Indicator 1.1 – American Oysters in Northern Estuaries

What is the desired restoration condition?

The desired restoration condition for the American oyster (*Crassostrea virginica*) in the Northern Estuaries is the restoration of oyster beds within the St. Lucie, Caloosahatchee, Loxahatchee, and Lake Worth Lagoon Estuaries, including the restoration of habitat function and oyster health in areas that become suitable habitat.

Why is the indicator important and why is it a good indicator of CERP restoration?

The American oyster is an almost exclusively estuarine bivalve mollusk. It is ecologically important because it improves water quality by filtering particles from the water, serves as prey and habitat for numerous other organisms, and plays an important role in the estuarine food chain. Oyster bars provide extensive attachment area for numerous organisms including oyster spat, mussels, tunicates, bryozoans, and barnacles (Woodward Clyde International Americas 1998). Several studies have demonstrated the species richness of oyster bars. Wells (1961) documented 303 faunal species from oyster beds in North Carolina. Other authors documented 40 to 140 species in oyster bars in brackish waters (Pearse and Wharton 1938, Frey 1946, Bahr and Lanier 1981). Salinity conditions suitable for oysters also produce optimal conditions suitable for a suite of other desirable estuarine organisms. Consequently, as a keystone species and valued ecosystem component, oysters are indicative of the ecosystem health as a whole.

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 ground water, 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 resulted 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.

The Comprehensive Everglades Restoration Plan (CERP) will result in more natural freshwater inflows (via retention in reservoirs, wetland rehydration, and changing delivery patterns), removal of muck, and introduction of artificial substrate into the Northern Estuaries. The CERP will provide beneficial salinity and habitat conditions that promote the reestablishment of healthy oyster beds.

Caloosahatchee Estuary

In 2004, the Caloosahatchee Estuary had 18 acres of oyster habitat (Figure 1.1.1). With changes in freshwater inflows into the Caloosahatchee Estuary resulting from CERP implementation, it is anticipated that salinities in the riverine portion (north of Shell Point) of the Caloosahatchee Estuary would increase (Aswani Volety, Gulf Coast University, electronic mail, July 19, 2004). This would result in estuarine salinities suitable for the growth and enhancement of oyster reefs in areas north of Shell Point. It is expected that the epicenter of oyster reef development in the Caloosahatchee Estuary would shift from its existing location in the south to the north of Shell Point. It is anticipated that oyster reef coverage will increase to approximately 100 acres in the next 10 to 15 years, with an annual increase of approximately 10 to 20 percent. Given the shift in estuarine conditions, it is anticipated that the focus of oyster reef development will be north of Shell Point. It is expected that approximately 40 acres of reefs will develop north of Shell Point while 60 acres of oyster reefs will be in the San Carlos Bay.

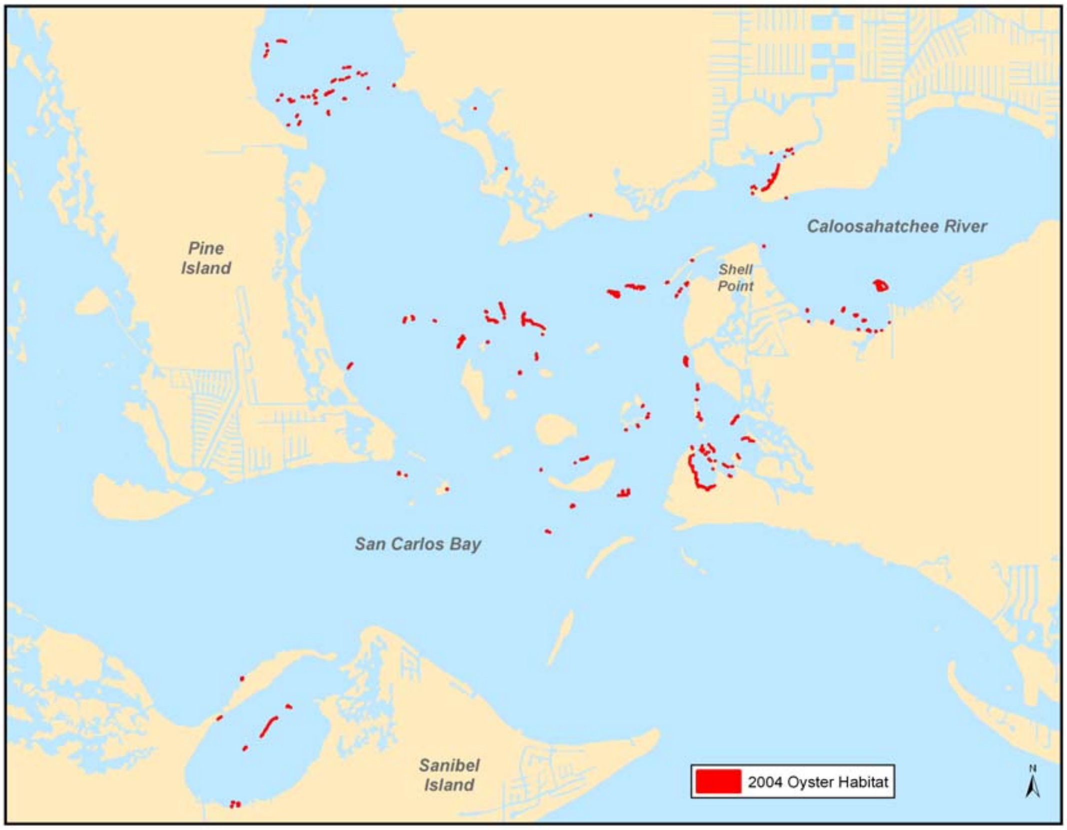

Figure 1.1.1. Existing oyster habitat in the Caloosahatchee River and Estuary

The Caloosahatchee Estuary 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 to 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 the San Carlos Bay (south of Shell Point).

St. Lucie Estuary

In 1997, the St. Lucie Estuary had 117 acres of oyster habitat (Figure 1.1.2). The CERP is expected to establish a salinity regime of 350 to 2,000 cubic feet per second (cfs) for the St. Lucie Estuary resulting in approximately 890 acres of oysters. These oyster are predicted to occur I the middle estuary from the Roosevelt Bridge downstream to the Ernest Lyons (A1A) Bridge.

