Charlotte Harbor National Estuary Program
Oyster Habitat Restoration Plan

Charlotte Harbor National Estuary Program
Technical Report
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The Charlotte Harbor National Estuary Program is a partnership of citizens, elected officials, resource managers, and commercial and recreational resource users working to improve the water quality and ecological integrity of the greater Charlotte Harbor watershed. A cooperative decision-making process is used within the program to address diverse resource management concerns in the 4,700 square mile study area. Many of these partners also financially support the Program, which, in turn, affords the Program opportunities to fund projects such as this. The entities that have financially supported the program include the following:

U.S. Environmental Protection Agency
Southwest Florida Water Management District
South Florida Water Management District
Florida Department of Environmental Protection
Peace River/Manasota Regional Water Supply Authority
Polk, Sarasota, Manatee, Lee, Charlotte, DeSoto and Hardee Counties
Cities of Sanibel, Cape Coral, Fort Myers, Punta Gorda, North Port, Venice,
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Glossary of Acronyms

CCMP	*Comprehensive Conservation and Management Plan*
CERP	Comprehensive Everglades Restoration Plan
CHNEP	Charlotte Harbor National Estuary Program
CZMA	Coastal Zone Management Act
ERP	Environmental Resource Permit
ESA	Endangered Species Act
FAC	Florida Administrative Code
FCMP	Florida Coastal Management Program
FDACS	Florida Department of Agriculture and Consumer Services
FDEP	Florida Department of Environmental Protection
FGCU	Florida Gulf Coast University
FWC	Florida Fish and Wildlife Conservation Commission
FWRI	Fish and Wildlife Research Institute
GIS	Geographical Information System
GSMFC	Gulf States Marine Fisheries Commission
HSM	Habitat Suitability Model
MFL	Minimum Flows and Levels
NMFS	National Marine Fisheries Service
NRCS	United States Department of Agriculture Natural Resources Conservation Service
NOAA	National Oceanic and Atmospheric Administration
NWR	National Wildlife Refuge
NWP	Nationwide Permit
PRMRWSA	Peace River Manasota Regional Water Supply Authority
RSM	Restoration Suitability Model
SBEP	Sarasota Bay Estuary Program
SCCF	Sanibel Captiva Conservation Foundation
SFWMD	South Florida Water Management District
SWFOWG	Southwest Florida Oyster Working Group
SWFWMD	Southwest Florida Water Management District
SWFRPC	Southwest Florida Regional Planning Council
TNC	The Nature Conservancy
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Service
WCIND	West Coast Inland Navigation District
WMD	Water Management District

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Short Executive Summary

The Charlotte Harbor National Estuary Program (CHNEP) Oyster Habitat Restoration Plan is the product of a partnership between the CHNEP and The Nature Conservancy (TNC). The purpose of the Plan is to provide a technically sound, consensus-based approach for identifying oyster habitat restoration goals, methods and partnerships for the estuaries within the CHNEP. The Southwest Florida Oyster Working Group (SWFOWG), a diverse group representing local stakeholders, was convened to assist in the development of this plan. The plan provides the guidelines for native oyster habitat restoration within the CHNEP study area using a regional partnership approach. For the purposes of the plan oyster habitat is defined as substrate upon which a self-sustaining native oyster community develops, providing habitat for commensal flora and fauna.

A Restoration Suitability Model (RSM) was developed as part of the plan to help guide future restoration decisions within the CHNEP study area, and progress towards the CHNEP restoration goal. The RSM uses the best-available GIS data to map the locations of suitable restoration areas on a scale of 0-100% suitability. The data layers used include: seagrass persistence, aquaculture lease areas, boat channels, bathymetry and tidal river isohalines. The output from the RSM indicates that there is over 40,000 acres of highly suitable areas for oyster restoration within the CHNEP study area. Due to the limitation of the data used to create the RSM model, prior to any restoration, site-specific field evaluations should be conducted to further evaluate if a site is suitable for oyster restoration, and what type of methods will be most successful.

Based on the limited amount of data available on historic oysters, estimates show a 90% loss of oyster habitat in the CHNEP study area. This loss is commonly thought to be a result of dredging, oyster mining for road beds, sedimentation and coastal development, and to a lesser extent commercial harvest. The CHNEP goal is to enhance and restore self-sustaining oyster habitat and related ecosystem services throughout the estuaries and tidal rivers and creeks in the study area. More research is needed to determine the number of acres of restoration required, but estimates provide that the CHNEP study area should have 1,000-6,000 acres of oyster habitat under ideal conditions. To accomplish the long term goal, the following actions are recommended over the short term:

- Map oyster habitats by type within the CHNEP by 2020.
- Design, implement and monitor the success of pilot oyster restoration projects in a variety of habitats in 50% of the CHNEP estuary segments by 2020.
- Increase public awareness of the ecosystem value of native oyster habitats by including community stewardship components in each oyster restoration project.
- Assist partners in seeking state, federal and organizational funding opportunities to support oyster habitat restoration projects.

The plan also provides guidance on permitting, success criteria, monitoring, funding opportunities and incorporating community stewardship opportunities into restoration projects. Through the development and implementation of this plan it was the intention of the CHNEP and TNC to provide a document that will guide a consistent approach towards oyster habitat restoration within the CHNEP estuaries. In recognizing that there are many unknowns about oyster habitat restoration in southwest Florida, this plan is intended to be adaptive, incorporating lessons learned into future updates; the next update is planned to be completed no later than 2020.

Introduction

The purpose of the Charlotte Harbor National Estuary Program (CHNEP) Oyster Habitat Restoration Plan (Plan) is to provide a technically sound, consensus-based approach for identifying oyster habitat restoration goals, methods and partnerships for the estuaries within the CHNEP. For the purposes of this document ***oyster habitat is defined as substrate upon which a self-sustaining native oyster community develops, providing habitat for commensal flora and fauna***. The plan was developed through a partnership between the CHNEP and The Nature Conservancy (TNC) to address oyster habitat loss throughout the region. Technical assistance for developing the Plan was provided by the Southwest Florida Oyster Working Group (SWFOWG) through a series of meetings and correspondence. The SWFOWG includes diverse representatives from state and federal agencies, municipalities, non-profits, academia and civic organizations. A list of SWFOWG members and meeting minutes are provided in Appendix A.

The national estuary program was established "to protect and restore the water quality and ecological integrity of estuaries of national significance" (http://water.epa.gov; accessed 8/31/2012). Each national estuary program has a defined study area that includes both the estuaries and their watersheds, within which their work is focused. The CHNEP study area is located in southwest Florida (see Figure 1). The 4,700 square mile (12,175 km^2) study area includes the Peace and Myakka River watersheds and the Caloosahatchee River watershed, upstream to the Franklin Locks near Alva. The CHNEP estuaries extend from Dona and Roberts Bays in Sarasota County, through coastal Charlotte and Lee County to the southern end of Estero Bay (see Figure 2). The CHNEP is a partnership of citizens, elected officials, resource managers and commercial and recreational resource users who are working to improve the water quality and ecological integrity of Charlotte Harbor's estuaries and watersheds. A cooperative decision-making process is used to address diverse resource management concerns throughout the study area.

The CHNEP is guided by the *Comprehensive Conservation Management Plan* (CCMP) (CHNEP 2008) which identifies the priority problems, quantifiable objectives and priority actions needed to protect and restore the natural resources throughout the watershed. The four priority problems in the CHNEP area are water quality degradation (WQ), hydrologic alterations (HA), fish and wildlife habitat loss (FW), and stewardship gaps (SG). The CHNEP Oyster Habitat Restoration Plan addresses all four priority problems and implements the following CCMP Objectives and Actions:

- FW-1: Meet the objectives for the target extent, location and quality of the following habitats: submerged aquatic vegetation, submerged and intertidal un-vegetated habitats, mangroves, saltwater marsh, freshwater wetlands, oyster bars, native upland communities and water column.
- FW-F: Restore and protect a balance of native plant and animal communities.
- WQ-E: Implement projects to restore or protect water quality to offset anthropogenic impacts.
- HA-1: Identify, establish and maintain a more natural seasonal variation in freshwater flows for rivers and tributaries.
- FW-P, WQ-M and HA-P: Support public involvement programs addressing habitat and wildlife, water quality, hydrology, water resource, water conservation and water use issues.

Figure 1: The CHNEP Study Area and Watersheds

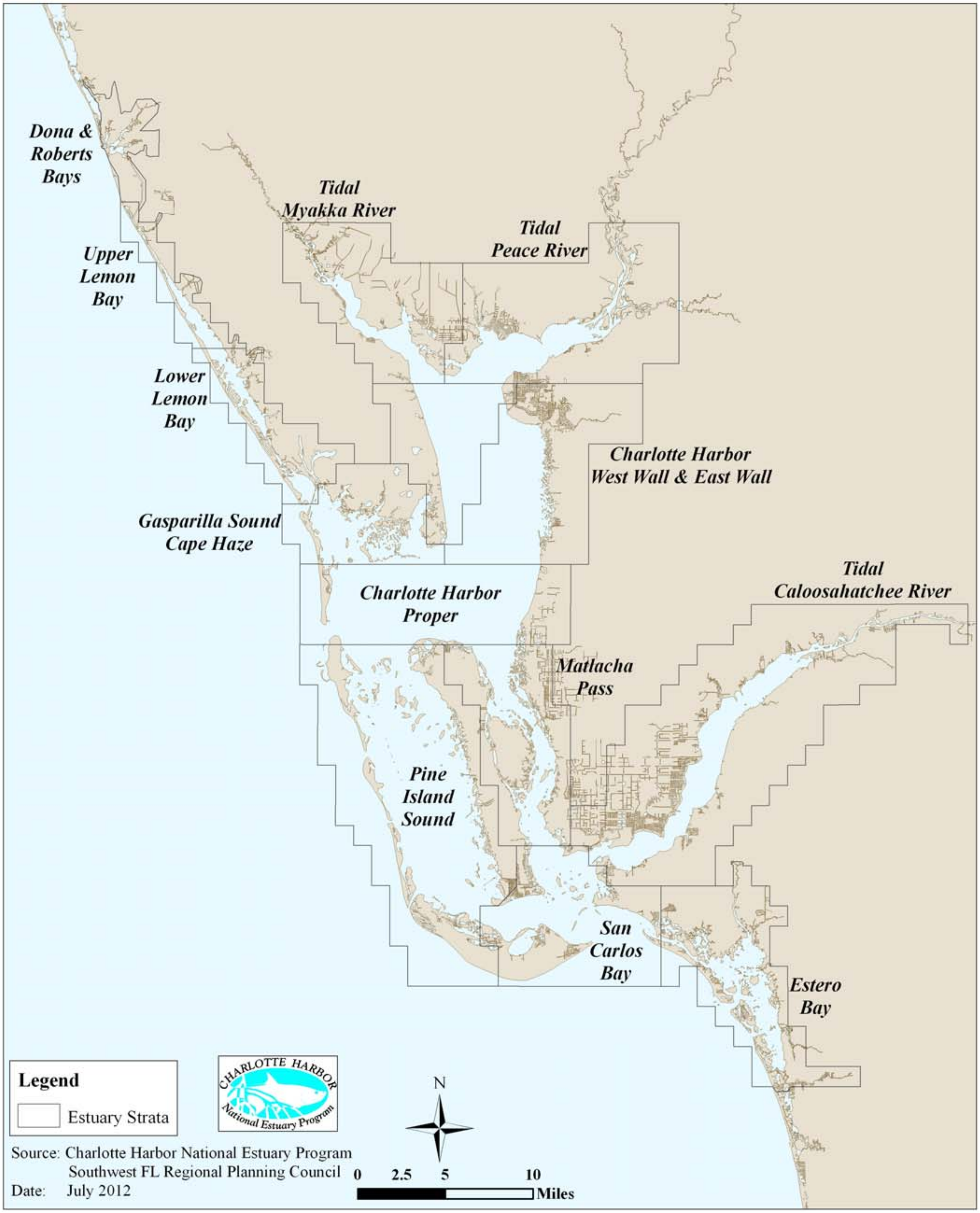

Figure 2: Estuaries and Estuary Strata in the CHNEP Study Area

- SG-B: Provide people with opportunities to be involved in research, monitoring and restoration.
- SG-D: Produce watershed and estuary communication tools.
- SG-R: Track and present monitoring data according to CHNEP adopted targets in Environmental Indicators and present information in a readily understood form.

The objectives of this document are to:

- Implement relevant elements of the CHNEP CCMP.
- Share information, develop consistency among restoration projects and form partnerships to implement restoration projects.
- Provide guidance on permitting requirements and other management considerations for oyster habitat restoration.
- Identify priority oyster habitat restoration sites for each of the CHNEP estuaries using a science-based approach and the best available data.
- Identify a set of appropriate oyster habitat restoration techniques using a science-based approach.
- Define success criteria for oyster habitat restoration projects.
- Develop a science-based restoration and monitoring plan for oyster habitat restoration projects which includes options for evaluating the success of individual restoration projects as well as minimum standard monitoring requirements for all restoration projects designed to contribute to achieving the CHNEP Oyster Habitat Restoration goals.
- Develop a science-based long-term monitoring plan for oyster habitat within the CHNEP study area.
- Identify potential partnerships and funding sources for oyster habitat restoration and monitoring projects.
- Identify opportunities for public outreach and public involvement in oyster habitat restoration.

Oyster Restoration Background

Oyster Population and Habitat Loss

World-wide oyster populations have been lost at a staggering rate, with a total estimated loss of 85% globally over the last two centuries (Beck et al. 2011). This rate of loss makes oysters the most imperiled marine habitat in the world (Brumbaugh et al. 2010). In the United States, since the late 1800s, 60% of oyster reefs have been lost in spatial extent and greater than 85% in total biomass. This indicates that even where oysters remain they are likely to be functionally degraded (zu Ermgassen 2012).

> **“Along with that of the American bison, the decline of the oyster population is one of the most striking cases of the depopulation of a once-flourishing species following in the wake of man’s activities.” (Gross and Smyth 1946)**

The intense mechanical harvest of wild oysters is the most wide-spread cause of oyster degradation (Beck et al. 2011). Mechanical harvesting results in loss of vertical relief of oyster reefs. Other stressors include alteration of shorelines (e.g., erosion and loss of mangroves), coastal watershed development, sedimentation, disease, changes in freshwater flow, anoxia, introduced species (e.g., green mussels), excess nutrients and pollutants, and intensive boating activity (Beck et al. 2009, 2011; Grizzle et al. 2002). The initial degradation and loss of vertical relief, typically from oyster fishing pressure, is thought to have made oysters more susceptible to these other stressors, now making recovery more challenging (Jackson et al. 2001).

The Gulf of Mexico is one of the few remaining regions in North America that is still providing wild caught native oysters to the oyster fisheries market (Beck et al. 2011). In fact by the early 1900s the native Eastern oyster (*Crassostrea virginica*) populations along the Atlantic coast had already declined greatly, and since then the Gulf States have been the only region with a stable oyster fishery production (GSMFC 2012, Kennedy 1996). Beck and others (2011) classified the majority of the Gulf as being in fair condition (50-89% loss); consistent with the results of Seavey and others (2011), who just recently estimated a 66% net loss of oysters in the Big Bend area of Florida.

Oyster harvest in northwestern Florida has remained relatively stable, and currently makes up 10% of the total harvest of oysters from the Atlantic and Gulf States. Harvest from the Gulf States contributes 80-90% of wild oysters harvested within the United States (GSMFC 2012). The stability of the oyster fishery in Florida is tied to a persistent oyster 'shell-planting' program which began in 1913 under the direction of Florida Department of Agriculture Shellfish Division (Zajicek and Wilhelm 2008, GSMFC 1991), as well as the ban of mechanical devices and trawls for harvesting oysters (put in place in 1988), and other fisheries management regulations (e.g., size and bag limits) (GSMFC 2012). Commercial oyster harvest was productive in southwest Florida until the mid-1980s (Geselbracht 2010). In the 1960s, with the decline of the oyster fishery along the Atlantic coast, there was an increased interest in commercial oyster harvest in Charlotte County and an oyster shucking plant was opened in Placida. Shell and oyster seed planting was practiced to help maintain productivity (Woodburn 1965). Prior to European settlement in the Charlotte Harbor area, the Native American population had long been sustainably utilizing the oyster reefs as a food source as evidenced by the remaining shell mounds throughout the area.

Although oyster harvest post-European settlement may have contributed in part to the loss of oyster habitat in the CHNEP study area, commercial harvest in the area was not long lasting, by the early 1970s large portions of the area were closed to harvest due to pollution (Taylor 1974). Adverse effects from a combination of dredging, oyster mining for road beds, sedimentation and coastal development are thought to have caused the decline of oyster populations in the area. Taylor (1974) noted that over 11,000 acres of the Charlotte Harbor estuaries had been effected by the development (and associated dredging) of Port Charlotte, Punta Gorda, Cape Coral, Fort Myers and Sanibel by the early 1970s. A few specific accounts of oyster habitat destruction include the use of dynamite to remove an extensive oyster reef in the mouth of the Caloosahatchee River in order to allow for boat traffic, oyster mining to build road beds in Fort Myers, and dredging of the intercoastal waterway through Lemon Bay that removed a subtidal oyster reef (Jim Beever, pers comm; Woodburn 1965). As a whole, oyster populations in southern and eastern

Florida are not in as good of condition as the rest of the Gulf, with an estimated 90-99% loss of historical oyster reefs (Beck et al. 2009); this higher percentage of loss may be a result of more intense coastal development.

