South Florida Ecosystem Restoration: American Oysters

What is this indicator?

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

In the Caloosahatchee, Loxahatchee and St. Lucie Estuaries, oysters have been identified as a "valued ecosystem component" (Chamberlain and Doering 1998a, b). Oysters are natural components of estuaries along the estuaries on the eastern sea board of the US as well as the Gulf of Mexico and were documented to be abundant in the system. The American oyster is the dominant species in these oyster reef communities. Oyster bars provide important habitat and food for numerous estuarine species including gastropod mollusks, polychaete worms, decapod crustaceans, various boring sponges, fish and birds. Over 300 macrofauna species can live in oyster beds and over 40 species may live in a single oyster bed (Wells 1961). Oysters are also an important commercial and recreational resource. Salinity is important in determining the distribution of coastal and estuarine bivalves. Adult oysters normally occur at salinities between 10 and 30 parts per thousand (ppt) but they tolerate a salinity range of 2 to 40 ppt (Gunter and Geyer 1955). Short pulses of freshwater inflow can greatly benefit oyster populations by reducing predator (e.g., oyster drill, whelk) and parasite (e.g. *Perkinsus marinus*) impacts (Owen 1953), while excessive freshwater inflows may kill entire populations of oysters (Gunter 1953, Schlesselman 1955, MacKenzie 1977; Volety et al. 2003, Volety and Tolley 2005).

The organism density, biomass, and richness of reef resident organisms such as crustaceans and fishes are greater in oyster reefs compared to the sand-bottom (Tolley and Volety (In press, 2005). Therefore freshwater alteration and/or habitat alteration to unfavorable levels will not only result in decrease of oyster reefs and filtration associated water quality, it will also impact the species residing on the oyster reefs that are of ecological and economic importance.

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

CERP MAP Hypotheses related to American oyster indicator.

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

Hypothesis 1.

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

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

Hypothesis 2.

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

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

Hypothesis 3.

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

Rationale. Oyster populations are affected by increased sediment loads resulting from alterations to the natural hydrology. Adult oysters have effective morphological adaptations for feeding in much higher levels of suspended solids than are usually encountered under normal conditions. Oysters from relatively turbid estuaries appear to be capable f feeding of total suspended solid concentrations as high as 0.4 g/l but significantly reduce their pumping rates at as low as 0.1 g/l. Suspended solids may clog gills and interfere with filtering and respiration of oysters. Deposition of sediment on oyster shells also makes them unsuitable for spat settlement.

Hypothesis 4.

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

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

What has happened to affect this indicator?

Water management and dredging practices have a major impact on the historical presence, density and distribution of oysters within the mesohaline areas of central and southern Florida estuaries. Historically, rainfall on the watershed was detained in natural wetland systems and gradually percolated into the groundwater, evaporated and /or flowed overland into tributaries. As south Florida developed, the canal network, built as a result of the Central and Southern Florida Flood Control project, worked too efficiently and drastically altered the quantity, quality, timing and distribution of fresh water entering the system. Freshwater flows into the estuary and its tributaries generally increased in the volume discharged over a given period of time, relative to the pre-drainage era. Under these conditions, rapid changes in salinity occurring in the estuaries results in degradation of biological integrity of the system. Additionally, the runoff now contains contaminants from urban and agricultural development including excess suspended solids, nutrients, pesticides, and other harmful pollutants. As a result, the water entering the estuary is of poor quality, and the quantity and timing of inflows are substantially altered. Inflows are extremely variable and tend to be too great in the wet season and too little in the dry season to support a healthy estuary. The inflow extremes and degraded water quality (particularly suspended solids and nutrients) severely compromise the development of healthy, sustainable oyster and related estuarine communities. Detailed description of the estuaries and specific alterations and environmental threats to oysters in these estuaries is presented in Appendix 1).

What areas of the Everglades does this indicator cover?

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

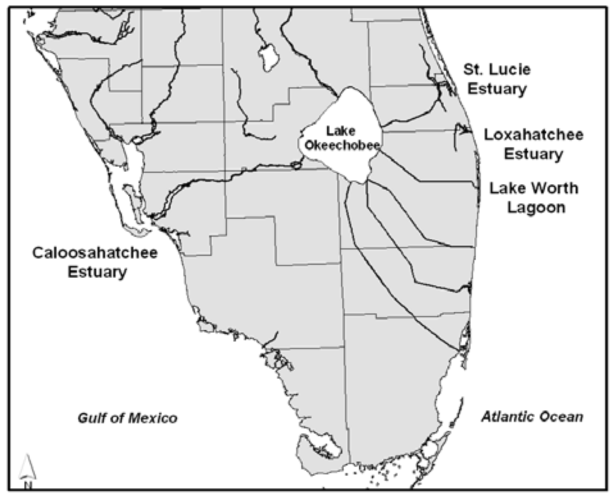

Figure 1. Northern estuaries.