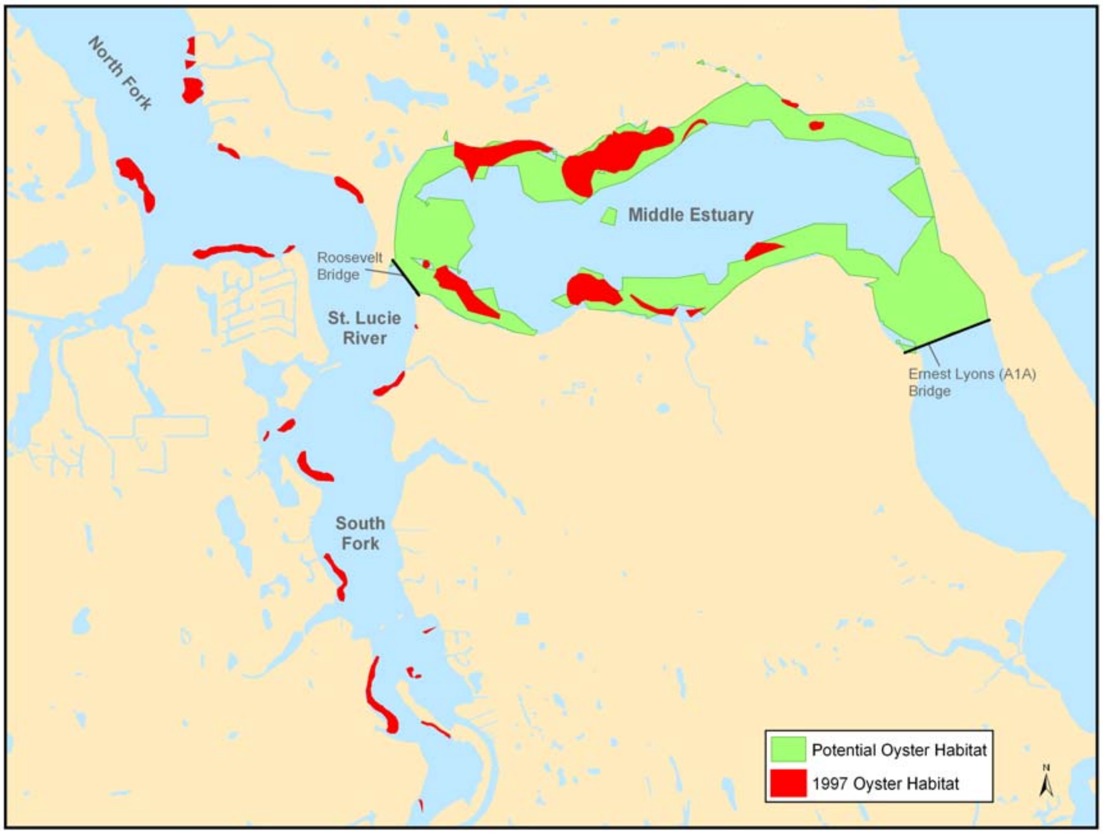

Figure 1.1.2. Existing and potential oyster habitat in the St. Lucie Estuary

Loxahatchee River and Estuary

In 2003, the Loxahatchee River and Estuary had 10 acres of oyster habitat (Figure 1.1.3). At the present time, the project managers of the North Palm Beach Project have not defined a number of acres of oysters the project is trying to achieve. The major objective for this valued ecosystem component in the Loxahatchee Estuary is to maintain existing population distribution and density and is described as the base case documented in 2003.

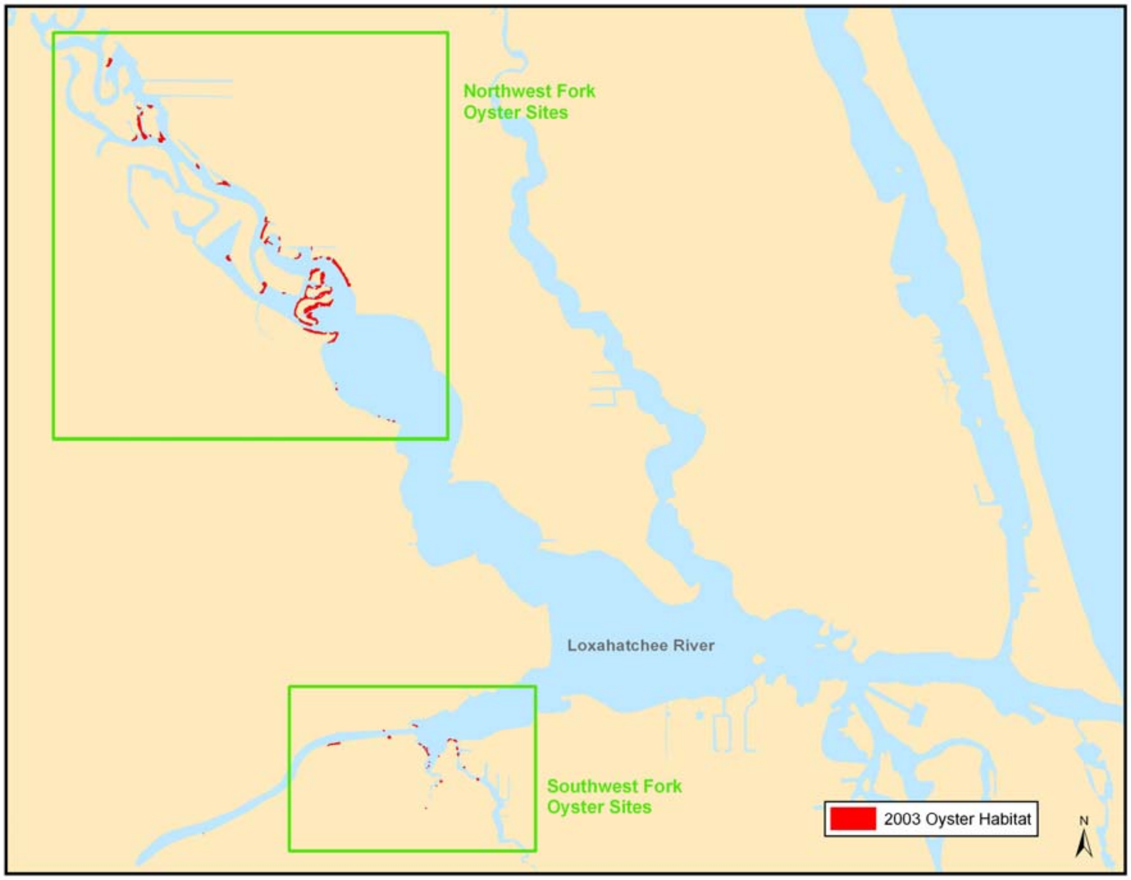

Figure 1.1.3. Existing oyster habitat in the Loxahatchee River and Estuary

Lake Worth Lagoon

It is not known how many acres of oyster habitat are within Lake Worth Lagoon.

How is the interim goal for this indicator predicted?

Caloosahatchee Estuary

Interim goal predictions were developed for the Caloosahatchee Estuary using two classes of hydrodynamic salinity models: one for research purposes and one for planning purposes. Hydrology differs for the two models that are described below (Ken Konyha, South Florida Water Management District, electronic mail, September 14, 2004). Figure 1.1.5 presents a graphical depiction of the models used to predict change in oyster habitat in the Caloosahatchee Estuary.