> **"In 1876 I came to the west coast of Florida from one of the largest oyster-growing sections in the world, Chesapeake Bay. I landed at Cedar Keys and at once became interested in the oyster-beds of Florida…I continued southward to the Alafia River, Big and Little Manatee, Sarasota, Boca Grande oyster-bars and 100 miles farther south, and on every hand I found the same condition – oysters, oysters everywhere. How little did I then think that in less than twenty-five years every one of these bars would be partially or totally depleted." (Smeltz 1898)**

The degradation and loss of native oysters in Florida and the need for restoration has been recognized for over 100 years (Smeltz 1898). However, it has only been over the past couple of decades that the critical role that oysters play in the larger ecosystem has been recognized along with the full array of benefits that could be realized through restoration (Coen et al. 2007a, Grabowski and Peterson 2007, Coen and Luckenbach 2000). Brumbaugh and others (2010) recommend that a paradigm shift in coastal ecosystem management is needed in order to restore and manage these habitats for the benefit of humans and ecological communities. In addition to its benefit to oyster fishery enhancement, oyster restoration should also be valued for the array of ecosystem services offered by healthy oyster communities (Brumbaugh et al. 2010, Beck et al. 2009).

> **"Actions recommended to reverse this decline and enhance oyster reef condition include improving protection; restoring ecosystems and ecosystem services; fishing sustainably; stopping the spread of non-natives; and capitalizing on joint interests in conservation, management, and business to improve estuaries that support oysters." (Beck et al. 2011)**

In the words of Brumbaugh and others (2010) "more deliberate action is needed for us to realize not just a no net loss of these particular habitats, but a dramatic net gain." These actions should include improved protection, restoration of oyster habitat ecosystems, sustainably managed oyster fisheries, management of non-native competing species, and partnerships between conservation, management and business entities to meet regional goals (Beck et al. 2011). This plan provides the guidelines for native oyster habitat restoration within the CHNEP study area using a regional partnership approach. In recognizing that there are many unknowns about oyster habitat restoration in southwest Florida, this plan is intended to be adaptive, incorporating lessons learned into future updates; the next update is planned to be completed no later than 2020.

Oyster Habitat Ecosystem Services

The ecosystem services that oysters provide are vast and complex (ASMFC 2007, Coen and Luckenbach 2000); the restoration of these services is an essential component of restoring oyster habitat in the CHNEP study area. As ecosystem engineers, oysters play a significant role in shaping the environment in which they live by forming a hard structure upon which an intricate biological community is built (Brumbaugh et al. 2006, Lenihan 1999, Jones et al. 1994). Similar to coral reefs, oyster reefs are 'biogenic' (formed by the accumulation of colonial animals) and provide structure and surface area for numerous other temporary and permanent species. One square meter of oyster reef can provide up to 50 square meters of hard surface (Brumbaugh et al. 2006, Harris et al. 1983, Bahr 1974). Providing complex habitat structure is the most fundamental of ecosystem services that oysters provide. The structure provides a place for algae and non-mobile invertebrates (e.g., sponges, hydroids, bryozoans) to attach, as well as a place for mobile invertebrates and fishes to be protected from predators (ASMFC 2007, Kennedy 1996). Larger fish species and many sportfish (e.g., red drum, sea trout, flounder) are also known to use oyster reefs (Scyphers et al. 2011, ASMFC 2007, Coen et al. 1999). Although the relationships between sportfish and oyster reefs are not as well studied as in other estuarine habitats such as seagrass beds, oyster reefs are considered essential fish habitat (ASMFC 2007, Coen et al. 1999).

> **"Ecosystem engineers are organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in biotic or abiotic materials. In so doing they modify, maintain and create habitats." (Jones et al. 1994)**

The numerous ecosystem services provided by oysters can be summarized into three general categories: habitat provision, water quality improvement and shoreline stabilization (Beck et al. 2009, Coen et al. 2007b, Grabowski and Peterson 2007, Brumbaugh et al. 2006). Oyster reefs provide habitat to a diverse array of flora and fauna, in fact over 150 taxa were identified in association with oyster habitat in a recent Tampa Bay study (Drexler et al. 2010). The role of oyster habitat to the estuarine food chain is highly significant (ASMFC 2007, Wells 1961). Through their feeding process oysters filter large quantities of water which transfers energy and material from the water column to the benthic community, subsequently reducing turbidity and water column nutrients (ASMFC 2007, Coen et al. 2007, Grabowski and Peterson 2007, Bahr and Lanier 1981). Through bio-deposition, nutrients are made available to the flora and fauna which comprise the complex oyster reef food web. As a result of these processes oyster restoration has the potential to reduce eutrophication (especially nutrient loads) and reduce the likeliness of harmful algal blooms and hypoxia (Jackson et al. 2001).

Additionally, oyster reefs stabilize sediments, shorelines and adjacent habitats by buffering wave energy, further aiding water quality (Scyphers et al. 2011, ASMFC 2007, Grabowski and Peterson 2007, Piazza et al. 2005, Bahr and Lanier 1981). Sediment stabilization and bio-deposition can result in an increase in sediment elevation (Bahr and Lanier 1981). Along with the potential for oyster reefs to sequester carbon and buffer wetlands and developed properties (Nicholas Institute 2011), sediment stabilization is an important factor when considering future sea level rise and climate change. For this reason Needelman and others (2012) identify oyster reef as a good conservation target because of their ability to help mitigate the impacts of sea level rise through shoreline and sediment stabilization. Oyster reef creation has specifically been identified as a means of reducing shoreline erosion and loss of saltmarsh habitat due to sea level rise in Charlotte Harbor (Geselbracht et al. forthcoming).

This short overview of the ecosystem services that are provided by oysters is not intended to be comprehensive. For more in depth information, practitioners should consult one or more of the following resources: Brumbaugh and Toropova 2008, Brumbaugh et al. 2006, Coen et al. 2007a, Grabowski and Peterson 2007. Table 1 provides a summary of oyster ecosystem services and some additional references.

Table 1: Oyster Ecosystem Services

Ecosystem Services Category	Ecosystem Services Sub-categories	Select References
Habitat Provision	Essential Fish Habitat, Foodweb, Biodiversity, Fisheries Enhancement, Attachment Habitat, Foraging Habitat	Scyphers et al. 2011, Hadley et al. 2010, Geraldi et al. 2009, ASMFC 2007, Breitburg and Fulford 2006, Rodney and Paynter 2006, Grabowski et al. 2005, Plunket and La Peyre 2005, Tolley and Volety 2005, O'Beirn et al. 2004, Glancy et al. 2003, Guiterrez et al. 2003, Peterson et al. 2003, Harding and Mann 2001, Meyer and Townsend 2000, Coen et al. 1999, Zimmerman et al. 1989, Wells 1961
Water Quality	Water Filtration, Nutrient Bio-assimilation, Turbidity Reduction	Higgins et al. 2011, Piehler and Smyth 2011, Fulford et al. 2010, Grizzle et al. 2008, Grizzle et al. 2006, Newell et al. 2005, Piazza et al. 2005, Nelson et al. 2004, Cressman et al. 2003, Pietros and Rice 2003, Gerritsen et al. 1994
Shoreline Stabilization	Living Shorelines, Decrease Erosion, Substrate Stabilization, Sedimentation, Benefit Adjacent Seagrass Beds	Geselbracht et al. 2012, Scyphers et al. 2011, Newell et al. 2005, Piazza et al. 2005, Nelson et al. 2004, Newell and Koch 2004, Pietros and Rice 2003, Meyer et al. 1997
Other	Carbon Sequestration, Cultural Significance, Species Migration Route for Sea Level Rise	Geselbracht et al. 2012, Grabowski and Peterson 2007

Oyster Life History

In order to design an effective restoration plan it is important to understand the general life history of the Eastern oyster, also referred to as the American oyster. An in depth review of this species' life history was written by Galtsoff (1964), followed by a more recent review by Kennedy and others (1996). Volety and Tolley (2004) and the Gulf States Marine Fisheries Commission (2012) also provide more updated reviews, with a focus on Eastern oyster life history in the Gulf of Mexico. These references should be consulted for more detailed information. Below is an overview of Eastern oyster life history as it pertains to restoration:

- Eastern oysters are oviparous, meaning that they spawn unfertilized eggs.
- Eastern oysters are 'protandric' (most are males earlier in life then change to females). The proportion of females is higher in the larger, older subset of the population.
- Oysters in southwest Florida are most reproductively-active from March-November, but can reproduce throughout the year.

- Maximum spawning in southwest Florida occurs when water temperature exceeds 26-28ºC, peaking in May-October.
- Temperature, depth, salinity, sediment, availability of food, and pollution can affect gonad development.
- Synchronized spawning is typically triggered by one male spawning which initiates spawning throughout the immediate population.
- Once an egg is fertilized, a free-swimming larva develops within 24-48 hours.
- Larvae remain in the water column for 2-3 weeks where they may vertically migrate to adjust movement with tidal flows in order to stay in optimal salinity waters.
- After 2-3 weeks the larva develops a foot; when the foot contacts a hard substrate the larva stops swimming, using the foot to move across the surface to find an attachment site; they can resume swimming at this point or settle permanently.
- Once the larva attaches or 'sets', the larval stage ends and they are referred to as 'spat'; spat are typically 248-400 µm in diameter.
- Spat settle more commonly on old shells and where other spat are located, most likely due to a waterborne attractant.
- Spat are known to settle preferentially on the underside of old oyster shells, presumably to avoid light and siltation.
- Individual oysters typically live 3-5 years in the CHNEP study area (SWFOWG, pers. comm.), though oysters have been documented to live up to 20 years.
- Oyster reefs can continue to grow for 100s-1000s of years.

Oyster Distribution

Eastern oysters are found along the estuaries of the Atlantic coast from Nova Scotia to Florida, throughout the Gulf of Mexico, and as far south as Brazil (Kennedy 1996). In addition to hard substrates to settle upon, one of the major contributing factors to oyster distribution is salinity. In southwest Florida, optimal oyster salinities are 14-28 psu, although they can tolerate a wider salinity range (GSMFC 2012, Volety and Tolley 2003). In the more northern regions of their distribution, oysters are found only subtidally due to freezing conditions in the winter. In southern states along the Atlantic coast oysters are primarily intertidal and are limited subtidally by predation, dissolved oxygen, sediment type and substrate availability (Wells 1961; Coen, pers. comm.). In the Gulf of Mexico there are both subtidal and intertidal oyster reefs (Kennedy 1996). Higher growth rates in the warmer Gulf waters (Kennedy 1996) may allow for oysters to survive subtidally despite higher predation rates. Due to the limited information about oyster distribution prior to the mid-1900s in the Charlotte Harbor area, it is unknown how extensive subtidal and intertidal oyster reefs were historically. However, the presence of subtidal oyster reefs was documented in Lemon Bay and Charlotte Harbor in the 1960s and recently in the Caloosahatchee River (Woodburn 1965; Volety and Rasnake, pers. comm.).

In addition to oyster reefs, oysters also settle on mangrove prop roots and seawalls in abundance, and any other hard substrate. These other types of oyster communities remain understudied. However, Drexler and others (2010) examined various oyster community types (i.e., natural reef, seawall, mangrove and restored sites) and found that they had similar biological parameters and faunal diversity. The study also provided a method for estimating total oyster abundance on seawalls and mangroves and found that in Tampa Bay these areas provided a greater overall abundance of oysters than do reefs. Mangrove habitats, and seawalls to a lesser extent, should be considered in future studies and mapping efforts for their ecosystem value.

Many factors can affect the spatial distribution, survival and success of oysters, including:

Substrate: Hard substrate provides protection from predators and allows for development of juvenile oysters (Krantz and Chamberlain 1978). Shifting sands and extremely soft mud are not generally suitable for oyster habitat (Galtsoff 1964). However, some restoration methodologies have been developed that are suitable for softer substrates (e.g., Manley et al. 2010), as discussed in the Oyster Restoration Strategies section of this plan.

Water flow: The flow of water should be great enough to provide oxygen and food, and to carry away waste products from the oysters and reef residents. However, strong currents and high flows are not beneficial to oysters because they can carry away larvae. (Galtsoff 1964, GSMFC 2012) Lenihan (1999) demonstrated that on experimental reefs water flow was the predominant influencing factor on oyster growth and mortality.

Salinity: Oysters are found in mesohaline (5-18 psu) and polyhaline (18-30 psu) estuarine waters (Galtsoff 1964). The optimal salinities for oysters in southwest Florida are 14-28 psu, although they can be found in salinities ranging from 5-40 psu (GSMFC 2012, Volety and Tolley 2003). Adult oysters can survive in salinities as low as 2 psu for up to a month (Volety and Tolley 2003). In higher salinities oysters are limited more by predation than by physiology. Most oyster predators are found in higher salinities, with the exception of blue crabs (Wells 1961) and non-aquatic organisms (e.g., oyster catchers).

Food Availability: Oysters rely on phytoplankton in the water column for food. Because they are sessile organisms there must be enough water flow and phytoplankton to continually renew the food supply. (GSMFC 2012) The CHNEP estuaries are naturally rich in phytoplankton, so food availability is not typically a limitation as long as there is adequate water flow. Food abundance will increase with algal blooms resulting from nutrient enrichment. However excessive algal blooms can lead to anoxic/hypoxic conditions and in some cases the production of harmful toxins. (GSMFC 2012)

Dissolved Oxygen: Oysters are not generally affected by low dissolved oxygen unless it drops below 3 mg/L for an extended time. Extended periods of hypoxia or anoxia can cause mass mortality (Lenihan and Peterson 1998). Although dissolved oxygen is not a limiting factor in the intertidal zone in southwest Florida, it is one of the primary factors limiting how deep oysters are found in certain areas.

Disease and parasites: *Perkinsus marinus* is a protozoan parasite that causes the disease 'Dermo' in oysters. The disease intensity generally increases with increasing temperature. Susceptibility to the disease and its progression are also correlated with temperature and salinity (Volety et al. 2000, Chu and

Volety 1997, Chu et al. 1993). Lower salinity levels associated with freshwater pulses have been shown to reduce disease intensity and help maintain the disease at non-lethal levels (La Peyre et al. 2003). Fast oyster growth rates and high recruitment in Gulf of Mexico oyster populations helps the oysters outcompete *P. marinus* (Soniat 1996). Volety and others (2000) also showed a lower prevalence and intensity of disease in oysters at shallower depths (<45 cm below MLW vs. >90 cm). Boring sponges and other fouling organisms can also be considered parasitic and can be harmful to oysters (Galtsoff 1964) by reducing reproductive output and damaging the settlement substrate (GSMFC 2012).

Contaminants: Runoff contains multiple types of contaminants (e.g., PCBs, heavy metals and pesticides) that could be deleterious to oysters, dependent on the concentrations. Although studies to date show that at environmentally relevant concentrations (in the lab) or current concentrations (in the field) contaminants are not greatly affecting oysters (Rasnake 2011, Volety 2008, Bolton-Warberg et al. 2007); oyster health may be affected where multiple stressors are present, including contaminants (Rasnake 2011). For example Volety and others (2003) hypothesize that higher parasite (*Perkinsus marinus*) infection and elevated mortality rates at the Cattle Dock Point oyster reef in the Caloosahatchee River may be related to stress from polluted runoff. Additionally, Volety (2008) showed correlations between some oyster health metrics and heavy metal concentrations but salinity fluctuation influenced conditions to a much greater extent.

Predators: Oyster predators are diverse and include flatworms, echinoderms, mollusks, crustaceans, fishes, birds and mammals (Galtsoff 1964). Oyster drills (e.g., *Stramonita haemastoma, Thais haemastoma, Urosalpinx cinerea, Eupleura caudate*) are among the most harmful to oysters, along with seastars, flatworms and crabs (Galtsoff 1964). Fodrie and others (2008) noted an interesting interactive effect between stone crabs and oyster drills; where present the stone crabs facilitated more successful predation of the oysters by oyster drills. Woodburn (1965) also noted an abundance of the crown conch, another predatory gastropod, in certain locations on Charlotte County oyster reefs.

Sedimentation: Galtsoff (1964) noted that even a thin layer of sediment (1-2 mm) will make surfaces unsuitable for larval settlement and that sedimentation can adversely affect oyster reproduction. In certain areas low profile reefs and the crests of high profile reefs have been less successful because of sedimentation burial (Lenihan 1999). High sedimentation rates at the Cattle Dock reef in the Caloosahatchee River are thought to contribute to poor oyster success rates (Volety and Encomio 2006). In some cases sedimentation is linked to boating activities, which have also been shown to have detrimental effects on oysters (e.g., Wall et al. 2005, Grizzle et al. 2002). In the shallow waters of the Mosquito Lagoon on the central east coast of Florida intense storms do not appear to negatively affect oyster reefs whereas repetitive boat wakes cause damage to the reef structures (e.g., Walters et al. 2007). In 2011 Lee County had the third highest number of boat registrations in the state; cumulatively there are over 80,000 boats registered in Lee, Charlotte and Sarasota Counties (www.flhsmv.gov; accessed September 27, 2012).

Harvesting: Intensive harvesting without replenishment of substrate is one of the primary causes of oyster loss world-wide (Beck et al. 2011), which has been exacerbated by other stressors (Jackson et al. 2001). Lenihan and Peterson (1998) noted that harvesting from subtidal reefs resulted in decreased reef height. Decreased reef height results in higher oyster mortality from hypoxia and anoxia, and adversely affects the invertebrates and fish utilizing the reefs. Proper management of oyster harvest based on accurate estimates of natural mortality, recruitment and harvest mortality, coupled with a substrate replenishment program can allow for sustainable harvest (Jordan and Coakley 2004, Berrigan 1990). There is not currently any commercial harvest in the CHNEP study area.