What does the Research Say?

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

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

The dominant biological features in the San Carlos Bay area are its numerous mangrove islands and many kilometers of mangrove shoreline, which are often closely associated with oysters. Because of its biotic richness and aesthetic appeal, San Carlos Bay supports a wide variety of recreational and fishery activities with significant economic value. The natural resources of this area are also impacted by large freshwater releases and are threatened by long-term shifts in water quantity and quality (Chamberlain and Doering 1998b; Doering et al. 2002; Volety et al. 2003). Under the current water management practices, the estuarine portion of the river is practically fresh due to freshwater releases and runoff from the watershed from summer / fall rains. In the winter when rains and freshwater releases cease, salinity conditions are hypersaline given the shallowness of the estuary and evaporation. Freshwater releases during summer months result in flushing of oyster larvae to downstream locations that have unsuitable substrate or create salinity conditions that are unfavorable for larval survival in the estuarine portions of the river. Recruitment of oyster larvae to the estuarine portions at the tail-end of the spawning season (Oct / Nov) when salinity conditions are tolerable is what is keeping the oyster populations at least at low levels (Volety et al. 2003)

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

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

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

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

Experimental results indicate that adults are able to tolerate salinities as low as 5 ppt up to 8 weeks, but can not tolerate salinities lower than 3 ppt, which can occur upstream of Shell Point when S-79 discharges exceed 4,000 cfs. Therefore, high discharges can limit population survival and abundance in this region where they were historically present. As a restoration note, Volety et al. (2003) indicated that because of high spat recruitment at intermediate salinities, along with good growth rates and low disease, it is very feasible to develop oyster reefs upstream of Shell Point by strategically placing oyster clutch in suitable areas, if provided the ability to control current [high] freshwater inflows.

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

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

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

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

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

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

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

Why is this indicator important?

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

- Oyster life cycle is typical of other estuarine species and hence water quality conditions that influence oysters similarly influence other estuarine species;
- Oyster reefs provide habitat, shelter and food for over 300 species;
- Oyster reefs are the primary components that link pelagic phytoplankton / detritus food source with the benthic fauna via deposition of mucus and uneaten food material on the floor – benthic-pelagic coupling;

- Primary consumers that rely on phytoplankton that forms the base of food chain in the estuaries in the Everglades as well as other estuaries;
- Productivity and community structure are directly linked to the hydrology and oyster reef survival and morphology;
- Crustaceans and fishes that are residents and transients of oyster reef communities provide critical prey for secondary and tertiary carnivores such as fish and birds;
- Oyster reef survival, distribution and abundance are key outcomes (performance measures) in most RECOVER Conceptual Ecological Models and in CERP Interim Goals;

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

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

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

- Key environment drivers (rainfall, water quantity, water quality, sediment loads) are statistically correlated to species abundance and indicators of oyster health;
- High and low salinity estuaries have distinct oyster abundance, distribution and health responses;
- Oyster abundance, density, survival and health indicies are causally linked to hydrological factors (water salinity, frequency of killing floods, sedimentation and contaminants in the water).

4. The indicator is integrative:

- Oyster survival, abundance and distribution is linked to water quality, phytoplankton production, sedimentation, and in turn crustacean, fish and bird success is linked to oyster reef health and abundance;
- Oyster reef and reef resident organism responses are representative of hydrological improvement (i.e. Water Management);

- Oysters are included in the following CERP RECOVER products; Interim Goals, all estuarine Conceptual Ecological Models, all estuarine module team assessments, and as a major Performance Measure for both RECOVER and many estuarine linked CERP project plans.