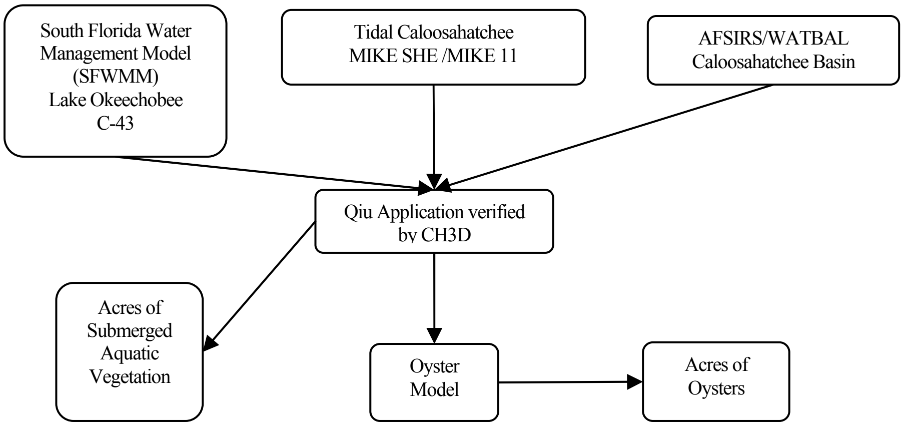

Figure 1.1.5. Models used to predict interim goals for oysters in the Caloosahatchee Estuary

For research purposes a classical three-dimensional hydrodynamic salinity model has been developed for the Caloosahatchee Estuary by Chenxia Qiu of the South Florida Water Management District. This model came from a larger Charlotte Harbor model developed by Peter Sheng of the University of Florida. This model simulates conditions within the estuary for relatively short time periods (< 1 year). During calibration, the hydrodynamic model used measured flows at the S-79 lock and dam structure. Since there are no measured flow data for the tidal portion of the Caloosahatchee River (downstream of S-79), inflows were estimated using a MIKESHE-MIKE11 model of the tidal Caloosahatchee River (Copp 2002).

For planning purposes, salinity estimates are developed using an application model (Qiu). This salinity model has been calibrated to the hydrodynamic model. The application model is needed to simulate salinity over longer time periods (>30 years). The applications model is driven by long-period watershed inflows that are predicted using hydrologic models. Several alternative sets of hydrology have been developed to describe flows at S-79. These include 2000 Base conditions, 2025 Base conditions, 2050 Base conditions, "Yellow Book" conditions, and the various alternatives considered by the South West Florida Feasibility Study and the C-43 Surface Water Storage Project implementation plan. At this time, 2000 Base, 2025 Base, and 2050 Base hydrology for the Upper Caloosahatchee watershed comes from Agricultural Field Scale Numerical Simulation/Water Balance (AFSIRS/WATBAL) Models (Konyha and Wilcox 2003). Added to these flows are Lake Okeechobee releases to the Caloosahatchee simulated by the South Florida Water Management Model (SFWMM). In future, AFSIRS/WATBAL model estimates will be replaced by MIKESHE-MIKE11 estimates. Flows downstream of S-79 are derived from a Stanford-type hydrologic model that has been calibrated to the Tidal Caloosahatchee MIKESHE-MIKE11 model.

The Caloosahatchee Estuary Oyster Model (Aswani Volety, Gulf Coast University, electronic mail, November 10, 2004) is a modification of habitat suitability index models developed by Cake (1983) and optimized for the western Gulf of Mexico by Soniat and Brody (1988). The model to be used in the Caloosahatchee River has to be optimized for environmental conditions prevailing in southwestern

Florida estuaries. For example, southwestern Florida experiences a very wet summer season with low salinities and high temperatures, and very dry winter season with high salinities and low temperatures. This seasonal pattern is very distinct from other areas of the Gulf of Mexico with the absence of seasonal rainfall, and thus influences disease prevalence of *Perkinsus marinus* and spawning activity of oysters in southwestern Florida estuaries.

The oyster model in the Caloosahatchee Estuary is comprised of a larval component index (LCI) and an adult component index (ACI) (Volety et al. 2004). The LCI comprises of factors such as spat settlement, salinity, temperature, substrate availability, and flow, while the ACI is comprised of spat settlement, density of living oysters, salinity, temperature, and frequency of killing floods. Frequency of killing floods is described as salinities of < 3 parts per thousand (ppt) at a given location lasting for more than 3 weeks. Each factor carries a value between 0 and 1. A brief version of the model is described below. Component indices are the weighted geometric mean of the variables, with no variable recording a zero.

$$\text{LCI} = \text{Spat Settlement}^{w} \times \text{Salinity}^{w} \times \text{Temperature}^{w} \times \text{Substrate Availability}^{w} \times \text{Flow}^{w}$$

$$\text{ACI} = \text{Spat Settelement}^{w} \times \text{Density of Living Oysters}^{w} \times \text{Salinity}^{w} \times \text{Temperature}^{w} \times \text{Frequency of Killing Floods}^{w}$$

The default weight is w = 1 / number of variables. The weight can take on different values for the variables; however, the sum of the weights must be equal to one, with no individual variables recording a zero.

The AFSIRS/WATBAL is a water budget model. It is a computer simulation model based on a daily water budget of the crop root zone. The model estimates irrigation requirements for daily, weekly, two-week, monthly, seasonal, and annual time periods. Because it is based on daily water budgets, irrigation requirements can be calculated for shorter periods of time than with the Soil Conservation Service model. However, estimates for very short (daily) time periods are often not very meaningful because these data are highly variable.

The AFSIRS/WATBAL Model is limited by few available data for some Florida crops and production systems. Because of the great diversity of Florida's agriculture, not all crops and production systems have been extensively studied. However, the AFSIRS model contains actual crop data when available and the author's best estimates for coefficients and data that can be extrapolated from other locations. In all cases, the user can change the model input data as required to customize the model for a specific application or based on the most recent research results.

Uncertainty. Predictions for the growth of oyster reefs in relation to changes in the freshwater inflow into the Caloosahatchee Estuary were made based on previous spat recruitment patterns, seasonality and quantity of freshwater flows, and disease levels of *Perkinsus marinus*. in the Caloosahatchee River from limited locations. A detailed analysis of substrate quality and availability is not known, nor are sedimentation rates, density of living oysters, growth rates of oysters from representative locations in the estuary that represent a range of salinities, and rates of predation. In addition, the weight of individual factors needs to be optimized for southwestern Florida estuaries (Aswani Volety, Gulf Coast University, electronic mail, November 10, 2004).