Ocean Acidification: Ocean acidification resulting from rising atmospheric carbon dioxide concentrations is a growing concern for future oyster populations (Doney et al. 2009). Acidification results in a lower calcium carbonate saturation state which negatively affects shell-forming organisms, including oysters (Doney et al. 2009). Ocean acidification is already causing deleterious effects in oyster hatcheries on the U.S. West Coast (http://www.nsf.gov/news/news_summ.jsp?cntn_id=123822; accessed August 20, 2012).

Local Context

Historical records of oyster reef locations, sizes and quality are limited in most areas, including the CHNEP study area. A coring study in Estero Bay provides that oyster reefs have been a dominant feature in the area since 470 ybp (Savarese et al. 2004). As noted above in the late 1800s the oyster reefs in the area were reportedly quite extensive, but already degraded (Smeltz 1898). The earliest aerial photos to be used for mapping oyster reefs throughout the CHNEP estuaries were from the 1950s (Photo Science 2007). The mapping effort estimated that there were 2,697 acres (10.9 km^2) (see Table 6) of oyster reefs in the region during that time period. However because of the lack of ground-truthing, the accuracy of the maps is unknown. A more recent assessment of aerial photos from 1999 shows 247 acres (1 km^2) of oysters in the same region (Avineon 2004); representing a 90% loss, consistent with the findings of Beck and others (2009). Harris and others (1983) estimated a 39% decrease in oyster habitat from 1945 to 1982 in the CHNEP estuaries, but they caution about the limitations of using aerial photography interpretation to identify the precise historical extent. For example, re-examination of an area mapped as oysters from 1950s aerials on the Gulf of Mexico coast of Fort Myers Beach revealed that this was a sand-spit and not an oyster reef (Laakkonen, pers. comm.); this area was removed from the total acreage referenced above.

Mapping oysters via aerial photography also limits the depth to which features can accurately be mapped, especially if photos are not taken during ideal tidal, water quality and weather conditions. In addition, mapping oysters only using aerial imagery omits oysters located underneath mangroves and reefs or clumps that are too small for aerial photo interpretation. Both historical and recent estimates of oyster habitat should be viewed cautiously due to the limitations and variability introduced from different mapping methodologies (Power et al. 2010). Despite lack of accurate estimates of historic and current acres of oysters, the limited mapping and anecdotal information clearly show that thousands of acres of oysters have been lost. Of the remaining oysters, little is known about the general condition or extent of the populations.

Additional research is needed into historical records, along with coring and other survey techniques to further delineate historic oyster distribution. Although photointerpretation may be one tool to use for future mapping efforts, ground-truthing is a necessity for understanding the accuracy of the maps. Other tools should also be examined (e.g., hyperspectral and multispectral remote sensing, LiDAR, sidescan sonar, low altitude aerial photos) for use in high-accuracy mapping for the CHNEP study area.

Although the majority of existing oyster reefs in the CHNEP study area are intertidal, subtidal oyster reefs are known to exist at least to a depth of six feet (1.8 m) in the Caloosahatchee River (Volety and Rasnake, pers. comm.). To date, oyster restoration projects in the CHNEP study area have focused on shallow (<4 feet) and intertidal waters less than four feet (1.2 m) deep (Volety, pers. comm.; Milbrandt et al. 2012). A recent 25 acre (0.1 km^2) oyster restoration project implemented in the St. Lucie Estuary by Martin County focused predominantly on waters deeper than three feet (0.9 m) (Fitzpatrick, pers. comm.); monitoring of the success of this project will provide insight into the potential for subtidal restoration in south Florida. A comparison of project success at different depths is needed within the CHNEP study area to better understand the ecological benefits of restoration at varying depths.

This Oyster Habitat Restoration Plan builds on research and restoration efforts that have been accomplished in southwest Florida. As new oyster restoration projects are implemented, they will draw on previous experience and local knowledge and in turn will continue to demonstrate both what is successful and what is not. A list of local on-going oyster monitoring efforts, restoration projects and workshops/working groups that contributed to the formation of this plan is provided below. Project contact names are provided for reference in designing and implementing future oyster restoration projects; contact information is provided in Appendix B.

Current Oyster Monitoring and Mapping Efforts

On-going oyster mapping and monitoring efforts in southwest Florida include:

- FGCU Oyster Monitoring Network for the Caloosahatchee Estuary: Conducts oyster monitoring in support of CERP in the Caloosahatchee Estuary and Estero Bay from (1999-present) under a SFWMD Recover contract. Contact Aswani Volety at FGCU.
- FWC State Oyster Monitoring: Conducts oyster monitoring in support of CERP in the St. Lucie estuary using similar protocols as FGCU uses in the Caloosahatchee estuary. (2005-present) Website: http://myfwc.com/research/saltwater/mollusc/ Contact Steve Geiger at FWC.
- Sarasota County Oyster Mapping: Mapping of oysters will be completed in 2012/2013 using a field-based methodology. Contact Kathy Meaux at Sarasota County.
- Sarasota County Oyster Monitoring: Monitoring of oysters as an environmental indicator in Dona and Roberts Bays has been ongoing since 2003. Contact Mike Jones at Sarasota County.
- An ongoing project, “The Deepwater Horizon oil spill: Assessing impacts on a critical habitat, oyster reefs and associated species in Florida Gulf estuaries” funded by a grant from BP/The Gulf

of Mexico Research Initiative through the Florida Institute of Oceanography, includes oyster monitoring and on-the-ground mapping within the Charlotte Harbor estuaries. (2010-2012) Contact Loren Coen or Ed Proffitt at Florida Atlantic University.

- FGCU collected cores throughout Estero Bay to study reef locations in relation to sedimentation and sea level rise in Estero Bay; the SFWMD-funded study was conducted from 1999-2004. The final report "Environmental and Hydrologic History of Estero Bay: Implications for Watershed Management and Restoration" provides a detailed analysis. Contact Michael Savarese at FGCU.

Current Oyster Restoration Activities

On-going oyster restoration projects in southwest Florida include:

- FGCU Oyster Reef Restorations: Restored 18 reefs in the Caloosahatchee Estuary and Estero Bay using a community-based bagged shell approach. (2003-present) Website: http://www.fgcu.edu/CAS/OysterResearch/. Contact Aswani Volety at FGCU.
- Clam Bayou Oyster Reef and Mangrove Restoration, Sanibel Captiva Conservation Foundation (SCCF): Implemented a research-based oyster restoration project in Clam Bayou on Sanibel Island using oyster bags. (2009-2011) Website: www.sccf.org. Contact Eric Milbrandt at SCCF.
- Sarasota Bay Estuary Program Oyster Reef Restoration: Successfully created five small reefs at two locations within Sarasota Bay using a combination of bagged shell along the perimeter and loose shell within each reef. (2010-2012) Website: www.sarasotabay.org. Contact Jay Leverone at Sarasota Bay Estuary Program (SBEP).
- Naples Bay Oyster Restoration, City of Naples: Used a community-based approach to restore reefs using bagged shell and facilitated an oyster-gardening program. (2005-2012) Contact Katie Laakkonen at the City of Naples.
- Tampa Bay Watch Oyster Reef Restoration: Constructed numerous oyster reefs in the Tampa Bay area through a community-based program using oyster bags and oyster domes. (2002-2012) Website: www.tampabaywatch.org. Contact Serra Herndon or Eric Plage at Tampa Bay Watch.

Shellfish Restoration Workshops and Working Groups

Past workshops and on-going working groups related to shellfish restoration in southwest Florida include:

- FWC TNC Florida Oyster Restoration Workshop in March 2007 in St Petersburg FL. Contact Laura Geselbracht at TNC.
- CHNEP Shellfish Restoration Needs Workshop in February 2011 on Sanibel Island. Contact Judy Ott at CHNEP.
- TNC Collaborating to Advance Oyster Restoration in Southwest Florida in February 2011 on Sanibel Island. Contact Anne Birch at TNC.
- IFAS "Creating Oyster Reef Habitat to Enhance Water Quality, Biodiversity, and Shoreline Protection" Workshop in June 2012 in Fort Pierce, FL. Contact LeRoy Cresswell at IFAS.
- Southwest Florida Oyster Working Group. Contact Judy Ott at CHNEP.
- Southwest Florida Regional Bay Scallop Working Group. Contact Betty Staugler at Charlotte County Sea Grant or Steve Geiger at FWC.

Management Considerations

Within the CHNEP estuaries there are various management considerations which should be reflected in the design and implementation of oyster habitat restoration projects.

Florida Aquatic Preserves: The majority of the CHNEP estuarine waters fall within one of six Florida Aquatic Preserves, these are: Lemon Bay, Cape Haze, Gasparilla Sound - Charlotte Harbor, Pine Island Sound, Matlacha Pass, Estero Bay (see Figure 3). This designation by the State of Florida provides additional protection and management by the FDEP with the intention of preserving these areas in their natural or existing conditions. Projects within an aquatic preserve will be evaluated based upon 18-20 Florida Administrative Code (FAC), as described further in the "State Permitting Process" section.

Florida Shellfish Harvesting Areas: The State of Florida, FDACS, designates Shellfish Harvesting Areas (SHAs) in accordance with the Interstate Shellfish Sanitation Conference (ISSC). The designations are reviewed and revised every five years to ensure that harvest areas are sanitary and thus provide a safe source for oyster harvest. There are four SHAs within the CHNEP study area, these are: Lemon Bay, Myakka River, Gasparilla Sound and Pine Island Sound (including Matlacha Pass) (see Figure 4). Within each of these SHAs the waters are further designated as approved, conditionally approved, restricted, conditionally restricted, or prohibited. Waters that are unclassified are considered unapproved for harvesting. Dependent on the goals of an individual restoration project, practitioners may prefer to locate their projects within an SHA (e.g., to provide an oyster fishery resource) or within an unapproved area (e.g., to provide a sanctuary) (Powers et al. 2009, Breitburg et al. 2000, Coen and Luckenbach 2000). For more information visit: www.floridaaquaculture.com.

Aquaculture Lease Areas: Within the SHAs FDACS manages shellfish aquaculture lease areas. There are currently two high density aquaculture lease areas within the CHNEP study area; one in Gasparilla Sound and one in Pine Island Sound (see Figure 4). Restoration of oysters in the vicinity of these lease areas should be designed so as not to impede navigation to and from the lease areas, or to significantly reduce the food availability (i.e., phytoplankton) to the farmed areas.

Endangered Smalltooth Sawfish and West Indian Manatee Critical Habitat: The National Marine Fisheries Service (NMFS) designated smalltooth sawfish critical habitat in September 2009 (50 CFR Part 226). The designation includes the Charlotte Harbor Estuary Unit, which covers the majority of the CHNEP study area (see Figure 5). As defined in the designation the essential features within the estuary unit are "red mangroves and shallow euryhaline habitats characterized by water depths between the Mean High Water line and 3 ft (0.9 m) measured at Mean Lower Low Water (MLLW)." Practitioners designing and implementing projects within the designated critical habitat should consider potential effects to sawfish and sawfish critical habitat. The following references may provide some direction: Poulakis et al. 2011, Poulakis et al. 2010, Smalltooth Sawfish Recovery Plan (NMFS 2009). The Recovery Plan will be updated in 2013. The critical habitat for the West Indian manatee also includes the majority of the estuaries within the CHNEP study area. The only areas not included are Dona and Roberts Bays, Lemon Bay, and the northern portion of Gasparilla Sound (50 CFR parts 1-199; revised October 1, 2000).

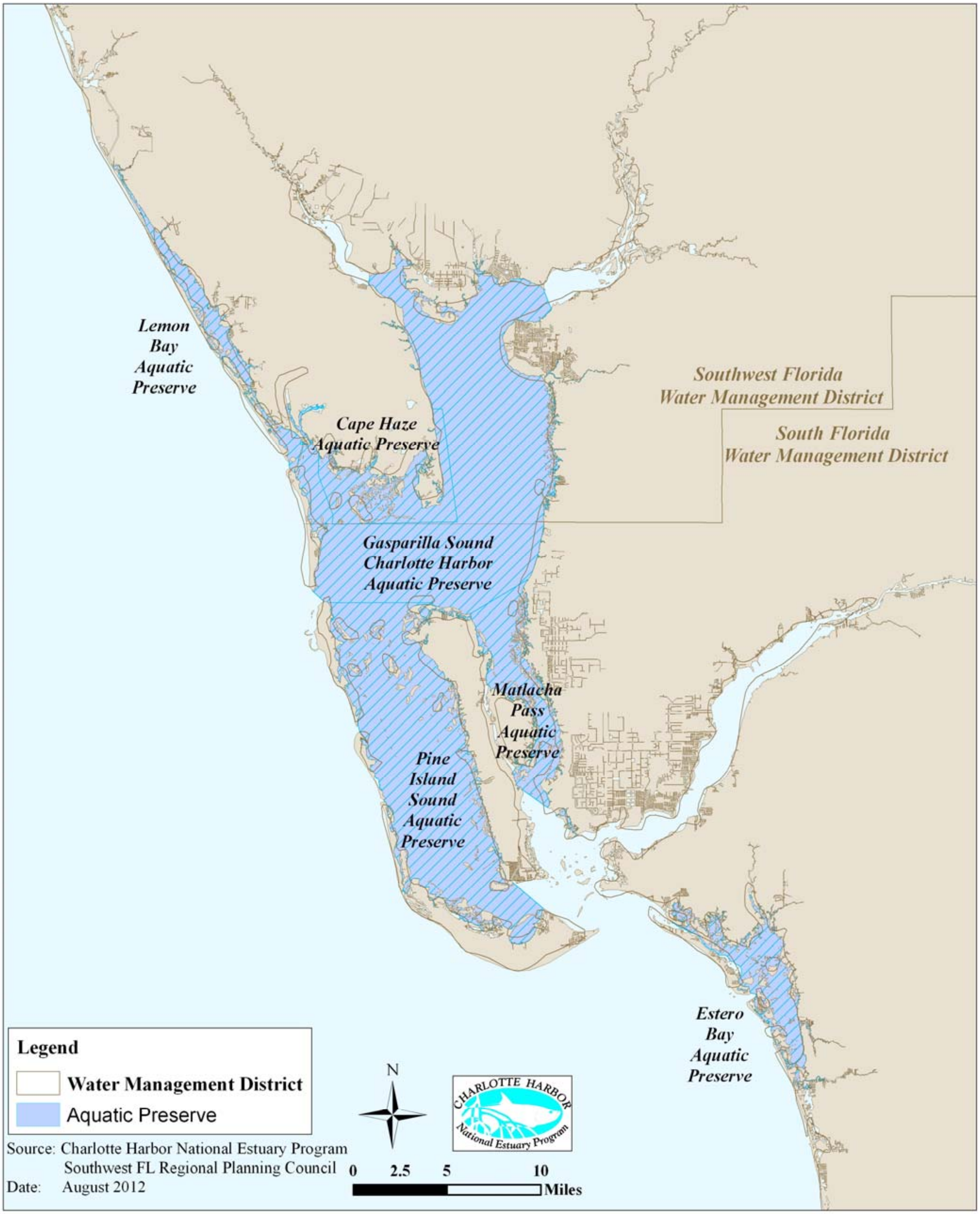

Figure 3: Florida Aquatic Preserves and Water Management Districts in the CHNEP Study Area

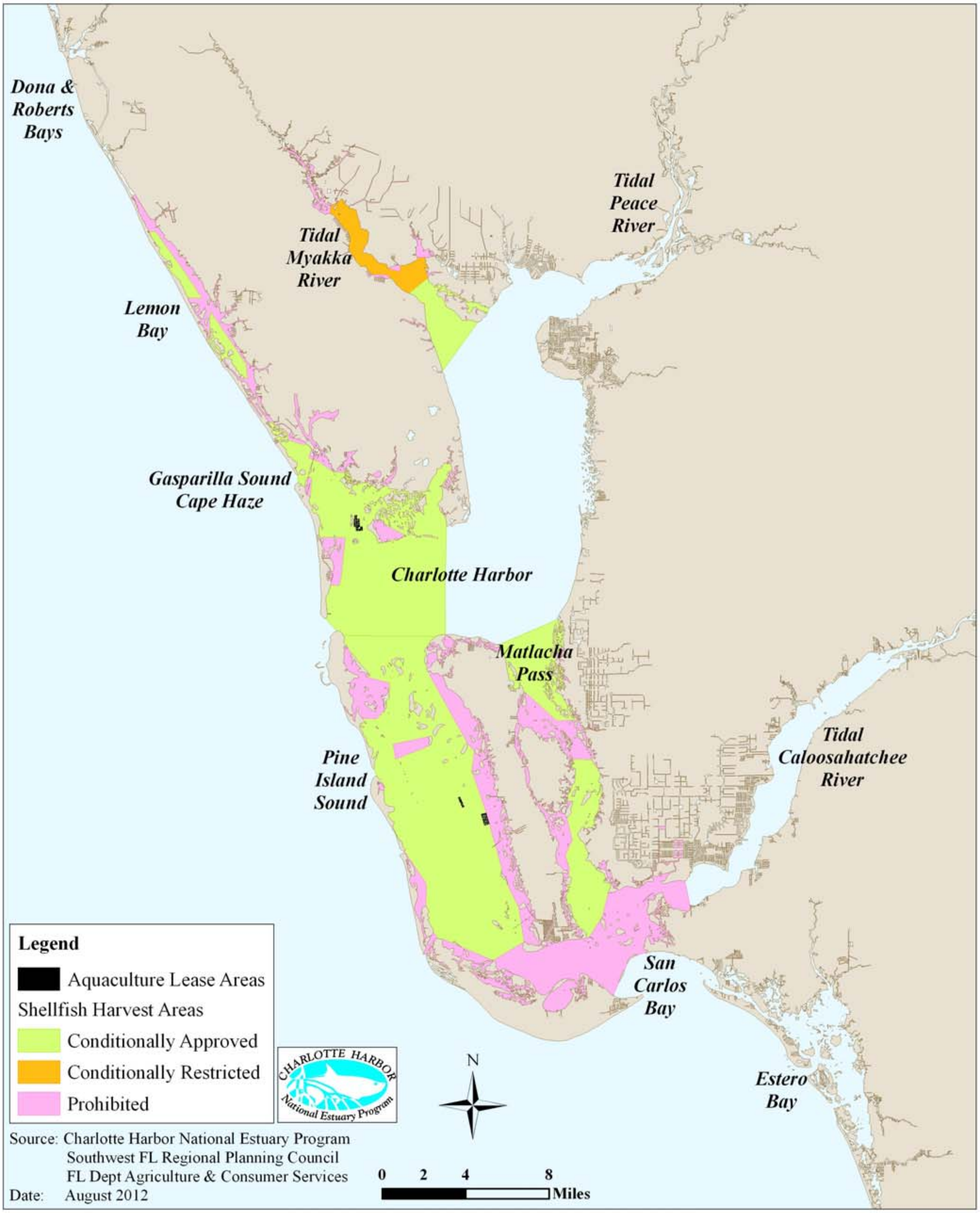

Figure 4: Shellfish Harvest and Aquaculture Lease Areas in the CHNEP Study Area

Figure 5: Critical Smalltooth Sawfish Habitat in the CHNEP Study Area

Water Management: Lastly, water management can greatly affect oyster restoration success. The CHNEP estuaries are managed by two Water Management Districts (WMD): Southwest Florida (SWFWMD) and South Florida (SFWMD) (see Figure 3). The Peace and Myakka Rivers are managed by the SWFWMD in accordance with the Minimum Flows and Levels (MFLs) established for the two rivers (SWFWMD 2011, 2010). The Caloosahatchee River is managed by the SFWMD and the US Army Corp of Engineers (USACE). The continued implementation of the Comprehensive Everglades Restoration Plan (CERP) and implementation of an MFL for the Caloosahatchee River has the potential to improve flows in the Caloosahatchee Estuary, as does the establishment of an MFL for Estero Bay. The effects of water management on the smaller tributaries throughout the CHNEP study area should also be considered when designing oyster habitat restoration projects.

