modules do.</td>
<td>See comment #209 above.</td>
</tr>
</tbody>
</table>

30 October 2007

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