St. Lucie Estuary

In the St. Lucie Estuary analysis (USACE and SFWMD 2004), formulation of the restoration plan to recapture the pre-drained watershed hydrology involved the use of three types of models:

- Watershed hydrology models to simulate the hydrologic responses of the developed watershed and the pre-drained watershed to the same climatic input
- A reservoir optimization model to size the storage reservoirs by optimizing the operational rules to achieve desired inflows
- Estuary salinity and a geographic information system (GIS)-based valued ecosystem component (VEC) Tool to evaluate the influence of watershed freshwater inflows on estuary salinity and oyster acreage under the pre-drained, current and future restored conditions.

These models were applied with a 31-year simulation period from 1965 to 1995 to ensure that a wide range of climatic conditions such as floods and droughts were included in the modeling process. Figure 1.1.4 presents a graphical depiction of the models used to predict change in oyster habitat in the St. Lucie Estuary.

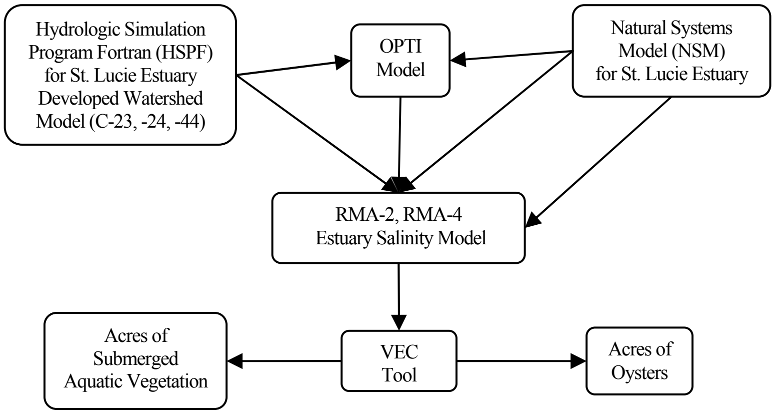

Figure 1.1.4. Models used to predict interim goals for oysters in the St. Lucie Estuary

For oysters, salinity and substrate type were considered to be the key environmental variables driving oyster occurrence in the St. Lucie Estuary. Accordingly, the Level I analysis for oysters used sediment data and hydrodynamic salinity model results to predict future distributions of oysters. A GIS graphical user interface and data base developed by Woodward-Clyde Consultants, hydrodynamic salinity modeling, and literature values for physiological tolerances of the key indicator species (Woodward Clyde International-Americas 1998) were used for the Level I evaluation. This initial analysis was geared toward identifying a general area where oysters may occur under the proposed flow regime (350 cfs to 2,000 cfs).

A GIS-based VEC tool was developed by URS Greiner Woodward-Clyde using a data set of sediment type based on transects sampled in 1997. The sediment data was collected at specific points along transects and GIS sediment grid coverage was created by interpolating from the point data. The resulting sediment coverage includes nine substrate classes: 1) rocks/gravel, 2) oyster bar/dense shell, 3) coarse/medium firm sand, 4) well sorted fine sand, 5) mucky/muddy fine sand, 6) muck/organics/ detritus, 7) firm mud/clay/silt, 8) muck, and 9) ooze. Oysters can colonize many types of substrates, as long as the substrate can support the weight of the oyster (Woodward Clyde International-Americas 1998). For the Level I analysis, sediment classes 2 to 5 were used as potential oyster substrates because these are the substrate types that currently support oysters in the St. Lucie Estuary.

RMA, a hydrodynamic salinity model developed by engineers of Resource Management Associates, was run to produce various salinity outputs. The currently proposed restoration salinity inflow target is to maintain flows between 350 cfs and 2,000 cfs. Model simulations were run until they reached equilibrium for these ranges of inflows. The output data sets from the 350-cfs and 2,000-cfs equilibrium runs were then converted into salinity grid coverages. Using the GIS-based VEC application created by URS Greiner Woodward Clyde, queries identified all areas with sediment classes 2 to 5 and appropriate salinities to support oysters. As discussed above, the recommended salinity range for oysters in the St. Lucie Estuary is 7.5 ppt to 20 ppt (URS Greiner Woodward Clyde 1999). These limits were used for the 2,000-cfs evaluation. However, for the 350-cfs run, a salinity range of 7.5 ppt to 32 ppt was used; the justification for this upper limit is provided below.

Under low flow (350-cfs) conditions, higher salinity water will migrate further upstream than under high flow conditions. It is very likely that the salinities in healthy oyster beds will exceed the recommended 20-ppt threshold during low flow conditions. As discussed above, oysters can survive in highly saline waters; however, predators and disease tend to be more problematic at higher salinities. However, if the high salinities (> 20 ppt) occur only a portion of the time, it is likely that predators and disease will not pose a serious problem to healthy oyster beds. To try and set a reasonable upper salinity limit for low flow conditions, the short-term maximum salinity value of 32 ppt for sustainable oyster populations cited in the Woodward Clyde International-Americas (1998) literature review was used for the 350-cfs evaluation.

A two-dimensional hydrodynamic model (RMA-2) and a salinity model (RMA-4) were constructed for both the St. Lucie Estuary and the Indian River Lagoon. The RMA model was calibrated using a wide range of flow conditions. Calibration used measured flow, elevation, and salinity data throughout the estuary. Because almost half of the watershed is unmonitored, flows from the unmonitored basins had to be estimated during the calibration process.

Stream inflows, tidal forces, and direct inflows (rain, evapotranspiration, seepage, and surface runoff from lands surrounding the estuary) drive the RMA. During calibration, these come from measured data. For applications, these input data come from watershed modeling. The distribution of the inflows are substantially different for simulations of natural conditions (where most inflow comes from the North Fork) than for existing conditions (where drainage canals carry most of the flow). The stream distributions differ substantially among the alternatives as a result of flow diversion. Most alternatives examined the viability of diverting harmful C-23 canal flows away from their current outfall location in the midestuary and towards their historic estuary inflow locations in the North Fork. Some alternatives also examined the viability of directing excess runoff away from the estuary and to

Lake Okeechobee whenever local C-23 and C-24 basins rainfall produced excess (i.e., more than natural) runoff and Lake Okeechobee levels were low.

The RMA model was applied by generating a family of dynamic-equilibrium solutions. These solutions were generated for steady inflows and a repeating series of tidal boundary conditions. The dynamic equilibrium simulations showed conditions throughout the estuary over a wide variety of flow conditions and formed the salinity envelope that defined the maximum low harm flow for oysters. These solutions also demonstrated that high salinity (>5 ppt) conditions exist frequently throughout the open water portion of the estuary, effectively eliminating the oligohaline ecosystem in this area.