Regulatory Permitting Considerations

Restoration of oyster habitat that involves substrate enhancement requires authorization by federal and state agencies prior to commencement. Federal permits for oyster habitat restoration projects are issued by the USACE. State permits are issued by either the Florida Department of Environmental Protection (FDEP) or one of the WMDs, either the SWFWMD or the SFWMD, in the CHNEP study area. A single joint application can be filed with the FDEP for the state and federal authorizations that are required. Instructions and additional information can be found at:
http://www.dep.state.fl.us/water/wetlands/erp/forms.htm (accessed August 9, 2012).

It is important to stress the value of developing a team approach to permitting oyster habitat restoration projects. Practitioners planning on implementing oyster habitat restoration projects are encouraged to seek pre-application meetings with the federal and state permitting agency staff. Discussions between permitters and practitioners prior to submittal of a permit application creates a team approach to designing a project that meets the desired objectives and helps to ensure that a project meets the permitting requirements. Specific permitting guidance based on individual project information (e.g., size, location, design) will be provided during pre-application meetings.

Federal Permitting Process

Federal authorization for restoration of oyster habitat begins with the USACE. In order to streamline certain types of permitting processes, the USACE has adopted several Nationwide Permits (33 CFR Part 330) for specific types of projects with minimal impacts. Nationwide Permit 27 (NWP 27) for "Aquatic Habitat Restoration, Establishment, and Enhancement Activities" is applicable to oyster habitat restoration activities, specifically "the construction of oyster habitat over unvegetated bottom in tidal waters." With NWP issuance the USACE is likely to include special conditions specific to the restoration location, to ensure that the project results in a net increase in aquatic resources and functions. No compensatory mitigation is required under this type of permit. The current set of NWPs will expire March 18, 2017.

The federal regulations state that no projects will be authorized under a NWP that are “likely to jeopardize the continued existence of a threatened or endangered species as listed or proposed for listing under the Federal Endangered Species Act (ESA), or to destroy or adversely modify the critical habitat of such species.” Applicants should research potential conflicts with federally listed species and notify the USACE at the time of their application.

A large area of the CHNEP estuaries is designated as endangered smalltooth sawfish critical habitat and falls within the boundary of the Charlotte Harbor Estuary Unit (74-FR45353) (see Figure 5). Oyster habitat restoration occurring in areas designated as smalltooth sawfish critical habitat, with the critical features defined above, will be reviewed by NMFS for potentially adverse effects to smalltooth sawfish critical habitat. NMFS will also evaluate the potential effects to the species as a result of specific restoration methodologies. Within the CHNEP estuaries, the other federally listed species that should be considered are the West Indian manatee and sea turtles. Guidance is available on standard construction conditions required when working in regions where these species are a concern. These conditions are considered good practice regardless of the location of the project (see Appendix C).

If federally endangered species or critical habitat might be affected by a proposed project, the USACE can either:

(i) Initiate Section 7 consultation and then, upon completion, authorize the activity under the NWP by adding, if appropriate, activity-specific conditions; or
(ii) Prior to or concurrent with Section 7 consultation, assert discretionary authority and require an individual permit.

When Section 7 consultation is initiated, the USACE will consult with NMFS where smalltooth sawfish and swimming sea turtles are concerned, and the U.S. Fish and Wildlife Service (USFWS) where birds, nesting sea turtles or mammals are concerned. If the permittee knows that a Section 7 consultation is likely to be required they may wish to pursue an ***early consultation*** with the agency ***prior to submitting a federal permit application***. The permittee should contact the USACE, the lead agency, to explain the project; the USACE will then setup pre-application meetings. The early consultation will result in a preliminary biological opinion and a determination of whether a formal consultation will be required. A determination that the project is “not likely to adversely affect” before the application is submitted would minimize the chance that the USACE would require an individual permit for reasons related to endangered species.

Alternatively, the permittee can ***submit their application*** acknowledging potential affects under the Endangered Species Act. At this point most applications will be reviewed through an ***Informal Consultation*** process, during which the agency will determine if the action is “likely to adversely affect species or critical habitat.” If the project is found to be “likely to adversely affect” then the application will be reviewed under a Formal Consultation process. The Formal Consultation results in a biological opinion that will determine if the project jeopardizes listed species or critical habitat. Please see the Endangered Species Consultation Handbook for additional information (http://www.fws.gov/endangered/esa-library/index.html; accessed August 10, 2012). The reviewing agencies may work with the applicant to include special conditions or project design criteria in the permit that will limit adverse effects while allowing the project to move forward.

The Coastal Zone Management Act (CZMA) requires the USACE to receive a consistency determination from the Florida Coastal Management Program (FCMP) prior to issuing a permit. Where a NWP is applicable the USACE will issue a verification letter with a special condition stating the applicant is required to obtain the consistency determination. This process ensures that each project is consistent with existing state statutes that are in place to protect the state's natural, cultural and economic coastal resources. More information can be found on the FDEP website (http://www.dep.state.fl.us/cmp/federal/index.htm; accessed July 31, 2012).

State Permitting Process

State permits for projects located on sovereign submerged lands (i.e., state owned) are generally issued by the FDEP. The exception is when FDEP is the permit applicant, in which case the permits are issued by the WMD (either the SWFWMD or the SFWMD for projects within the CHNEP study area, depending on the project location). There are several other exceptions where permit review is delegated to the WMD, including when a project, such as oyster habitat restoration, is part of a larger project already being reviewed by the WMD.

Within the CHNEP estuaries, most of the submerged lands are state owned, with the exception of a few privately held submerged parcels. Therefore, most oyster habitat restoration projects will require sovereignty submerged lands authorization, and an Individual Environmental Resource Permit (ERP), both of which are evaluated through the ERP review process. As mentioned above a joint application can be filed that will include all required federal and state authorizations.

The ERP process follows Chapter 373, Florida Statutes, and the rules there under. Chapter 18-21 FAC governs sovereignty submerged lands management and uses, and guides the permitting decisions. The rule defines several types of authorization for different activities and 18-21.005 FAC states that a letter of consent is the type of authorization for habitat restoration and enhancement activities. Rule 18-21 FAC requires that all projects occurring on sovereign submerged lands must not be contrary to the public interest. Therefore, when designing and permitting oyster habitat restoration projects, practitioners should review the public interest conditions included in 18-21 FAC, and consider things such as the location of the project in relation to navigational channels, and other public or private interests such as commercial fishing. Additionally, practitioners should consider the potential effect of the project on state threatened and endangered species. Maintaining a minimum distance of 300 feet from active bird rookery islands is also suggested; in cases where oyster habitat restoration may be beneficial to the rookery islands the FDEP and USFWS should be involved in the project design process.

The CHNEP estuaries include six Florida Aquatic Preserves (see Figure 3). Aquatic Preserves are established under Florida Statute 258, allowable uses and management policies are provided in 18-20

FAC. Activities in the Aquatic Preserves must have a positive public benefit, and dredging and filling is prohibited, with few exceptions. One exception is that "other alteration of physical conditions as may, in the opinion of the trustees, be necessary to enhance the quality or utility of the preserve or the public health generally" may be authorized. The Aquatic Preserve rule states that "other uses of the preserve, or human activity within the preserve, although not originally contemplated, may be approved by the Board, but only subsequent to a formal finding of compatibility with the purposes of Chapter 258, Florida Statutes, and this rule chapter." In order to receive authorization, an oyster habitat restoration project proposed within an aquatic preserve should demonstrate that the project is designed to have an overall benefit to the aquatic preserves, and should be consistent with existing aquatic preserve management plans.

To meet the intent of 18-20 FAC, an authorized project, should clearly demonstrate more benefits than costs. Some of the benefits, as listed in 18-20.004 FAC, that oyster habitat restoration may provide to the aquatic preserve include: improving public land management, improving and enhancing water quality, enhancing and/or restoring natural habitat and functions, and improving/protecting endangered/threatened/unique species. Dependent on the design of the project some "costs" to the aquatic preserves could be increasing navigational hazards and congestion, and reducing or degrading aesthetics.

Table 2 provides a summary of regulatory and permitting requirements for oyster restoration and enhancement projects. Aquatic Preserve, Water Management District and Critical Smalltooth Sawfish Habitat boundaries are shown in Figures 3 and 5, respectively. Estuary specific maps are provided in Appendix E.

Table 2: Regulatory Requirements for Oyster Habitat Restoration and Enhancement Projects

Authorization	Statutory Authority	Agency	Agency Role
Nationwide Permit 27 or Individual Permit	Section 10, Rivers and Harbors Act; Section 404, Clean Water Act	USACE	Lead agency, reviews permit applications, determines if NWP 27 is applicable, determines if Section 7 consultation is required, determines if an individual permit will be required, sets up pre-application meeting
	Endangered Species Act	NMFS	Section 7 consultation for projects that the USACE determines may affect smalltooth sawfish and swimming sea turtles or their critical habitat
		USFWS	Section 7 consultation for projects that the USACE determines may affect threatened or endangered species other than fish and swimming sea turtles
Environmental Resource Permit (ERP) and Sovereign Submerged Lands Approval	Chapter 373 FS (ERP); 18-20 FAC (for projects within Aquatic Preserves); 18-21 FAC (for projects on Sovereign Submerged Lands)	FDEP	Typically reviews permit applications for oyster habitat restoration projects for consistency with state statutes
		SWFWMD or SFWMD	Reviews permit applications for oyster habitat restoration projects when FDEP is the applicant or if it is part of a larger project being reviewed by the district

Planning for Successful Oyster Habitat Restoration

One of the most critical aspects of any habitat restoration project is to ensure that it is designed to succeed. This Plan provides a suite of science-based tools that will help ensure the successful restoration of oyster habitat within the CHNEP estuaries through appropriate site selection and goal-related success criteria. Oyster habitat restoration has been occurring within the CHNEP study area on a project by project basis over the past ten or more years. With growing interest in the ecosystem services provided by oysters, CHNEP identified the need for a more systematic approach to restoring these valued habitats. Lessons from previous restorations are incorporated in this Plan. However, there is still much to learn about oyster restoration in southwest Florida and as more knowledge is gained, this restoration plan will be adapted to reflect new information (the next update will be completed no later than 2020).

The development of this Plan was guided through TNC's experience, and by their four-step 'Conservation by Design' systematic approach for defining restoration needs and identifying strategies for shellfish restoration. As adapted from Brumbaugh and others (2006), TNC's four steps include: 1) identifying priorities through data compilation, 2) developing strategies for restoring sites to fullest functionality, 3) implementing strategies, and 4) measuring the effect of implementation. Described below are the steps taken to identify priority oyster habitat restoration areas within the CHNEP study area using an Oyster Restoration Suitability Model and developing potential restoration designs, implementation strategies and measures of success; technical support was provided by the SWFOWG.

CHNEP Oyster Restoration Suitability Model

Oyster Restoration Suitability Model Development

Because of the size (220,000 acres; 890 km^2) and complexity of the CHNEP estuaries, a system-wide approach is essential for identifying suitable oyster habitat restoration locations and priority areas based on best available spatial data. A GIS-based oyster habitat Restoration Suitability Model (RSM) was developed to score all estuarine areas within the CHNEP study area for their potential for future oyster habitat restoration using a method that is consistent throughout the region, repeatable, and adaptable with future data. The CHNEP oyster habitat RSM is similar to other Habitat Suitability Models (HSMs) developed for oysters (e.g., Barnes et al. 2007, Cake 1983). In addition, it includes consideration of areas where restoration is not feasible because of non-biological constraints, such as regulatory requirements. The CHNEP oyster habitat RSM is based on two assumptions for local oyster habitat restoration: 1) that substrate enhancement is the most appropriate restoration approach, and 2) that larval supply is plentiful in the CHNEP study area (Milbrandt et al. 2012, Rasnake 2011, Volety et al. 2009, Volety 2008).

In developing the CHNEP oyster habitat RSM, a comprehensive list of factors affecting oyster habitat restoration success was developed and vetted through the SWFOWG. Each factor was evaluated for availability of 1) spatial-data, 2) quality of data, and 3) relevance for application in the model. The majority of factors evaluated by the SWFOWG were ultimately not included in the model, as detailed in Table 3. However, many of these excluded factors should be considered further during site-specific evaluations before oyster habitat restoration projects are designed and implemented. Key oyster habitat restoration factors not included in the model are discussed in the next section of this Plan. The final CHNEP oyster habitat RSM includes five key components: 1) bathymetry, 2) tidal river salinity isohalines, 3) seagrass persistence, 4) boat channels, and 5) aquaculture lease areas (see Table 4).

Table 3: Spatial Factors Evaluated but Not Included in the Restoration Suitability Model

Factor	Metric	Source	Evaluation	Future Action
Dissolved Oxygen	Avg. Annual DO (10 yr avg.)	Water Atlas	DO is adequate region-wide based on annual surface DO contour maps.	Site-specific evaluation for subtidal restoration.
Salinity	Avg. Annual Salinity	Water Atlas	Salinity contours did not accurately depict known salinity conditions throughout the region.	Site-specific evaluation
	Avg. Wet Season Salinity	CHNEP & SWFRPC		
Temperature	Summer Month Contours	Water Atlas	Temperature contour maps showed relatively consistent temperatures throughout the region. Some areas with low-flushing or that are located near power plants may not be appropriate.	Site-specific evaluation for areas with low-flushing or are located near a powerplant
Sediment	Sediment Type	NOAA	Sediment type should be considered in the design of projects, but all mapped sediment types can be suitable for oyster restoration.	Site-specific evaluation
Larval Distribution	Spat	N/A	Larvae are generally thought to be plentiful throughout the region, no wide-spread spatial data is available.	Site-specific evaluation
Water Flow	Velocity	Sheng Model	Not relevant to the scale of most oyster restoration projects.	Site-specific evaluation
Disease	Intensity and Prevalence	N/A	FGCU monitors disease intensity and prevalence in the Caloosahatchee Estuary and Estero Bay; it does not appear to be a major stressor in the region.	Environmental indicator
Predators	Abundance	N/A	Predation will be site-specific, but will likely be higher on sub-tidal reefs in higher salinities.	None recommended
Current Oyster Locations	Presence	Avineon 2004	Comprehensive, accurate region-wide data is not available, additional mapping is needed.	Region-wide high-quality mapping with ground-truthing
Shellfish Harvesting Areas	Harvesting Allowed or Restricted	FDACS	Dependent on the restoration goals, if conducting oyster restoration where future harvesting is a goal this must be considered.	Project-specific consideration
Historic Oyster Habitat	Presence in 1950s	Photo Science 2007	Accuracy of historic data not adequate for model, and historic data may not reflect where oysters should be currently.	Research historic oyster distribution, dredging, harvest etc.
Managed Areas	Management of Lands Adjacent to Site	FNAI	Adjacency to managed lands may be important for some funding opportunities, but does not affect restoration suitability.	Consider adjacent landuse when siting and designing restoration projects.
Shoreline Type	Natural or Altered Lands Adjacent to Site	CHNEP	Type of shoreline may be a consideration in designing some projects, but does not affect restoration suitability.	Consider adjacent landuse when siting and designing restoration projects.
Identified Climate Change Habitat Migration Shorelines	Cape Haze, Charlotte Harbor, Estero Bay Buffer - where public conservation lands have been acquired and will allow for habitat migration.	SWFRPC	The SWFRPC is currently identifying migration corridors, the effect of oyster restoration in these areas should be considered.	Consider conservation corridors & climate change habitat migration routes when siting and designing restoration projects.
Sea Level Rise	Future water depth, habitat types and salinity	Geselbracht et al. 2012, Savarese et al. 2004	Sea level rise is expected to affect the Charlotte Harbor estuarine habitats; future scenarios should be considered when identifying appropriate restoration sites; reef development may not keep up with sea level rise.	Consider how future sea level rise will affect site suitability, and consider the future effects to adjacent habitats (e.g., shoreline stabilization).
Sawfish Hotspots	1 km Buffer Around Identified Sawfish "Hotspots"	FWC Poulakis et al. 2011	Fisheries biologists do not yet understand the interaction between sawfish and oyster habitats, it is unknown whether locating restoration near sawfish hotspots may or may not be beneficial to sawfish.	Consider proximity to identified sawfish hotspots when siting, designing and permitting projects.
Aquaculture Lease Buffers	Access Routes into Aquaculture Lease Areas	FDACS	Determined not to be necessary in the model, but FDACS will review in permitting process.	Consider proximity to lease areas, and potential conflicts with navigation and depleting food source for shellfish.