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

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

Discussion

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

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

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

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

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

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

Longer-Term Science Needs

Oyster Monitoring in the Northern Estuaries:

Basic information about salinity changes and their impacts on oysters and their associated communities has been relatively well-understood. However, this data is mostly from areas outside the Northern estuaries and oysters are adapted to local conditions and therefore their responses to ambient environmental conditions in northern estuaries will be some what different. Continued work is needed to standardize the measurements between estuaries and continue to capitalize on developing time-series information on oysters in various estuaries. Some of the techniques currently employed are time-taking and expensive. For example, assessment of reproductive stage and reproductive potential using histological techniques is expensive and very time consuming limiting the number of samples that can be assessed from each location and time series. Development of anti-body based techniques will quicken the process. Also, habitat suitability index model is currently under development for oysters in the Caloosahatchee estuary. This GIS-linked HSI will enable resource managers to make comparisons between different scenarios easy enhacing the decision making process. This model has to be optimized and expanded to other northern estuaries (and southern estuaries). Metrices to be measured currently include: changes in oyster distribution and abundance at a variety of estuarine sites on both east and west coasts of Florida, including the SLE, Caloosahatchee, Loxahatchee, and Lake Worth Lagoon. This long-term monitoring program for the eastern oyster will focus on four aspects of oyster ecology: spatial and size distribution patterns of adult oysters, distribution and frequency patterns of the oyster diseases, reproduction and recruitment, and juvenile oyster growth and survival. Data will be analyzed to determine if the health and spatial extent of oysters is improving with time as CERP projects are implemented. Maps of oyster bed location, density and health needs to be produced.

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Appendix 1: (from Northern estuaries module intro.doc)
The Northern Estuaries includes the Caloosahatchee , St. Lucie, Loxahatchee, and Lake Worth Lagoon (Figures 2 and 3). The Caloosahatchee Estuary is located on the southwest coast of Florida. Most of the freshwater flowing into the estuary comes from the Caloosahatchee River. Historically the Caloosahatchee River was a meandering system with numerous oxbows, flowing from its headwaters at Lake Hicpochee to the Gulf of Mexico (Figure 2). Activities that led to its degradation, beginning in the1890s, include channelization, connection to Lake Okeeechobee, and construction of an extensive canal network associated with agricultural development in the watershed. The channelized portion of the Caloosahatchee River (C-43) as well as this canal network has changed the timing, quantity, and direction of runoff within the watershed and led to abnormal salinity fluctuations. The tidally influenced portion of the estuary has been reduced by the operation of the S -79 control structure (Figure 2) which allows periodic large regulatory releases from Lake Okeechobee. Prior to these impacts, the Caloosahatchee estuary was a highly productive system with an abundance of aquatic plants and animals. Today, the abundance, health, and functionality of these species have been greatly reduced. The eastern oyster, important component of the biological community, has been reduced from a widespread distribution to a sparse occurrence.

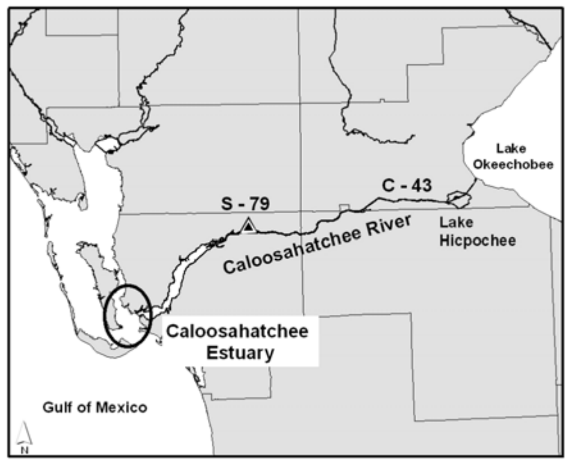

Figure 2. The Caloosahatchee estuary.

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

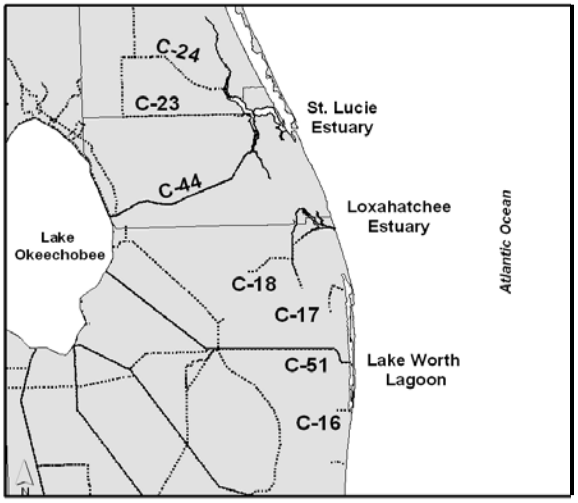

Figure 3. The St. Lucie, Loxahatchee, and Lake Worth Lagoon estuaries.

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

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

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