Under current conditions, regulatory releases from Lake Okeechobee are common (more frequently than once every other year). After the CERP has been fully implemented, the regulatory releases will be greatly reduced. For modeling all future scenarios, including 2050 Base, it is assumed that other CERP components are in place and, therefore, that Lake Okeechobee releases will be minimal. The Indian River Lagoon South Plan is intended to solve basin runoff problems; not regional storage problems.

RMA modeling is too slow to be compatible with the long-duration (31-year) simulations used by the watershed models. A statistical model was developed that can quickly estimate daily salinity at two locations (the upstream and downstream extent of the oyster beds) for a 31-year period of simulation. Finally, an oyster growth model driven by daily salinity data was developed. This model was used to show the increased oyster stress under today's conditions as compared to natural conditions, and to show how oyster stress declines under the preferred selected plan.

The RMA model did not originally extend into the riverine portions of the North Forks. When it became apparent that the oligohaline habitat in the riverine section of the St. Lucie Estuary was important to the overall health of the ecosystem, the RMA model was extended and a second, analytical model was developed to predict salinity in the North Fork. These models helped justify the 200-cfs diversions of water into the North Fork from the C-23 and C-24 basins.

The Reservoir Optimization Model (OPTI), based on genetic algorithms, was developed to meet the multiple criteria involved in sizing and operating storage reservoirs, which are major components of the restoration solution (Labadie 1997). The OPTI model establishes operational rules for a reservoir in an environment of conflicting operational demands. The model simultaneously tries to 1) achieve the target distribution of flows to the estuary, 2) supply water from the reservoir to meet all Floridan irrigation demands, and 3) minimize reservoir size. The objective function incorporating these three requirements is expressed in the following equation:

$$Minimize \sum_{c=1}^{NC} \left[WC_c \left(100P_c - 100T_c\right)\right]^2 + \sum_{t=1}^{n} \left[WI_t \left(100P_t - 100\alpha\right)\right]^2 + \sum_{t=1}^{n} WS_t \left(S_{t,\max}\right)^2$$

where

$P_c =$ the probability of mean monthly watershed inflow to the St. Lucie Estuary of a discrete range, represented by class c, based on flow frequency analysis under a given operational rule

Tc = the probability of the providing target mean monthly watershed inflow to the St. Lucie Estuary within the same discrete range represented by class c

Pi = the probability of failing to meet the irrigation demand associated with storage option i in any year

α = the acceptable risk level, which is typically the 1-in-10 year drought in the St. Lucie Estuary watershed (a failing year is defined as a year when the number of days that the irrigation demands are not satisfied exceeds a given threshold of days per year)

WCc = a user defined penalty weighing factor that provides a subjective rating of the relative importance of meeting the target for each frequency class c

WIi = a user-defined penalty factor for ranking the importance of meeting irrigation demands by direct diversions from each storage option i

WSi = a user-defined penalty factor intended to discourage excessive allocation of each storage option i

Si,max = the maximum storage capacity actually used in storage option *i* as computed from hydrologic simulation of the system

The relative importance of minimizing reservoir size versus satisfying the other objectives is dictated by the weighing factor WS_i assigned by the user. A genetic algorithm program (Carroll 1996) was used to minimize the objective function and generate operational rules. The microgenetic algorithm option is coded in the model to allow for generations of small population sizes and improvement of computation efficiency.

Although the objective function as shown is set up to calculate monthly flow frequency distribution, the OPTI model is embedded with a reservoir routing model that tracks the water budget in the reservoir on a daily basis. The user defines the maximum reservoir size, seepage from the reservoir, and the reservoir type (in-stream or off-line). Model output includes optimal operational rules, required storage capacity for each basin, daily inflow to the estuary, daily irrigation allocation, and daily storage and release from each of the storage options.

A model has been developed by Haunert and Konyha (2004) to relate salinity at any location in an estuary with oyster stress. The model quantifies the total yearly salinity stress on oysters for each year of simulated salinity data. The model can predict oyster stress for the any number of years. Examination of a chosen base case of salinities (natural system salinity if possible) would reveal the long-term health of oysters under these conditions, which can be contrasted with alternative watershed inflows/salinity to quantify the difference in stress and mortality of the alternative.

The oyster stress model has the following form:

Yearly stress = sum of daily stress throughout the year and

$$\text{Daily stress} = A * \cosh(\text{daily salinity stress})$$

where

A =	temperature-dependant oyster susceptibility factor; A = 0.66 from November 1 to February 28 and A = 1.00 from March 1 to October 31
daily salinity stress =	K * (T – daily salinity)/T
K =	scaling factor (K = 15.38)
T =	threshold salinity above which no stress occurs (T = 12 ppt)

This model fits the known literature information relating to adult mortality of oysters. The parameters A and K were selected so that equivalent stresses had equivalent stress values. Table 1.1.1 shows the available literature information and the corresponding values of oyster stress associated with each case. Note that the oyster-stress model only shows the negative impacts of fresh water in the estuary. The model is insensitive to differences in low flows.

Table 1.1.1. Defining oyster stress for different levels of harm (adult mortality) to oysters

Level of Harm	Season	Duration (days)	Salinity (ppt)	Salinity Stress (percent of maximum)	A	Oyster Stress
Stress	Cold	90	10	17%	0.67	300
	Warm	60	10	17%	1.00	300
Harm	Cold	60	5	58%	0.67	160,000
	Warm	40	5	58%	1.00	160,000
Death	Cold	21	2	83%	0.67	2,600,000
	Warm	14	2	83%	1.00	2,600,000
	Cold	3	0.5	96%	0.67	2,500,000
	Warm	2	0.5	96%	1.00	2,500,000

Uncertainty. The St. Lucie Estuary evaluation (USACE and SFWMD 2004) is based on equilibrium model runs that oversimplify salinity conditions in the estuary. These equilibrium conditions are unlikely to occur but do provide a general indication of what estuarine salinity conditions would be like at the two extremes of the proposed “salinity envelope” (350 cfs and 2,000 cfs). The equilibrium evaluation does not account for natural variability in the system or for managing inflows to meet oyster salinity requirements for spawning/setting periods.

Another limitation of this evaluation is the sediment data. The sediment grid was created by interpolating between actual data points. This could lead to inaccuracies within the grid coverage between actual sample points. Additionally, the analysis assumes all areas with sediment classes 2 through 5 will be appropriate for oyster colonization. Although these areas are the most likely to be able to support oyster populations, it is unlikely that all of these areas will support oysters. Even some existing oyster shell areas may not be suitable for colonization. The Woodward Clyde International-Americas (1998) literature review indicated that oyster shell areas that are not “clean enough” might discourage oyster set. This could be a concern in silty areas of the estuary.