Restoration Suitability Model Scoring

For the CHNEP oyster habitat RSM, a scoring system was developed for each model component. The scoring system was designed to score areas that are totally unsuitable for oyster habitat restoration as a 0 while the most optimal areas receive a score of 1. Where appropriate, scores between 0 and 1 are assigned to reflect an intermediate level of suitability for oyster habitat restoration. The final model score for each area was calculated by multiplying the scores for each individual model component, as follows:

$$\textbf{Final Score} = \textbf{Component}^1 * \textbf{Component}^2 * \textbf{Component}^3 * \textbf{Component}^4 * \textbf{Component}^5.$$

The result is a range of scores from 0-1. In the model where one component is considered unsuitable the model returns a final unsuitable score of 0. Where one or more components have an intermediate level of suitability, the score will be less than 1. The scoring of each component was determined through consensus of the SWFOWG, as described in greater detail below. The CHNEP oyster habitat RSM potential scores for each model component are provided in Table 4.

Table 4: CHNEP Oyster Habitat Restoration Suitability Model Components and Scoring

Component	Factor	Metric	Source	Reference	Model Scoring
Avoidances	**Seagrass Habitat**	Seagrass Persistence (1999, 2001/2003, 2004, 2006 and 2008)	SWFWMD, SFWMD, Janicki 2009	CHNEP Numeric Nutrient Criteria Documents	Seagrass Absent = 1 Seagrass Present 1-4 years = 0.5 Seagrass Present 5 years = 0
	Aquaculture Lease Areas	High Density Lease Area Footprint	FDACS	FDACS	Lease Absent = 1 Lease Present = 0
	Boat Channels	Official Boat Channels	WCIND, NOAA Bathymetry - Dredged Channels	Wall et al. 2005; Grizzle et al. 2002; Boutelle, Lee Co. Natural Resources, pers. comm.	Channel Absent = 1 Channel Buffer = 0.2 (75' Wide) Channel Present = 0 (150' Wide)
Biological, Chemical and Physical	**Depth**	Depth at MLW	NOAA Bathymetry	Kennedy 1996; Crosby et al. 1991	Land Exposed at MLW and 0-3 Feet = 1 3-6 Feet = 0.8 > 6 Feet = 0 Spoil Areas, Dredged Channel and Inland Water = 0
	Tidal River Salinity Isohalines	Wet-Season 3 psu Isohaline	SWFWMD, PRMRWSA, SFWMD	Volety et al. 2010; Bierman 1993; Cake 1983	Downstream of Isohaline = 1 Upstream of Isohaline = 0

Note: Model Score 1 = 100% suitable, 0.8 = 80% suitable, 0.5 = 50% suitable, 0.2 = 20% suitable, 0 = not suitable.

Restoration Suitability Model Component Descriptions

Bathymetry: The depth to which oysters are naturally found varies widely along the Atlantic and Gulf of Mexico coasts (Kennedy 1996). Because of the lack of information about the historical and current distribution of oysters throughout the CHNEP study area, questions remain about the extent and depth at which subtidal oysters would be found in an undisturbed estuarine system. Currently, a subtidal oyster reef is known to exist in the Caloosahatchee River in approximately six feet (1.8 m) of water (Volety and Rasnake, pers. comm.). In a 1965 survey of Charlotte County waters, the presence of subtidal oyster reefs were noted, but they were not considered to be substantial oyster harvesting grounds (Woodburn 1965). The literature and anecdotal information does indicate that by the mid-1960s oyster habitats in southwest Florida had been significantly degraded from dredging, oyster-shell mining and oyster harvesting activities (Woodburn 1965, Smeltz 1898).

The depth of oyster distribution is limited by several factors, including dissolved oxygen, predation, sediments and lack of hard substrate. The SWFOWG discussed dissolved oxygen information available for the CHNEP estuaries. Based on the data and local expertise, the SWFOWG agreed that low dissolved oxygen was not a concern for oyster habitat restoration in the CHNEP estuaries at depths less than three feet (0.9 m). Additionally, dissolved oxygen typically would not be a problem in depths less than six feet (1.8 m). The group also agreed that although oxygen levels could become sub-optimal at times, it would not likely result in high oyster mortality. However, in some areas deeper than six feet (1.8 m), hypoxia and anoxia do occur, especially during the rainy season, and could result in high oyster mortalities. The rates and effects of predation and fouling on subtidal versus intertidal oysters are not documented for the CHNEP estuaries. Therefore, it is not possible to estimate whether either predation or fouling would lower the success rates of oyster habitat restoration projects at different depths.

Based on discussions and current information, the CHNEP oyster habitat RSM score associated with bathymetry was determined to be primarily a proxy for dissolved oxygen. Therefore, for the RSM, the most suitable depths for oyster restoration in the CHNEP are those less than three feet (0.9 m) MLW (mean low water) and are scored with a value of 1 in the model. Areas between the three to six foot (0.9-1.8 m) MLW depth-contours are considered to be less suitable for restoration because dissolved oxygen concentrations are less certain, but the assigned model score of 0.8 reflects relatively high suitability. All other areas of the estuaries deeper than six feet (1.8 m) MLW are currently considered unsuitable for restoration and are assigned an RSM value of 0, but the RSM could be modified in the future to include deeper areas as suitable. Additional research is needed to evaluate the suitability of deeper locations (>6 feet) for oyster habitat restoration and the success of subtidal vs. intertidal restoration projects.

Tidal River Salinity Isohalines: Optimal salinities for oyster growth and survival are generally thought to be within the range of 14-28 psu (Volety and Tolley 2004). However research in the CHNEP study area should be done to determine if there is an upper salinity limit for successful oyster habitat restoration. Oysters in higher salinities have been found to experience higher mortality from predation and fouling (Volety et al. 2010, Galtsoff 1964), whereas oysters in lower salinities may become stressed during prolonged low salinity events. When salinities drop below 3 psu for extended periods of time (generally greater than two-three weeks depending on temperature), mass oyster mortalities can occur. These prolonged low salinity events are called ‘killing floods.’ Areas experiencing killing flood conditions more frequently than once every three years are considered to be unsuitable for oyster restoration (Cake 1983).

The SWFOWG reviewed various methods for including salinity in the CHNEP oyster habitat RSM, including: 10-year average salinity contours, 10-year wet season salinity contours and tidal river salinity isohalines. Initially, salinity contours were discussed as the most appropriate approach, where the RSM score would have represented varying levels of suitability. However, after extensive analysis, it was determined that salinity data was not currently available in a format that accurately represented salinity conditions throughout the CHNEP estuaries for the purposes of the RSM. The two primary concerns with the salinity contour data layers were: 1) they did not adequately portray near shore salinities, and 2) salinity contours developed from randomly sited data points resulted in spotty contours in areas where salinity values were expected to be more homogeneous. In the future, more detailed analysis of all available fixed and random station water quality data using various spatial analysis tools could result in a usable GIS salinity contour layer (see Meyer 2006).

The third salinity approach was an analysis to determine the typical locations of the wet-season (June through October) 3 psu isohaline in the three major tidal rivers within the CHNEP area—the Myakka, Peace and Caloosahatchee Rivers. This approach is used in the RSM, where estuarine areas downriver of the 3 psu isohalines are considered suitable for oyster restoration and areas upriver of the isohalines are considered unsuitable, thus omitting those areas most likely to experience frequent killing flood conditions.

Salinities are monitored along the Peace and Myakka Rivers to determine the location (river km) of certain isohalines on a monthly basis. The raw data for the locations of the 2 psu and 4 psu isohalines for the Myakka River and the 0 psu and 6 psu isohalines for the Peace River were readily available and were provided by SWFWMD and the Peace River Manasota Regional Water Supply Authority (PRMRWSA), respectively. The isohaline locations for 2000-2011 were used to determine the average wet-season isohaline locations for the two rivers. For the purposes of the oyster habitat RSM, the 3psu isohaline was assumed to be halfway between the two average isohaline locations for each river. For the model, the Myakka River 3 psu isohaline is located at 11.5 km upriver, and the Peace River 3psu isohaline is located at 15 km upriver. The river kilometers are identified in the Myakka and Peace River MFL documents (SWFWMD 2011, 2010).

For the Caloosahatchee River, measured isohaline locations were not available. However, models have been developed to predict salinity at specified locations in the river based on 30-day average flow rates at the S-79 locks near Alva (e.g., Volety et al. 2010, Bierman 1993). Flow data was downloaded from the USACE for the period of 2001-2011 and daily 30-day average flow rates were calculated using the wet-season data (June-October). The highest 30-day average flow for each year was identified and the mean for the 10-year period was calculated using those values. Based on the analysis, the mean maximum 30-day average flow for the Caloosahatchee River for the time period was approximately 6,000 cfs. The results indicate that in most years there would be a prolonged period of flows at or above 6,000 cfs. Assuming that these flow conditions would result in prolonged low salinity conditions in the river, the 6,000 cfs flow rate was used to estimate the location of the 3 psu isohaline for the Caloosahatchee River. The Bierman model (Bierman 1993) predicts that a 30-day average flow of 6,000 cfs would result in salinities of 3 psu at four kilometers upriver from Shell Point, near Peppertree Point. Volety and others (2010) also developed linear regression salinity models for specific sites within the Caloosahatchee estuary which predict salinities <1 psu at Peppertree Point under the 6,000 cfs scenario. However, their research also shows consistently healthy oyster populations at Peppertree Point and further downriver, with the exception of Cattle Dock Point which receives flows from Cape Coral. Based on review and discussion of the available Caloosahatchee River salinity data (i.e., RECON-SCCF, City of Sanibel, USGS, Water Atlas), the SWFOWG agreed that locating the 3 psu isohaline cut-off point near Peppertree Point accurately captures the area of the river currently suitable for restoration.

It is anticipated that improved management of Caloosahatchee River flows would result from implementation of CERP and MFLs. Ideally, these improvements would result in average high flow events no greater than 3,000 cfs, which is the upper limit for freshwater inflow for maintaining healthy oyster populations in the Caloosahatchee estuary (Volety and Tolley 2003, Chamberlain and Doering 1998). Under the 3,000 cfs scenario, the 3 psu isohaline would be located eight kilometers upriver from Shell Point (near the Cape Coral bridge), providing additional suitable oyster habitat restoration areas; this scenarios is more representative of a natural system. Substantial oyster habitat restoration should not be undertaken upriver from Peppertree Point until it can be demonstrated that salinities under improved flow management regimes during average or above average rainfall conditions are adequate to sustain the restoration. However, for the purposes of demonstrating the potential gain in suitable oyster restoration habitat associated with improved flow management, the 3,000 cfs scenario was modeled using the RSM.

Note that the locations of the 3 psu isohalines for the Myakka, Peace and Caloosahatchee Rivers define the upstream extent of the model output. For maps of the isohaline locations refer to the furthest upstream extent of suitable restoration areas in the RSM output maps (Figure7 and Appendix D).

Seagrass Persistence: Seagrass is an essential estuarine habitat, as such it is protected by regulatory processes and should not be displaced by oyster restoration. The majority of seagrass beds within the CHNEP estuaries are persistent from year to year. However, there is some annual variation in seagrass bed locations and extent as a result of varying environmental conditions. Therefore, seagrass presence and persistence over several years is an important component of the RSM. Seagrass presence is regularly mapped using aerial photography throughout the CHNEP study area by SWFWMD and SFWMD. Seagrass aerial maps are available for the entire CHNEP study area for 1999, 2001/2003, 2004, 2006 and 2008. Previously, Janicki Environmental formed a seagrass persistence spatial dataset from the 1999, 2001/2003, 2004 and 2006 aerials (Janicki 2009). For the CHNEP oyster habitat RSM, the existing seagrass persistence spatial dataset was combined with the 2008 data to create a new seagrass persistence dataset for the most current five years of mapping. The revised seagrass persistence dataset was reviewed and corrected as needed by CHNEP and SWFRPC staff and the SWFOWG to ensure accuracy.

The SWFOWG determined that oyster habitat restoration would be most suitable in areas where seagrass was not present during any of the five years in the dataset (1999, 2001/2003, 2004, 2006 and 2008). Areas with no seagrasses during these five years are assigned an RSM value of 1. Areas where seagrass was found in one to four years of the dataset are given a score of 0.5 in the model to reflect the potential for seagrasses to recolonize those areas. Oyster restoration is not suitable in areas where seagrasses were found during all five years, and those areas are assigned an RSM value of 0. The SWFOWG discussed the need for a buffer around seagrass beds, but determined it would not enhance the RSM for three reasons: 1) seagrasses often grow directly adjacent to oysters, 2) adjacent seagrasses can benefit from improved water quality associated with oyster restoration, and 3) due to the scale used to map the seagrasses (e.g. sparse seagrasses may not be included) and temporal variation, the actual location of the bed edge is uncertain. Seagrass surveys are a necessary part of assessing site suitability prior to designing and implementing an oyster restoration project. The intent of the RSM is to show general areas that have been mapped as seagrasses in the recent past and are therefore either unsuitable or not optimal for further evaluation for oyster restoration.

Navigation Channels: Officially designated boat channels were identified as areas to avoid for oyster restoration and to be excluded from the RSM. Although other environmental conditions might be appropriate for oyster restoration, projects in these locations could interfere with the existing uses and cause a navigational hazard. Unofficial boat channels, including unmarked channels, were not considered avoidance areas in the RSM; however, local boat traffic patterns should be considered during project planning in order to avoid conflicts with existing uses. Two data layers were used to identify the designated boat channels. The most extensive and accurate channel data layer was a line file, available from the West Coast Inland Navigation District (WCIND), that was created by on-site verification of all features. The layer provided all boat channels except for the Intercoastal Waterway (ICW). An ICW shapefile was created for the RSM using the NOAA bathymetry shapefile. Polygons in the NOAA bathymetry file that were characterized as ‘dredged channel’ and associated with the ICW were selected and exported into a new polygon shapefile for the model.

Channel widths for the RSM were established based on the NOAA bathymetry file for the ICW. The typical width of the ICW polygon features was 150 feet (45.7 m), but the WCIND shapefile did not include channel width. Therefore a standard width for non-ICW channels was created by buffering the WCIND channel line by 75 feet (22.8 m) on each side. The resulting channels are consistently included in the RSM as 150 feet (45.7 m) wide, are considered unsuitable for oyster restoration and are assigned a model score of 0. The assumption of a consistent channel width throughout the study area was necessary based on available data. However it is recognized that some channels will be narrower and some non-dredged areas of the ICW may be much wider. In addition, non-dredged areas of the ICW, which are all greater than six feet (1.8 m) deep, are assigned a score of 0 in the RSM based on bathymetry and are considered unsuitable for oyster restoration.

An additional buffer of 75 feet (22.8 m) wide on either side of the 150 foot (45.7 m) channels was identified to represent low suitability for oyster restoration and was assigned a RSM score of 0.2. The low suitability score reflects that oysters immediately adjacent to a boat channel would generally be considered a navigational hazard and would not be permitted. Because there may be some cases where oyster restoration areas adjacent to channels may be appropriate, depending on local conditions, the

SWFOWG determined that these areas should be scored to represent low suitability. In locations where practitioners might be interested in conducting an oyster restoration project near identified, unmarked or narrow channels, site-specific field surveys and discussions with permitting agency staff are necessary to determine suitability for restoration before further project planning is initiated.

Aquaculture Lease Areas: Aquaculture lease areas are also considered unsuitable for oyster restoration due to their existing use. FDACS Division of Aquaculture manages aquaculture leases in Pine Island Sound and Gasparilla Sound. These areas were identified as suitable for clam aquaculture through a similar GIS process as that used for the RSM (see Arnold et al. 2000) and are leased to clam-farmers for this purpose. A GIS file of the aquaculture lease areas was provided by FDACS. For the RSM, a 30 foot (9.1 m) buffer was applied to the lease areas, and the lease areas and buffers were classified as unsuitable for oyster restoration and assigned a score of 0 in the model.