It is likely that the analysis overestimates oyster acreage within the middle estuary since it assumes that all category 2 through 5 sediments will support oysters. It is also likely that the analysis underestimates oyster colonization in the North and South Forks. Even under current inflows, with extreme salinity variations, some oysters are able to survive in the North and South Forks. Under proposed flow management, some oysters will likely be able to colonize the North and South Forks.

Loxahatchee Estuary

Interim goal predictions were made for the Loxahatchee Estuary using hydrodynamic salinity models. Figure 1.1.6 presents a graphical depiction of the models used to predict change in oyster habitat in the Loxahatchee Estuary.

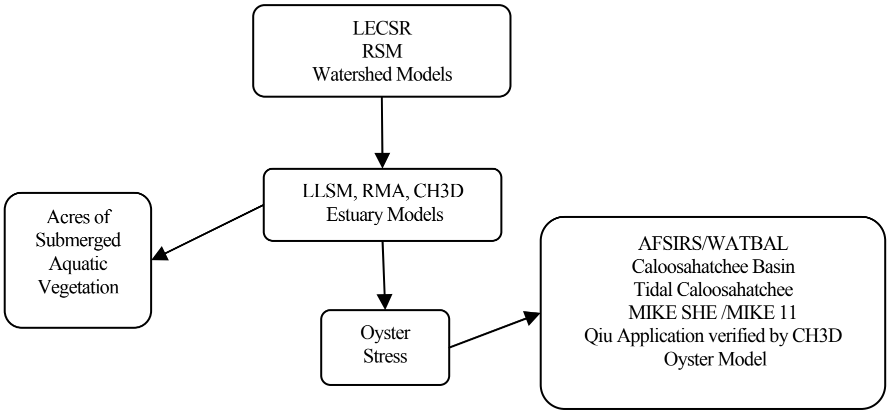

Figure 1.1.6. Models used to predict interim goals for oysters in the Loxahatchee Estuary

The Loxahatchee River Hydrodynamic Salinity Model (LRHSM) is an existing two-dimensional RMA model that the South Florida Water Management District used for evaluations of minimum flows and levels for the river. This model has been updated with 2003 bathymetry and calibrated against tide and salinity data that was collected in 2003. The LRHSM Model (RMA2-D) (Hu 2004) will be used to generate a salinity/flow curve by river mile to assess the needed freshwater flow to produce reduced levels of salinity across the upper tidal floodplain swamp. Flow over Lainhart Dam makes up approximately 50 percent of the total flow. Further refinements may be necessary based on subsequent model evaluations.

The LRHSM Model also will provide a preliminary assessment of the impacts that inlet deepening and sea level rise have had or will have on the salinity regime in the estuary. Model inputs used include daily averaged inflow from four major inflows - Northwest Fork at Lainhart Dam, Kitching Creek, Cypress Creek and Hobe Grove Ditch, and flow from S-46 to the South Fork for a year, as well as field-collected tide and salinity data.

The Curvilinear-Grid Hydrodynamic Three-Dimensional (CH3D) Model was developed by the South Florida Water Management District as a three-dimensional surface water model for the Loxahatchee River and Estuary. The results generated from the RMA (two-dimensional model) will be compared to the results from the CH3D Model and any needed refinements will be made to the family of salinity/flow curves. During steps 4 and 5 of the United States Army Corps of Engineers' Planning Process, the Lower East Coast Sub-Regional (LECSR) model or the Regional Simulation Model (RSM), if available, will be used to establish freshwater inflows into the river and estuary for various alternatives and that information can be compared to the family of curves or input into the RMA or CH3D to assess impacts on salinity/target adherence. The LECSR will also provide an estimate on the amount of groundwater seepage into the estuary in daily time steps. The LECSR or RSM model output will provide the flow simulation records needed to assess the feasibility of achieving the indicated high flow target as well as the low flow target into the river system at key modeled inflow points, and assessment of performance at Lainhart Dam will be supported through these modeling outputs.

The Loxahatchee Estuary Salinity Management (LESM) Model is based on the concept that salinity in the estuary consist of a series of transitions from one quasi-equilibrium condition to another. The model runs on a daily time step. It calculates the potential target (equilibrium) salinity based on the amount of freshwater inflow from the watershed. Daily salinity change is then calculated for daily salinity adjustment. The model runs on a daily time step, allowing for the evaluation of salinity conditions possible under a long-term hydrologic condition (e.g., 36 years in the CERP). The model can be used to estimate the amount of fresh water that is needed for salinity management in the Loxahatchee River and Estuary.

The Loxahatchee Oyster Stress Model will relate watershed flows to estuarine salinity. This model is previously described under the St. Lucie Estuary model description. This will be accomplished by developing a long-term salinity prediction model that is based on the results of the short-term detailed hydrodynamic modeling (LRHSM). The long-term salinity model will predict daily mean salinity at selected estuarine locations for any number of years, if provided, with a time series of inflows from the watershed. These salinities will then be compared with the VEC salinity tolerances to evaluate and contrast the effect on the VECs and also whether conditions would be suitable for the VECs to repopulate in another portion of the estuary.

The North Palm Beach Project team has proposed several watershed infrastructure scenarios to enhance water management in the watershed and inflows to the Loxahatchee Estuary. To assess the affects of proposed flow modifications on the oysters as a VEC in the receiving water body, several models will be utilized. The short-term Loxahatchee River Hydrodynamic/Salinity Model (LRHSM) was used to develop a Loxahatchee Long-Term Salinity Model (LLSM). Thirty-six years of daily inflows for each scenario, including the base case for comparison, will be used as input to the LLSM to generate daily salinity at many locations in the estuary. These salinities will in turn be used as input to the existing "Oyster Stress Model" to determine how these time series of salinities affect the amount of oyster stress and mortality in contrast to the base conditions. The oyster model only considers salinity and temperature, using literature-defined tolerances, and therefore needs to be enhanced to make more reliable evaluations.

Uncertainty. At the present time, the North Palm Beach Project team has not defined a number of acres of oysters the project is trying to achieve. The major objective for this VEC in the Loxahatchee

Estuary is to maintain existing population distribution and density and is described as the base case documented in 2003.

Prediction of the acreage of oyster change in the Loxahatchee Estuary will have to be performed based on a long-term evaluation (i.e., 1965 to 2000) due to hydrologic variability. A daily salinity model will have to be used. Assumptions include that 1) watershed inflow under the CERP plan is accurate and 2) simplification of hydrodynamic conditions during the period of analysis is acceptable. One of the most important factors that make the prediction uncertain is the understanding of the oyster-habitat relationship. Oyster acreage prediction is based on oyster habitat suitability. Salinity is the dominant habitat factor; however, our local knowledge on how benthic sediment and nutrients would interact with salinity and, thus oyster growth, during 1965 to 2000 under CERP conditions is limited. When the acreage is estimated based on such a long-term scale it can be either a range or one number, depending on how the restoration zone is defined. A distribution function from the long-term data can be established (Y. Wan, South Florida Water Management District, electronic mail, September 16, 2004).