Restoration Suitability Model GIS Processing

The best available data was used to represent the five key components discussed above; a list of GIS data sources is provided in Table 5, including each layers level of accuracy. The accuracy of the RSM output is linked to that of the data used to create the model. Due to limitations in spatial accuracy the model output should be used to identify the general locations of suitable restoration areas, and then suitability should be field-verified. The grid size used for the model output is 2500 square feet (50'x50'; 232 m^2). As a result areas smaller than this, which may be suitable for restoration, may show up as unsuitable in the model output. One example of this is the intertidal zone between the seagrass bed edge and mangroves.

Table 5: List of GIS Data Layers Used in the Restoration Suitability Model

GIS Data Layer	Source	Dates	Accuracy
Aquaculture Lease Areas	FDACS	1997/1998	±0.5 acres
Bathymetry	NOAA	2000	10m intervals
Seagrass Persistence	Janicki Environmental	2009	±0.5 acres
Seagrass Coverage 2008	SWFWMD/SFWMD	2008	±0.5 acres
Boat Channels	Florida Seagrant	2002-2011	±0.1 acres
Shoreline	FWC	2004	1:12,000 scale

All RSM components were combined into one GIS shapefile containing a field for each of the individual model component scores. The scores were assigned as described above, by selecting specified criteria and then using the field calculator to assign specified values. All areas within the CHNEP estuaries were assigned a value for each component, so that there were no null values. A new field was added to the shapefile within which the model score was calculated. The field calculator was used to populate the model score using the following formula:

> **Model Score = bathymetry score * isohaline score * seagrass score * navigation channels score * aquaculture lease areas score.**

The final model shapefile can be used to identify both the total oyster restoration suitability scores and the suitability score for each component. This is a benefit of designing the RSM to result in a shapefile for the final model output as compared to a raster format which would only contain the final model score. This allows the RSM to be easily adapted to future data and components, and to determine the individual component scores for a given area.

Restoration Suitability Model Results

The RSM results in potential scores of 1, 0.8, 0.5, 0.4, 0.2, 0.1 and 0. For the purposes of discussion and prioritization, these scores were associated with a percent suitability by multiplying each by 100. Scores of 0.4 and 0.5 were lumped together and are represented as 50% suitable. The CHNEP oyster habitat RSM model results are shown in Table 6 and Figure 6. The model shows that approximately 10% (22,170 acres; 89.7 km^2) of the 224,450 acres (908.3 km^2) of CHNEP estuaries are 100% suitable; an additional 20,430 acres (82.7 km^2) are 80% suitable. Based on the RSM results, over half of the CHNEP estuaries are unsuitable for oyster restoration, which helps guide further site-specific evaluations into more suitable locations.

The RSM results are also provided for each CHNEP estuary (see Table 6 and Appendix D). The CHNEP estuaries are divided into 14 estuary 'strata' that have relatively homogeneous conditions and are used to assess water quality and seagrass status and trends. Evaluating oyster restoration suitability using these smaller estuary strata is useful for analyzing localized trends and reflecting resource management in greater detail. Based on the RSM results, each CHNEP estuary stratum has at least 100 acres (0.4 km^2) of area that is 100% suitable for further site-specific evaluation for oyster restoration. The CHNEP oyster habitat RSM results and estuary maps can be used to guide practitioners to the areas that are most suitable for oyster habitat restoration; additional on-the-ground site-specific assessments will also be needed.

It is important to note that improved management of the Caloosahatchee River, resulting in maximum 30-day average flows no greater than 3,000 cfs, would result in the expansion of suitable oyster restoration habitat. Based on the RSM, this improvement would result in an additional 1,109 acres (4.5 km^2) of habitat that is 100% suitable for potential oyster restoration, and 1,466 acres (6 km^2) of habitat that is 80% suitable.

Additional Spatial Considerations for Oyster Restoration

As identified in Table 3 there is a lot of additional spatial information available that can be used to further identify and describe oyster habitat restoration sites. Dependent on the project-specific goals and funding requirements, certain criteria may be desirable in one case, while it may be viewed as something to avoid in another case. For example one competitive grant opportunity may be available for restoring natural habitat in a highly impacted area, while another may focus on restoration adjacent to publicly managed lands. In the first case it may be beneficial to show a restoration site adjacent to a shoreline armored by seawalls, while in the second case it would be beneficial to show surrounding managed lands (e.g., Ding

Darling NWR or Charlotte Harbor State Park Buffer Preserve) and mangrove shorelines. The location of projects within or outside of shellfish harvesting areas should also be considered when defining the goals of the project; is one of the goals to enhance the oyster fishery or to provide a sanctuary free from harvest pressure? Some other considerations include sea level rise, adjacent habitats, shoreline protection, water quality and recreational fishing—how each of these is considered will be determined by the goals of each project.

Table 6: CHNEP Oyster Habitat Restoration Suitability Model Results

RSM Score Percent Suitability	1.0 100%	0.8 80%	0.3-0.5 50%	0.2 20%	0.1 10%	0.0 0%	Total by Stratum
Strata	(acres)						
Dona & Roberts Bays	108	40	34	170	22	432	807
Upper Lemon Bay	163	220	461	190	187	1,278	2,499
Lower Lemon Bay	514	582	1,062	256	140	2,797	5,351
Gasparilla Sound-Cape Haze	1,321	1,526	3,237	69	48	6,675	12,875
Tidal Myakka River	2,231	1,778	298	314	1	2,513	7,136
Tidal Peace River	3,834	3,371	343	431	2	5,422	13,402
Charlotte Harbor West Wall	455	1,332	780	7	1	14,453	17,029
Charlotte Harbor East Wall	1,482	1,363	1,247	30	16	18,252	22,390
Charlotte Harbor Proper	360	1,027	1,709	69	65	30,271	33,502
Pine Island Sound	2,481	4,171	8,471	267	182	34,606	50,177
Matlacha Pass	2,271	1,265	3,252	134	100	6,940	13,962
San Carlos Bay	1,563	2,663	3,802	197	83	8,585	16,892
Tidal Caloosahatchee River	728	977	340	140	11	15,082	17,278
Estero Bay	4,660	114	2,982	492	99	2,807	11,154
Total	**22,172**	**20,428**	**28,016**	**2,766**	**956**	**150,114**	**224,453**

Additional spatial factors that affect permitting should also be considered during the planning process. For example, practitioners should know whether or not the project is located within an aquatic preserve and/or within the designated sawfish critical habitat, and if the project is located near an aquaculture lease area or active bird rookery. In order to receive permits from the state (FDEP, SFWMD or SWFWMD) and the USACE the guidelines described in the Regulatory Permitting Requirements section of this plan should be followed; specific permitting requirements will vary dependent on the location of the project.

Figures 7 and 8 provide an overview of additional spatial factors for the entire CHNEP study area; Appendix E provides a series of maps for each stratum. For permitting guidance these maps include the boundaries of the aquatic preserves, the aquaculture lease areas and the critical sawfish habitat. The critical sawfish habitat is further delineated to show the essential features within the boundary, which are areas less than three feet MLLW (0.9 m) in depth; due to data availability the map shows areas less than three feet MLW. In addition the maps show shoreline vegetation, location of oysters mapped in 1950s and 1999, previous oyster restoration sites, accommodation space (discussed below), shellfish harvesting areas and active bird rookeries.

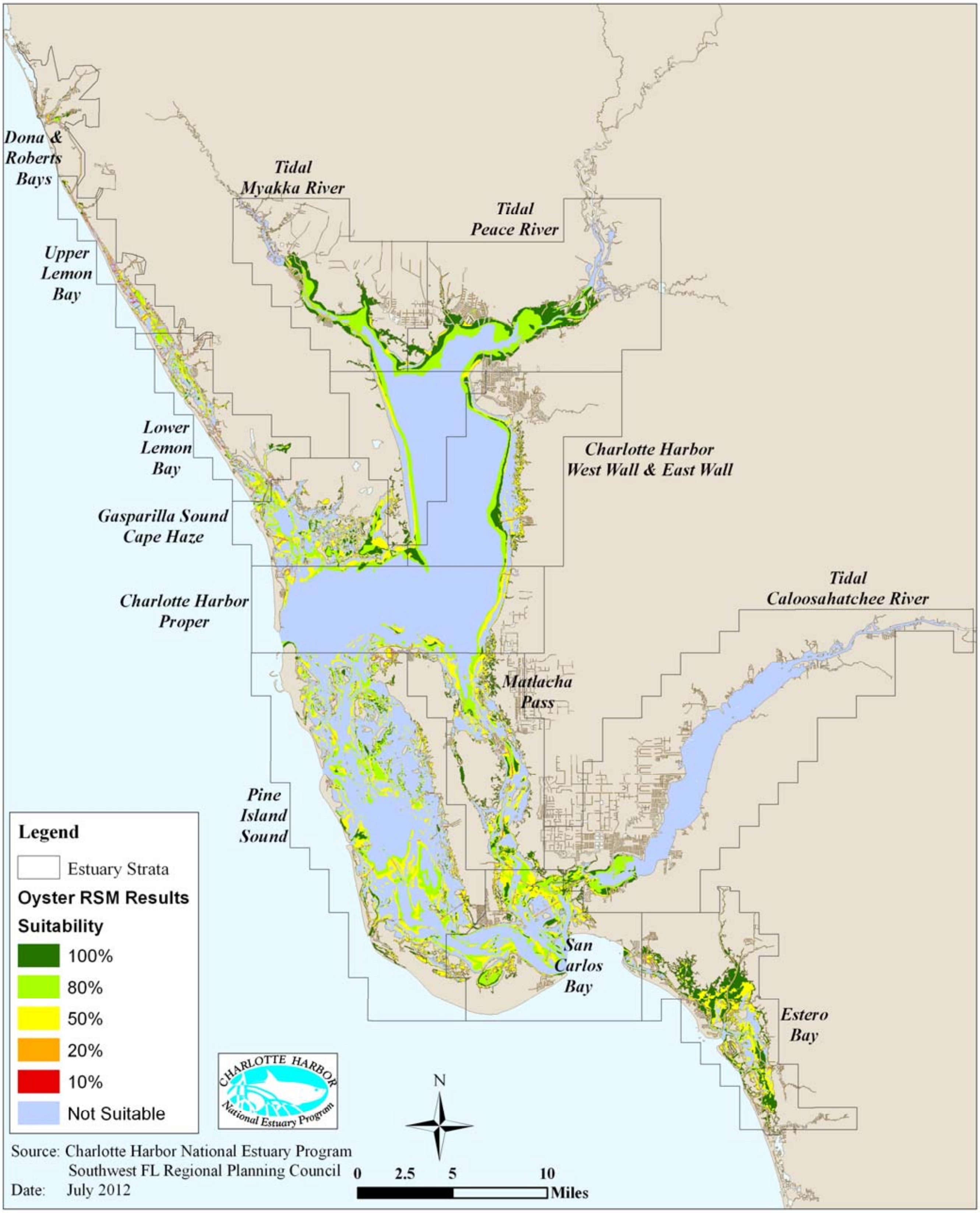

Figure 6: CHNEP Oyster Habitat Restoration Suitability Model Results

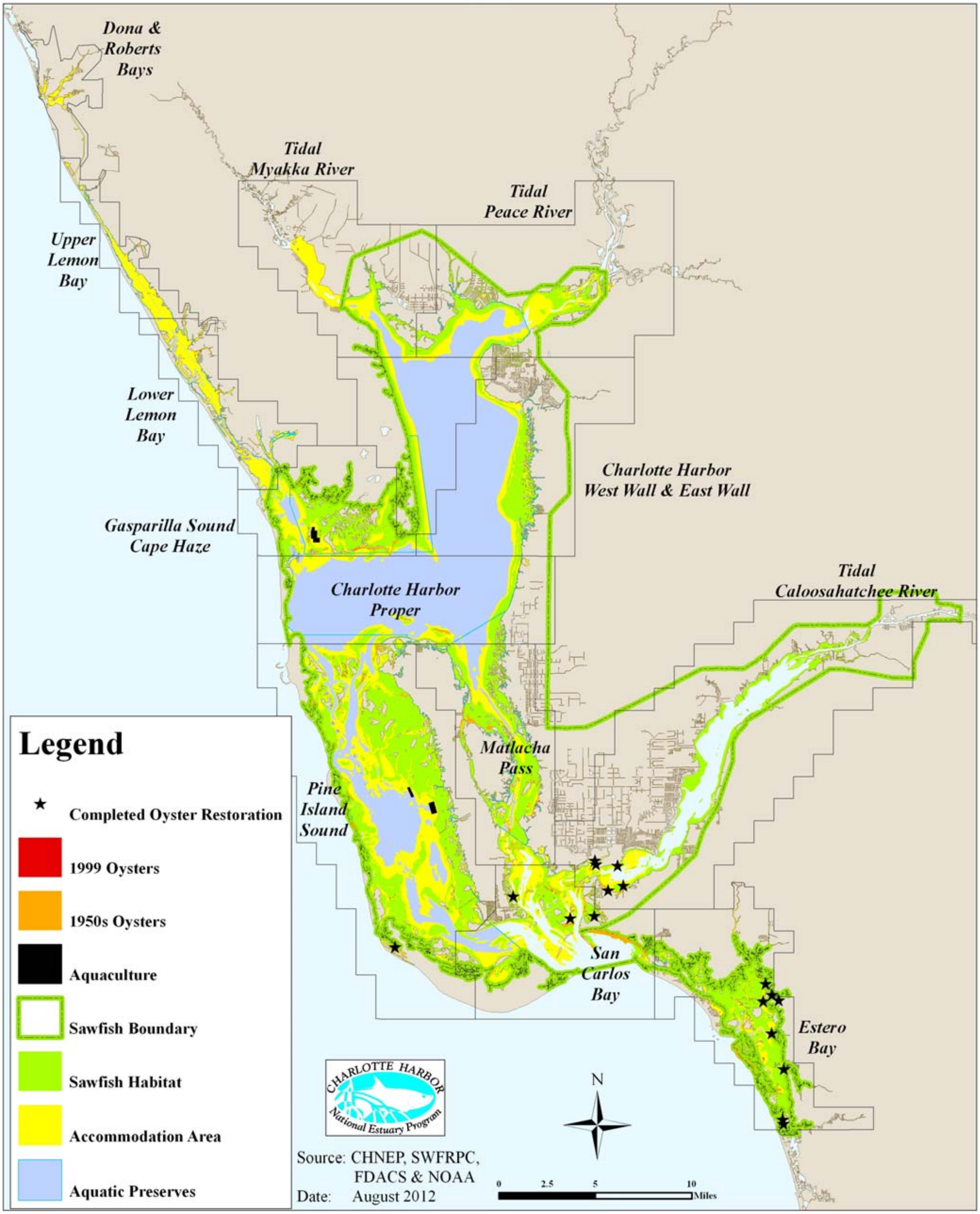

Figure 7: CHNEP Oyster Habitat Restoration Additional Considerations

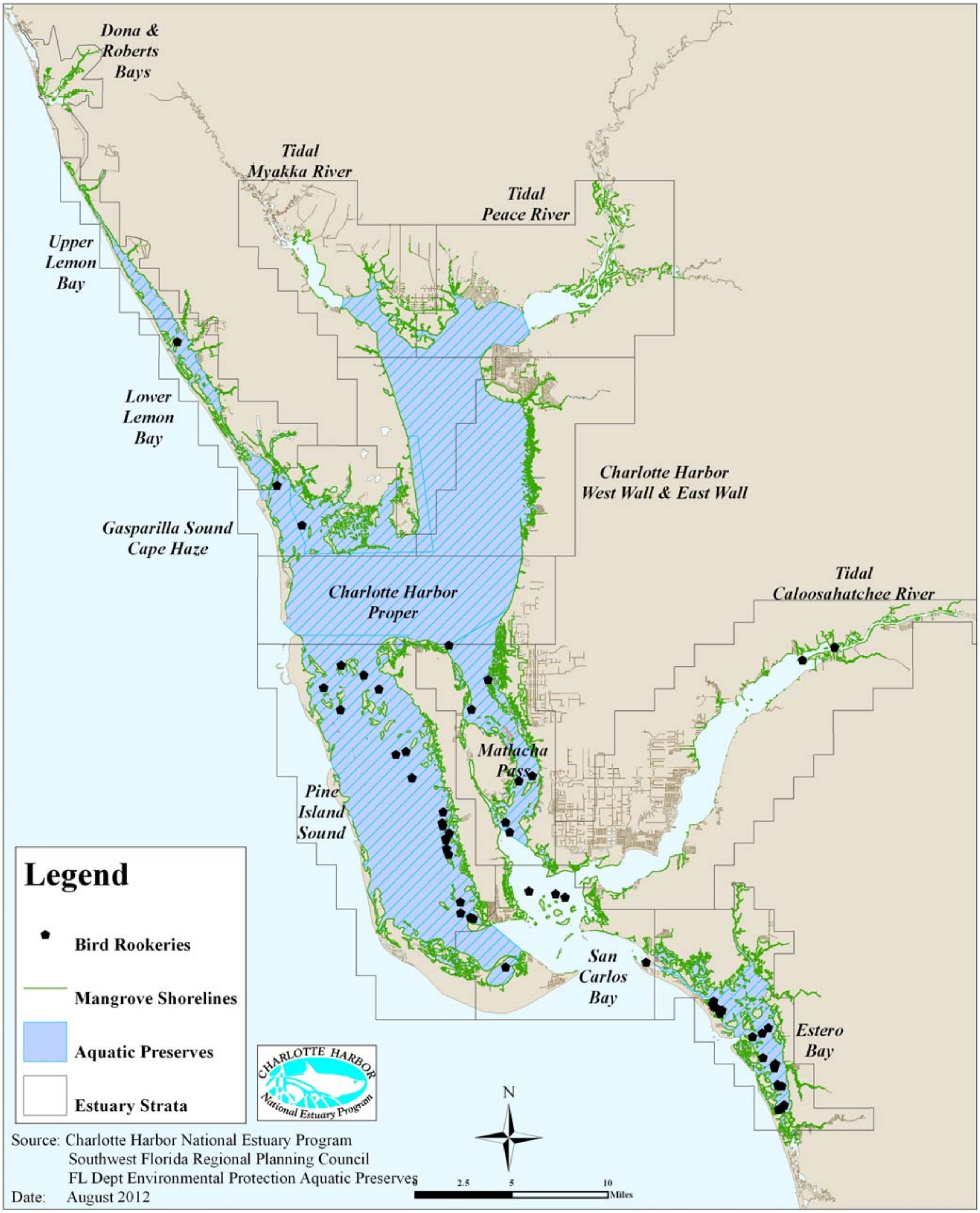

Figure 8: CHNEP Mangrove and Bird Rookery Island Locations

Developing CHNEP Oyster Habitat Restoration Goals

Typically habitat restoration goals are set based on historic knowledge of the natural extent of the habitat. As previously discussed, the historic extent of oysters in the CHNEP study area is largely unknown. However, from anecdotal information we know that oyster habitat was highly degraded even prior to 1900 (Smeltz 1898). The mapping conducted using the 1950s aerials represents the earliest quantitative estimate of oyster habitat within the CHNEP study area. As discussed earlier this mapping does not account for oysters associated with mangroves or small oyster reefs, and we are unsure of the overall accuracy or the depth to which oysters were detected. Despite the uncertainties of the mapping, a comparison of the acreage from the 1950s to 1999 shows a 2,450-acre (9.9 km^2) or 90% loss during that 50-year time-period in the CHNEP study area.