The advantage of CH3D over RMA is that CH3D predicts salinity stratification while RMA can not. The prediction accuracy of both models is strongly influenced by the input data of freshwater inflow from the watershed. Both of them are sufficient for developing the daily salinity model for oysters.

What are the predictions for five-year increments?

Table 1.1.2, presents the predictions for oysters in all the Northern Estuaries. Figure 1.1.7 compares oyster habitat change without CERP implementation to oyster habitat with full CERP implementation (D13R). Figure 1.1.8 compares oyster habitat change without implementation of the Indian River Lagoon South Selected Plan to oyster habitat change with full implementation of the Indian River Lagoon South Selected Plan. Also, Figure 1.1.2, presented earlier in the document, presents potential oyster habitat in the St. Lucie Estuary. Oyster bed response in the Caloosahatchee Estuary to full CERP implementation (D13R) and to no implementation are presented in Figure 1.1.9.

Table 1.1.2. Interim goal predictions for oysters in the Northern Estuaries

Estuary	Existing Oyster Acres (year)	Restoration Target
St. Lucie (Figure 1.1.3)	208 (1997) 117 (2003)	834 acres live oyster habitat with Alternative D13R (full CERP implementation), plus Indian River Lagoon South Plan (wetland rehydration, stormwater treatment areas, muck removal, and addition of artificial substrate)
Caloosahatchee	18 (2004)	100 acres of live oyster habitat with the C-43 Reservoir and Aquifer Storage and Recovery Projects 500 acres of live oyster habitat with C-43 Reservoir and Aquifer Storage and Recovery Projects and addition of artificial substrate
Loxahatchee	10 (2004)	Under development
Lake Worth Lagoon	unknown	Under development

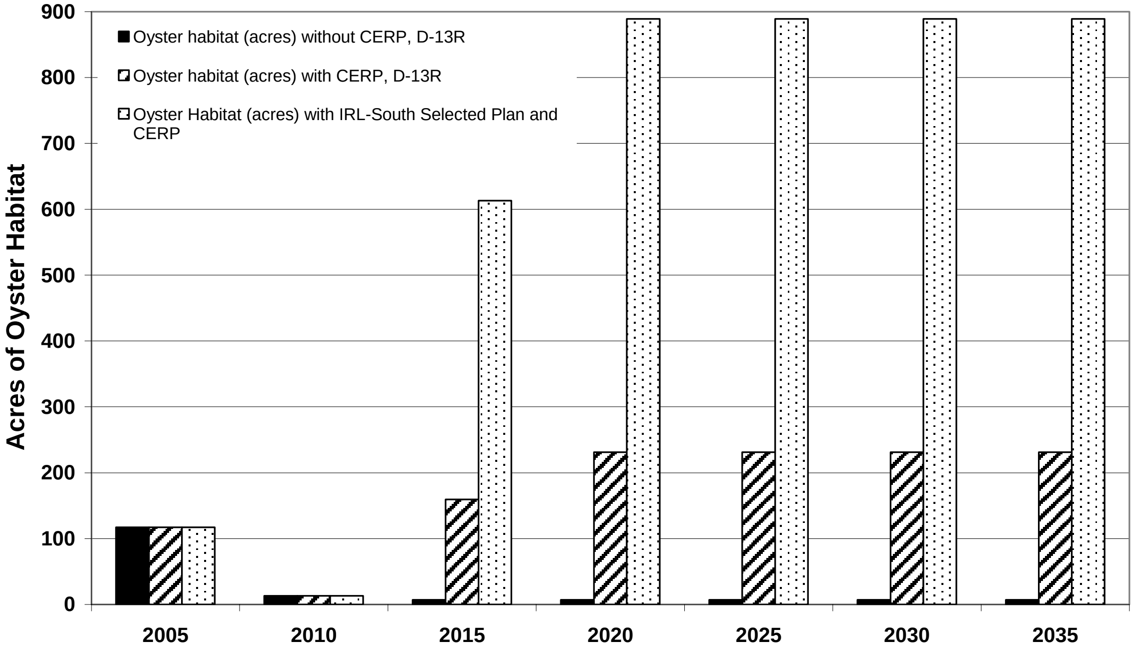

Figure 1.1.7. Comparison of acres of oyster habitat in the St. Lucie Estuary without CERP implementation and with full CERP implementation (D13R)

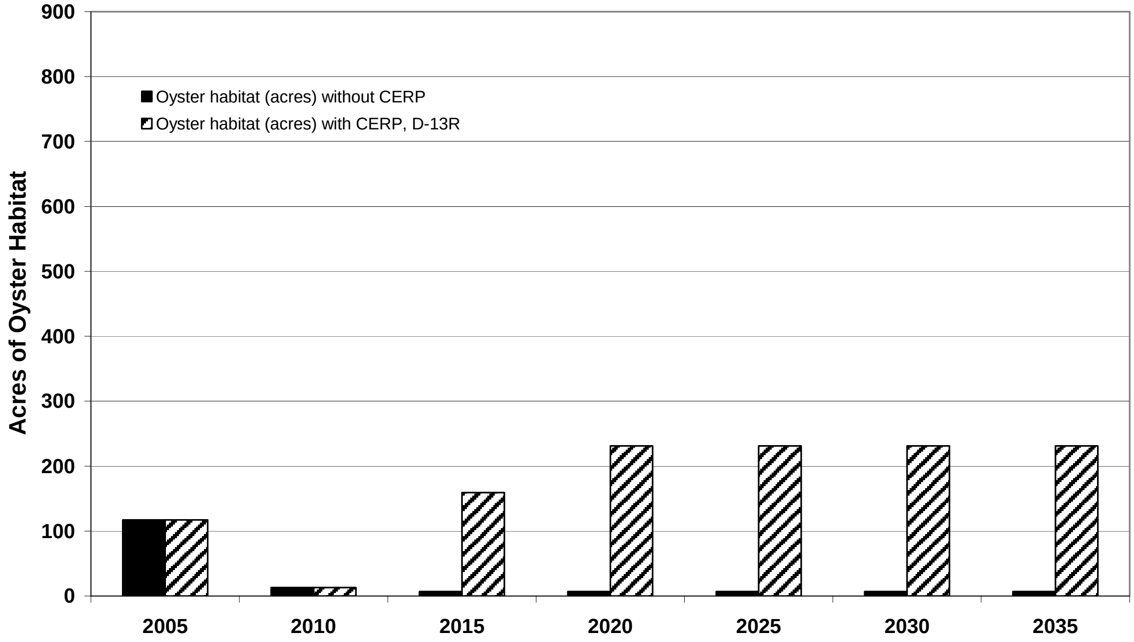

Figure 1.1.8. Change in acres of oyster habitat in the St. Lucie Estuary comparing future without implementation of the Indian River Lagoon-South Selected Plan and the CERP and with full implementation of both plans.