An alternative way to set a restoration goal is to determine what the natural conditions are likely to be based on other reference sites. A study conducted by the EPA on the relative abundance of oysters in Gulf estuaries found that oysters typically occupy 1-5% of accommodation space (Volety, pers. comm.). As defined by Volety and Savarese (2001) accommodation space is “the area of shallow water habitat that is accessible to oyster recruitment and reef development.” Based on this definition, accommodation space within the CHNEP study area was defined as all areas less than six feet deep that are downstream of the 3 psu isohalines, which equals approximately 124,000 acres (501.8 km^2) (see Table 7; Figure 3). If optimal conditions are for 1-5% of accommodation space to be occupied by oysters, then the CHNEP study area should have 1,243-6,217 acres (5-25.2 km^2) of oysters. The estimated 2,697 acres (10.9 km^2) of oysters from the 1950s is within this range, representing 2.2% of accommodation space. Volety and Savarese (2001) calculated that the oysters at three locations in the ten-thousand islands (i.e., Faka-Union, Henderson, Blackwater) occupied 1-1.7% of accommodation space; they recognize that none of these sites are pristine.

The CHNEP goal is to enhance and restore self-sustaining oyster habitat and related ecosystem services throughout the estuaries and tidal rivers and creeks in the study area. Because of the lack of data on historical oyster distribution within the CHNEP study area, the acreage of restoration is more appropriately characterized by defining a percentage of the habitat likely to support sustainable oyster restoration. Based on the current level of understanding, there is consistency between the CHNEP oyster habitat RSM results and the estimated accommodation area (less than 6 feet deep and waterward of the 3 psu salinity isohaline). Comparing a range of 5-25% of the RSM 100% suitable acres and 1-5% of the accommodation area acres suggests that attaining a range of 1,000-6,000 acres of total oyster habitat is appropriate over the long term. To accomplish the long term goal, the following actions are recommended over the short term:

- Map oyster habitats by type within the CHNEP estuaries by 2020.
- Design, implement and monitor the success of pilot oyster restoration projects in a variety of habitats in 50% of the CHNEP estuary strata by 2020.
- Increase public awareness of the ecosystem value of native oyster habitats by including community stewardship components in each oyster restoration project.

- Assist partners in seeking state, federal and organizational funding opportunities to support oyster habitat restoration projects.

Table 7: CHNEP Oyster Habitat Restoration Goal Considerations

Strata	Total Area	1950s Oyster Map	1999 Oyster Map	RSM Results 100% suitable	RSM Results 80% suitable	Accommodation Area (<6' deep & >3 psu isohaline) All	1%	5%	Sawfish Critical Habitat <3'deep	Aquatic Preserve
	(acres)									
Dona & Roberts Bays	807	0	14	108	40	726	7	36	0	0
Upper Lemon Bay	2,499	13	4	163	220	2,335	23	117	0	2,287
Lower Lemon Bay	5,351	56	21	514	582	4,750	47	237	50	5,309
Gasparilla Sound-Cape Haze	12,875	352	35	1,321	1,526	11,502	115	575	8,017	13,746
Tidal Myakka River	7,136	2	13	2,231	1,778	5,246	52	262	1,809	4,802
Tidal Peace River	13,402	16	7	3,834	3,371	8,728	87	436	5,103	7,813
Charlotte Harbor West Wall	17,029	0	2	455	1,332	4,057	41	203	2,394	16,960
Charlotte Harbor East Wall	22,390	6	10	1,482	1,363	6,629	66	331	5,250	22,798
Charlotte Harbor Proper	33,502	139	9	360	1,027	5,567	56	278	2,984	33,520
Pine Island Sound	50,177	441	41	2,481	4,171	37,914	379	1,896	24,716	52,294
Matlacha Pass	13,962	494	15	2,271	1,265	12,479	125	624	9,615	13,210
San Carlos Bay	16,892	726	23	1,563	2,663	11,272	113	564	6,457	4,739
Tidal Caloosahatchee River	17,278	186	2	728	977	2,328	23	116	6,575	2
Estero Bay	11,154	247	42	4,660	114	10,803	108	540	9,632	13,755
Out of Oyster Accommodation Area	---	---	---	---	---	---	---	---	5,614	---
Total	**224,453**	**2,679**	**238**	**22,172**	**20,428**	**124,336**	**1,243**	**6,217**	**88,217**	**191,235**

Oyster Habitat Restoration Strategies

An essential component for oyster restoration success is developing the most appropriate restoration strategy for the location. Alternatively, a site may be selected that fits a desired strategy. Ultimately, success will depend on matching the unique characteristics of each restoration site with a restoration strategy that will enable the practitioners to attain their goals. Prior to selecting the restoration method(s) to be implemented, it is strongly suggested that a detailed site-specific evaluation of all potential limiting factors or stressors be conducted to determine the method(s) most likely to be successful. In southwest

Florida, local experts and the SWFOWG agree that one of the primary factors limiting oyster colonization within the CHNEP estuaries is lack of suitable hard substrate for settlement of spat. In addition, it is recognized that other stressors may limit oyster sustainability in localized areas. By identifying these stressors upfront a strategy can be developed that incorporates one or more methods to maximize the chances of success, or an alternative site can be chosen.

A variety of oyster restoration methods have been used successfully throughout the U.S. Atlantic and Gulf of Mexico coasts where lack of suitable substrate is the primary limiting factor. Based on review of scientific literature and local expertise, the SWFOWG identified a suite of oyster restoration methods that may be suitable within the CHNEP estuaries. These methods are described in Table 8. The success of various restoration strategies is largely unstudied in the CHNEP study area. As identified in the goals, research projects should be conducted to further elucidate the most appropriate strategies for oyster restoration in the CHNEP study area.

It should be noted that in an initial evaluation of the following methodologies NMFS identified bagged cultch and caged cultch as having the greatest potential for sawfish entanglement. However, NMFS will evaluate the specific information on the installation techniques, during the permitting process, to assess potential effects on the species from the various methods.

For all of the methods the USACE provides the following guidance:

- Navigation: Ensure oysters do not impact navigation. In addition to high-speed boat traffic, slow-speed boat traffic in shallow near-shore areas should also be considered. Marking the oyster area with signs or buoys may be required. All aids to navigation and regulatory markers must be approved by and installed in accordance with the requirements of the U.S. Coast Guard. If oysters are located along the shoreline near dock structures boater access to shore shall be maintained by leaving channels no less than 100-feet wide and no oyster material will be placed closer than 100-feet to an existing dock unless the owner of the dock has given written consent.
- Federal Channel: Oysters shall be placed no closer than 150 feet from the near bottom edge of the Federal channel. If location is within 150 feet of the near bottom edge of the channel XY coordinates signed and sealed by a surveyor will be required.
- Substrate: Place oysters in proper substrate void of aquatic resources such as submerged aquatic vegetation. If proposed oyster area is in a location adjacent to SAV, additional monitoring and reporting may be required. The substrate should also be stable enough to prevent the cultch and/or reef material from sinking or being covered by sediment.
- Endangered Species: Standard construction conditions for the manatee, and the smalltooth sawfish and sea turtles. (see Appendix C)
- Notification: Provide written notification at least two weeks before deployment to National Oceanic and Atmospheric Administration (NOAA), Office of Coast Survey, N/CS26, Sta. 7317, 1315 East-West Highway, Silver Spring, MD, 20910-3282 and U.S. Coast Guard.

Each method provides a substrate for spat to settle upon, this substrate in oyster restoration is called 'cultch.' A suite of cultch types are reviewed in Table 9. These tables are a starting point to which additional methods and cultch types can be added as new techniques and substrates are evaluated.

This Plan provides a summary of the options available for practitioners to consider according to the unique characteristics of each restoration project so that the most appropriate strategy (e.g., cost-benefit, likelihood of success) can be employed. Depending on location, funding and project-specific goals, the design of each project will vary. A few of the questions that practitioners should consider when determining a strategy are:

- Is the restoration site in a high-energy area, with significant boat traffic, wave action or water flow?
- Is there a high rate of sedimentation?
- What depth of water will the restoration be in?
- What is the target oyster reef height and size?
- How much community outreach and involvement is desired?
- What type of monitoring will be needed to assess the success of the project-specific goals?
- Is the project within a Florida Aquatic Preserve and/or within Federal Endangered Smalltooth Sawfish Critical Habitat?
- How can harm to threatened and endangered species be minimized and avoided?

Oyster Restoration Method Descriptions

The following are brief descriptions of some appropriate oyster restoration methodologies.

Bagged Cultch: Aquaculture grade mesh (≤1 inch mesh size) is used to create bags that are filled with cultch, typically fossilized shell or fresh oyster shell. The bags, usually about two feet (0.6 m) long, are tied shut on both ends, creating a building block for the oyster reef (see Figure 9). Dependent on the desired oyster reef height bags can be stacked, a typical design in soft sediments would have bags stacked two to three high, while those in more stable sediments would not require stacking (Volety and Milbrandt, pers. comm.). The technique of using bagged cultch to form the footprint of the restored oyster reef has been the most commonly utilized for projects geared toward ecosystem restoration (Brumbaugh and Coen 2009). Within the CHNEP estuaries this is the only restoration technique that has been used for oyster reef restoration in the recent past. The SCCF and the City of Sanibel completed a project in Clam Bayou that utilized 4,200 bags to restore a 0.2-acre (750 m^2) area (Milbrandt et al. 2012). Florida Gulf Coast University (FGCU) has restored small reefs at numerous sites using this technique, totaling approximately 0.5-0.6 acres (2,000-2,500 m^2) throughout the Caloosahatchee Estuary and Estero Bay. Bagged cultch has also recently been used by the City of Naples. In these examples and others around the country, bagging cultch and placing the bags in a restoration project site, has involved a large number of volunteers, adding value to the project through community outreach (Milbrandt et al. 2012, LRC and Layman 2010, Hadley and Coen 2002). Other benefits of bagged cultch are: they remain stable in areas with high boat wakes or wave energy, they stabilize sediments, they do not sink as easily as loose shell in soft sediment, they may decrease shoreline erosion, they are easy to handle and carry into shallow locations and the footprint of the oyster reef can easily be controlled by bag placement. Potential for wildlife entanglement can be minimized by ensuring bags are as full as possible, and that 'pony-tail' ends are trimmed (see Figure 9). The USACE recommends the use of biodegradable materials to reduce wildlife entrapment concerns. However when choosing a material the overall function of the material should be considered; the function of alternative biodegradable materials should be tested prior to large-scale use.

Caged Cultch: Cages similar in design to crab traps can be filled with cultch to form oyster reef building blocks that can easily be anchored, especially beneficial in areas of high wave energy. Many of the benefits of bagged cultch may also be realized through the use of caged cultch. Although caged cultch has not been used within the CHNEP study area, it has been successful in high-energy areas, and has been used where shoreline protection is a project goal (Brumbaugh and Coen 2009). Manley and others (2010) also demonstrated that in a comparison to bagged cultch, in a high sedimentation area in Georgia, success was greater for caged cultch. The cages used are typically standard crab traps; these could be plastic coated for longer durability, or plain wire to allow for degradation over time. It is possible that abandoned or recycled crab traps could be used and incorporated into a community outreach program. The aesthetics of this method should be considered. There are no documented cases of sawfish entanglement in crab traps (Seitz and Poulakis 2006). The USACE recommends the use of biodegradable materials to reduce wildlife entrapment concerns.

Loose Cultch: Loose cultch, typically distributed from a barge (see Figure 9), is placed either directly on the estuary floor or on top of another material to create the oyster reef footprint. This method is used most commonly for oyster fishery enhancement/restoration, and primarily for large subtidal oyster reef restoration (Brumbaugh and Coen 2009). Other distribution methods can be used to locate loose cultch in shallow intertidal waters, such as dumping shell from bags (Brumbaugh and Coen 2009), five gallon buckets or from a helicopter (Tritaik, USFWS, pers. comm). Wildlife entanglement is not an issue with the loose cultch method. Loose shell may not be suitable in areas with moderate to heavy boat traffic, or other high-energy areas where cultch can easily be dispersed, thus reducing the likelihood of successful spat settlement and growth (Brumbaugh and Coen 2009, Piazza et al. 2005). However, the Sarasota Bay Estuary Program (SBEP) recently used a combination of loose shell surrounded by bagged shell to provide stabilization, as required by the project's FDEP permit. This combined method may provide the benefits from both loose and bagged cultch techniques; caged cultch may also be suitable to use in place of bags in a similar manner to create a stabilizing barrier. The placement of loose cultch is less time intensive and therefore larger areas can be restored. For example, Martin County recently restored 31 acres (125,452 m^2) of oyster reef habitat primarily using loose cultch transported by barges. A small barge, such as FDACS *Hoglet* used in the Cedar Key area (see Figure 9), has the capacity to transport 24 cubic yards of cultch into three feet of water (Shields 2009). In Apalachicola FDACS has used larger barges to transport larger amounts of shell for harvest-based restoration of hundreds of acres of oyster reef using this method; approximately 250 yards of shell are distributed per acre (4,047 m^2) (Berrigan 1990). The USACE may require assurance in the form of engineering reports and/or models that loose cultch will remain in place and not drift due to storms, vessel wake, or tidal fluctuations; this will be determined based on project-specific information (e.g., location).

Cultch Type: The type of cultch used for any of the above methods can vary, dependent especially on the availability and cost of materials (Brumbaugh and Coen 2009). Fresh oyster shell or fossilized oyster/mixed calcium carbonate typically provides the best results. The interstitial space created by shells appears to be important in limiting predation on spat, producing higher success rates (O'Beirn et al. 2000). If fresh shell from other areas is used it should be aged for at least one to three months to ensure no transfer of parasites or disease (Bushek et al. 2004). Cohen and Zabin (2009) caution that longer periods of at least six months may be necessary to ensure highly tolerant exotic species are not transferred. The state of New Hampshire mandates that shell is aged for at least six months prior to use in restoration (Grizzle, pers. comm.). Although most other states do not have regulations regarding shell quarantine, most states do have a standard practice of quarantining shell for several months at a minimum (Bushek and Cohen, pers. comm.). There are currently no permitting requirements in Florida; however shell used by FDACS in Apalachicola and Cedar Key is 'seasoned' for at least six months (Berrigan, pers. comm.). Shell recycling programs have been established in many areas of the country and can be a source of local cultch and a means of community outreach. See Table 9 for a comparison of various types of cultch.

Oyster Mats: The 'oyster mat' method, developed for use in the Mosquito Lagoon on the east coast of Florida, utilizes recycled fresh, quarantined shell (Barber et al. 2010). The mats are made of a hard aquaculture grade mesh. Fresh oyster shells that have been quarantined for three or more months are zip-tied through drilled holes onto the mesh (see Figure 10). When placed in the field the mats are anchored with cement donuts (i.e., sprinkler head covers). The mesh foundation settles into the sediment leaving the shells exposed; wildlife entanglement is not a problem. This method is very low profile and although making the mats is labor intensive it provides an excellent outreach and education opportunity for people of all ages and abilities. The mats have been highly successful in restoring dead margins (piles of disarticulated oyster shells from nearby reefs) in high boat traffic areas (Barber et al. 2010), and show potential for use in the CHNEP study area.

Other Methods: Other less traditional methods, such as vertical stakes, cement reef/oyster balls and cement oyster grates (Figure 10) are alternatives to be considered depending on the project objectives and project site characteristics. Vertical stakes, grooved PVC enriched with calcium carbonate, have been shown to out-perform both bagged and caged cultch in high sedimentation intertidal conditions by providing vertical relief (Manley et al. 2010). Stakes are placed securely in the intertidal zone at densities up to 81 per m^2. Tampa Bay Watch has successfully used cement oyster domes (Reef Balls™) in an oyster restoration project with the primary goal of shoreline protection in a high-energy area (www.tampabaywatch.org). The domes or Reef Balls™ are hollow cement structures that can be formed to various sizes to meet specific project needs. Other lower profile cement structures, such as oyster grates (see Figure 10), may provide a relatively cheap, stable substrate for oyster habitat restoration. Community groups may even be engaged to make and help place the cement structures at the restoration sites (LRD and Layman 2010).