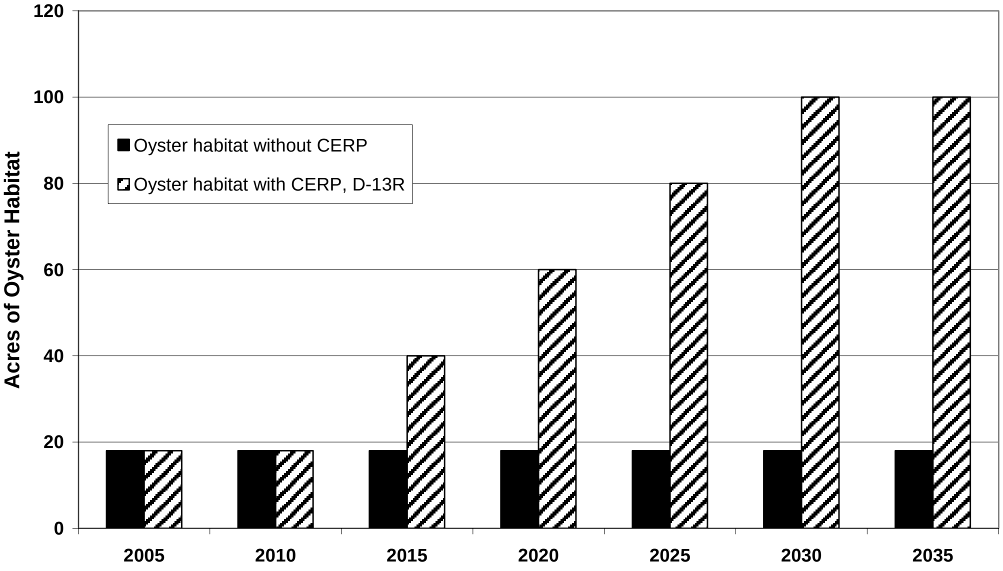

Figure 1.1.9. Change in acres of oyster habitat in the Caloosahatchee Estuary comparing future without CERP implementation and with full CERP implementation (D-13R).

How will we track whether the interim goals established for the indicator have been achieved?

The interim goal for oysters will be assessed by measuring spat abundance and distribution, the spatial extent of oyster beds, and oyster health. The following metrics are proposed in the *CERP Monitoring and Assessment Plan: Part 1, Monitoring and Supporting Research* (RECOVER 2004): spat settlement during the months of peak recruitment, percent of adults live and dead, and adult sizes (live and dead), condition and gonadal index, and disease intensity of *Perkinsus marinus* (Dermo). A description of metrics is provided below:

- **Spat** - Recruitment of spat can be determined for each estuary by one or more of the following methods: shell hangers (Haven and Fritz 1985), tiles, or trawls.
- **Survival** - Spat survival to maturity can be monitored by measuring growth parameters throughout a 2-year cycle. Alternatively, growth and survival of hatchery raised juvenile oysters deployed in the field may be monitored
- **Distribution** - Aside from the existing periodic mapping of oysters, at least three monitoring sites will be established in each estuary. Each site should support an existing population of oysters. The sites should be distributed along the estuarine salinity gradient. Number and sizes of live and dead shells will be estimated on an annual basis, at minimum.
- **Health -** Oyster health can be assessed in several ways: 1) monitoring infection intensity of Dermo, a highly pathogenic protozoan parasite; 2) determining the condition index on adult oysters for evaluation of reproductive and metabolic

activity (Lucas and Beninger 1985; CI=dry meat weight/dry shell weight x 100); and 3) visual observation of the shell for presence of drill holes, boring sponges, etc.

A baseline for oysters in each estuary must be established by mapping the existing distribution of reefs/beds, size class distribution, and percentage of alive/dead. Historical distributions, if available, would assist in identifying areas that may have suitable habitat conditions for reestablishment, given predictive changes in the salinity regime with CERP implementation. During CERP implementation, maps of the area including size distribution, percentage alive/dead, and depth of the oyster community should be prepared at various time intervals depending on the existence of oyster reefs prior to CERP implementation. Since each estuarine system is different and the life history of oysters in each system is known at varying levels of detail, it may not be necessary to monitor all metrics in all systems.

What additional work is needed to improve this interim goal?

Tasks that must be completed in all Northern Estuaries for model creation and verification include the following:

- Evaluate oyster density based on a salinity gradient, which corresponds to distance from an inlet.
- Perform an oyster mortality study to verify data collected in mesocosm experiments with field data (short-term with and without Dermo).
- Collect recruitment data along salinity gradients by monitoring spat settlement.
- Collect growth and survival of multiple cohorts along a salinity gradient by monitoring live and dead oysters.
- Monitor longevity of spat through mature oyster by measuring growth parameters throughout a 2-year cycle. Alternatively, growth and survival of hatchery raised juvenile oysters deployed in the field may be monitored (Dermo mortality rates).

Caloosahatchee Estuary

In order to provide quantitative and specific goals for the Caloosahatchee Estuary, a detailed population level model for oysters is required. This model would need to provide predictions of recruitment, growth, and survival of multiple cohorts as a function of hydrologic changes. A habitat suitability index model exists for Gulf of Mexico oysters (Cake 1983). The model has to be optimized on a local/regional basis to be used as a predictive tool for each restoration project.

St. Lucie Estuary

In order to provide quantitative and specific goals for the St. Lucie Estuary, a detailed population level model for oysters is required. This model would need to provide predictions of recruitment, growth, and survival of multiple cohorts as a function of hydrologic changes. Such models simply do not exist at the present time.

Loxahatchee Estuary

Information needed to improve the predictive capabilities of the existing Loxahatchee Estuary oyster model includes the following:

- Laboratory salinity/temperature assays of endemic oyster populations to replace incomplete literature-derived information from other estuaries
- A field study that exposes local oysters to many different sets of variable salinities and temperatures to use for verification of a model developed from laboratory data that had constant conditions until mortality occurred
- A filed study that determines oyster food composition and assimilation efficiency under varying water quality conditions needs to be addressed (i.e., nutrients, phytoplankton density/composition, seston composition)
- Field evaluation of recruitment, growth, disease, condition, and density in relation to environmental conditions
- A field investigation to determine recruitment of newly placed cltch to document the succession and success of this method to expand population distribution by providing appropriate substrate for colonization when water quality improves as a result of watershed runoff modification

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