Table 8: Oyster Habitat Restoration Methodology Matrix

Method – Typical Size	Closest Location of Known Use	Relief (high or low)	Water Depth	Materials	Entanglement Potential	Pros	Cons
Bagged Cultch 10s-100s m^2	CHNEP estuaries (FGCU, SCCF), Naples Bay (City of Naples), SBEP	high or low	Typically intertidal	Polyethylene Mesh Bags - aquaculture grade, diamond oriented tubular 1/2"-1" mesh, cultch	Possible	Community involvement, stable, stays put in high-energy areas, controlled reef footprint, could be used in canals instead of riprap	Highest entanglement potential
Caged Cultch 10s-100s m^2	Texas, Georgia	high or low	Typically intertidal	Plastic wire or plain wire crab traps - 3.8-cm mesh - anchored with rebar, cultch	Low	Higher success than bags in high sedimentation areas, plain wire would degrade over time, potential for using derelict crab traps and community involvement	Less natural profile, aesthetics
Loose Cultch 100s m^2 - acres	Cedar Key & Appalachicola (FDACS), SBEP, Martin County	high or low	Typically subtidal, use in intertidal where low wave energy	Cultch material, turbidity curtain, means of transport (e.g. bags, barge, buckets, helicopter)	No	No foreign materials remaining at site, larger footprint more feasible, can be stabilized with bagged shell around perimeter	Turbidity (use turbidity curtain), less control of footprint, movement of material from waves/boat wakes, limited by transportation

Table 8: Oyster Habitat Restoration Methodology Matrix (cont.)

Method – Typical Size	Closest Location of Known Use	Relief (high or low)	Water Depth	Materials	Entanglement Potential	Pros	Cons
Oyster Mats 10s-100s m^2	Mosquito Lagoon	low	Intertidal	16 1/2" mesh (1/2" mesh) aquaculture grade squares, zip ties, cement donut weight	No	Community involvement, stable, controlled reef footprint, less shell needed, lower profile	Time intensive method
Reef Balls 10s-100s m^2	Tampa Bay (Tampa Bay Watch), Loxahatchee	high or low	Intertidal or subtidal	Cement reef ball – available in various sizes, signage for navigation hazard	No	Can be made in various sizes, community involvement, successful in shoreline stabilization	Unnatural profile, FDEP permitting concerns, aesthetics, navigation hazard
Vertical Stakes 10s m^2	South Carolina, Georgia	low	Intertidal	Spat sticks - longitudinally grooved P.V.C. infused with calcium carbonate (81 per square meter), or other plain vertical stake material	No	Best method for high sedimentation areas, less shell needed, less chance of entanglement	Success not tested in Florida, has mostly been used intertidally for aquaculture, FDEP permitting concerns (i.e., aesthetics, navigation, potential to dislodge and become marine debris)

Table 8: Oyster Habitat Restoration Methodology Matrix (cont.)

Method – Typical Size	Closest Location of Known Use	Relief (high or low)	Water Depth	Materials	Entanglement Potential	Pros	Cons
Experimental - Concrete Grates 10s-100s m^2	Mosquito Lagoon - needs more development	low	Intertidal	Concrete with embedded shell	No	Community involvement, stable, controlled reef footprint, less shell needed, lower profile, no entanglement, no plastics	Success not as high as oyster mats
Experimental - Recycled Crab Traps 10s-100s m^2	N/A	high or low	Any	Recycled crab traps and cultch	Low	Same as caged cultch, with added benefit of recycling crab traps and community outreach	Less natural profile
Experimental - Other	N/A	high or low	Any	N/A	Low or no	Continue development of new techniques for successful restoration	N/A

Table 9: Oyster Habitat Restoration Cultch Matrix

Cultch Materials	Locations	Source	Success	Considerations
Fresh oyster shell	Northern FL	Shell recycling - restaurants, processing plants	Generally considered best	Quarantine for at least 1-3 months, more fragile and weigh less than fossilized shell
Fossilized shell/calcium carbonate	Charlotte Harbor	Mining	Good substitute for fresh shell	Heavier/more stable than fresh shell
Other clean shell (clam, whelk)	Louisiana	Shell recycling - restaurants, processing plants - dredging	Comparable to fresh oyster shell (Manley et al. 2010)	May not provide as much interstitial space as oyster shell
Sandstone	Louisiana	Mining	Significantly less successful than Limestone (Soniat and Burton 2005)	May not provide as much interstitial space as oyster shell
Limestone/Marl	Louisiana	Mining	More successful than clam shell - used as replacement when clam shell became limiting (Soniat et al. 1991)	May not provide as much interstitial space as oyster shell
Cement – loose recycled or shaped (e.g., reef balls)	Florida, Alabama, Louisiana	Recycled cement, or commercially available, can incorporate shell	Tampa Bay Watch successful use for shoreline stabilization	May not provide as much interstitial space as oyster shell
Spat sticks	South Carolina, Georgia	see Michener and Kenny 1991, Manley et al. 2010	Comparable to fresh oyster shell (Manley et al. 2010)	FDEP permitting concerns (i.e., navigation, potential to dislodge & become marine debris)
Experimental	N/A	N/A	N/A	Readily available resources, such as coquina rock may be suitable for use as cultch, but need to be tested.

Figure 9: Bagged Cultch and Loose Cultch Pictures
Top Left: Oyster bags being filled by volunteers (picture courtesy of SCCF), Top Right: Filled oyster bags with 'pony-tail' ends (picture courtesy of SCCF), Middle: Oyster bags after eight months deployed (picture courtesy of SCCF), Bottom Left: Small barge transporting loose cultch (picture courtesy of FDACS), Bottom Right: Spreading loose cultch by use of a large barge and back hoe within a turbidity curtain (picture courtesy of Martin County).

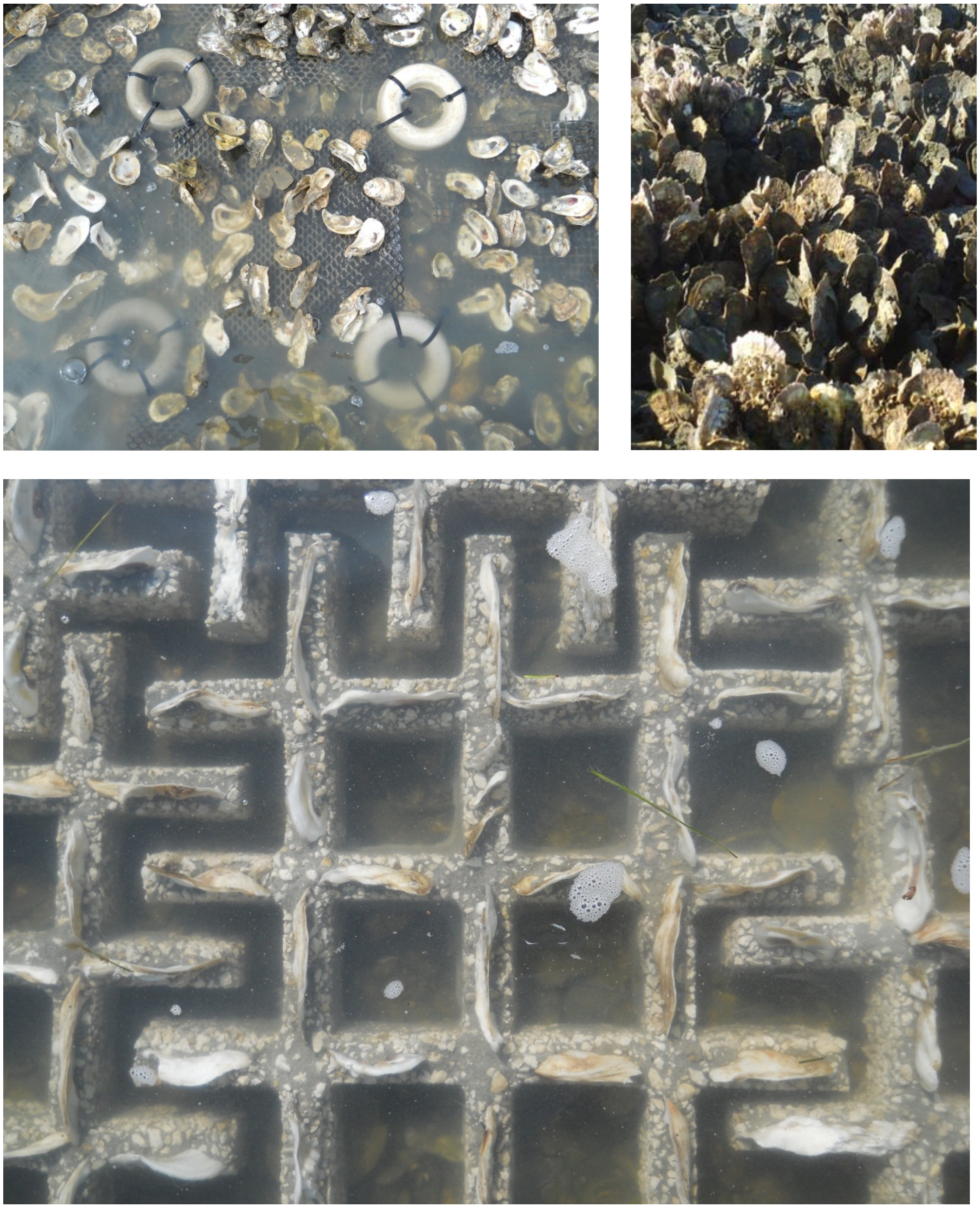

Figure 10: Oyster Mat and Oyster Grate Pictures
Top Left: Oyster mats deployed and anchored with cement donuts (picture courtesy of Anne Birch). Top Right: A restored oyster mat (picture courtesy of Anne Birch). Bottom: Close-up of oyster grates deployed for restoration (picture courtesy of Anne Birch).

Oyster Restoration Success Criteria

The purpose of success criteria is to establish measures by which specific project goals can be evaluated (Coen and Luckenbach 2000). Until recently, most oyster restoration efforts were conducted to enhance oyster fisheries, with goals to increase harvest using cost-effective methods (NRC 2004, Coen and Luckenbach 2000). Restoration of ecological function is not necessarily exclusive of oyster fisheries enhancement, but is essential to establishing a self-sustaining population (NRC 2004). Despite a new focus on restoring oyster reefs for ecological purposes, most restoration programs continue to use success criteria originally established for oyster fisheries restoration, primarily the density of market-sized oysters (Oyster Metrics Workgroup 2011, ASMFC 2007, Coen et al. 2007, Luckenbach et al. 2005). These success criteria do not ensure that a population is self-sustaining or providing ecosystem functions, the intent of CHNEP oyster habitat restoration. Although oyster fishery enhancement may be the goal of a specific project, this is not a comprehensive restoration goal throughout the CHNEP study area. Therefore, reaching a certain density of marketable oysters is not necessary for restoration to be deemed successful. In fact Luckenbach and others (2005) demonstrated that achievement of market-sized oysters is not necessary for the development of ecological functions.

Independent of other project goals, success of oyster restoration projects can be demonstrated by the ability to achieve self-sustaining oyster populations (Coen and Luckenbach 2000). Although some ecological functions do not require the consistent presence of live oysters (Luckenbach et al. 2005, Tolley and Volety 2005), a sustainable population is essential to the maintenance of the oyster reef structure and functions over time (Luckenbach et al. 2005, Coen and Luckenbach 2000). A self-sustaining population will, at a minimum, have vertical growth that exceeds the rate of sedimentation and subsidence (Coen and Luckenbach 2000) and will have multiple year-classes of oysters (Oyster Metrics Workgroup 2011, Luckenbach et al. 2005).

Two sets of success criteria are provided here for assessing oyster restoration success: for the region as a whole (Table 10) and goal-specific criteria for individual projects (Table 11). The intent of the CHNEP success criteria is to provide measures that can be used relatively easily to assess the coverage and condition of oyster reefs throughout the CHNEP study area, and to assess the CHNEP goal for oyster habitat restoration. The goal-specific success criteria provide measures that can be used to evaluate various project-specific goals, as well as the general success of the oyster restoration. For both sets of success criteria, the primary criteria are those that are recommended to be assessed at the minimum, while secondary criteria are additional measures that would add value to assessing success and condition. In all cases the success criteria used should reflect the individual project goals. Where appropriate success criteria include measures for varying levels of success; these varying levels can be used to assess projects over time and to compare relative success between projects.

CHNEP Success Criteria

The region-wide success criteria builds upon the oyster indicators used to assess CERP. Although these indicators were developed to assess the success of Everglades restoration, they are also applicable to assessing the general condition of the oyster population throughout the CHNEP study area. Monitoring and assessment of these indicators is underway in the Caloosahatchee Estuary (Volety et al. 2009). Using existing metrics and building upon this program provides consistency between projects and encourages the development of partnerships.

Primary CHNEP success criteria: The primary CHNEP success criteria are intended to provide the information necessary to determine if the oysters are self-sustaining and increasing or decreasing in overall coverage throughout the CHNEP study area. An accurate baseline oyster habitat map is needed in order to assess restoration success in the future and track progress towards the CHNEP restoration goal. Measurements of oyster density, size structure and larval recruitment throughout the study area would provide the metrics needed to assess the general viability of the community. The presence of more than one size class is important for reproductive success of the oysters and sustainability of the reef (Oyster Metrics Workgroup 2011). Annual spatfall is essential to the continued success and growth of the oyster reef, while density provides a measure of overall population size. These measures can be used to predict future population structure, similarly to that done by Berrigan (1990) to predict oyster fishery yields.

Secondary CHNEP success criteria: The secondary CHNEP success criteria are measures that can provide additional information about the condition of the oyster reefs. Four out of the five measures are currently being utilized in the CERP monitoring program, including: Condition Index, Gonadal Index, Disease Prevalence and Disease Intensity. These measures evaluate the condition of individual oysters and can indicate increasing or decreasing oyster health prior to large-scale oyster reef loss. In addition to these four secondary criteria, measuring the biodiversity of resident biological community found at the oyster reef provides a gauge of the condition of the associated oyster reef species. To simplify the use of oyster reef resident community as an indicator, this measure only considers decapod crustaceans and fishes. However, it is assumed that many more species will utilize the oyster reefs and a high diversity of decapods and fish would reflect the overall diversity of the reef.

Following the establishment of a program to assess restoration success throughout the CHNEP study area, an assessment tool could be developed to translate the findings into readily interpreted results for decision-makers and citizens. For example, the CERP monitoring program uses stoplight colors to demonstrate good conditions (green), neutral conditions (yellow) and undesirable conditions (red) (Volety et al. 2009). Sarasota County also uses a color-coded mapping system to depict monitoring results spatially, placing the information in the context of the larger landscape (Jones 2007).

Goal-specific Success Criteria

Practitioners implementing individual oyster habitat restoration projects within the CHNEP study area are encouraged to measure restoration success using the goal-specific primary success criteria at a minimum and additionally the secondary success criteria where appropriate and when possible (see Table 11). The primary success criteria are intended to assess the potential for the restored oyster habitat to be self-sustaining and provide ecosystem services. It is understood that each individual project will have specific goals, a limited budget and variable requirements dependent on funding sources. With this in mind this suite of measures provides a tool for ensuring some consistency of criteria between projects within the region, while allowing flexibility for the needs of each project.

Table 10: CHNEP Region-wide Oyster Restoration Success Criteria

	Success Measure	Level I	Level II	Level III	Reference
Primary	Reef Coverage	= Baseline	> Baseline	5000 acres	-
	Density/m^2	0-200	200-800	800-4000	Volety et al. 2009
	Size Structure	1 size class	2 size classes	3+ size classes	OMW 2011, Luckenbach et al. 2005
	Larval Recruitment (spat/shell)	0-5	5-20	20-200	Volety et al. 2009
Secondary	Oyster Reef Resident Community	10 decapod and fish species	6-10 decapod species; 6 -10 fish species	10+ decapod species; 10+ fish species	Milbrandt et al. 2012, Tolley and Volety 2005, Glancy et al. 2003
	Condition Index	0-1.5	1.5-3.0	3.0-6.0	Volety et al. 2009
	Gonadal Condition (modified scale)	0-1	1-2	2-4	Volety et al. 2009

Because the intent of CHNEP oyster restoration activities is to restore oyster habitats and their functions, it is expected that each oyster restoration project within the region will have a goal of restoring a sustainable oyster community as well as one or more ecosystem services. TNC identifies four broad categories of success measures relevant for restoring ecosystem services, including: 1) recruitment and growth, 2) provision of habitat for other associated species, 3) direct and indirect effects on local water quality, and 4) shoreline protection (Brumbaugh et al. 2006); others identify similar categories of ecosystem services (Coen et al. 2007, Grabowski and Peterson 2007). The four categories listed above were used as the basis for establishing the suite of goal-specific success criteria. At a minimum the primary measures of oyster reef stability, growth and recruitment (i.e., reef footprint, reef relief, density and size structure), and adjacent habitat stability should be assessed for all projects. In addition, the primary measures for provision of habitat and water quality should also be assessed if possible. The secondary measures may also be useful where needed and when funding allows.

These goal-specific success criteria were developed based on previous or ongoing studies where available, to build off of an existing knowledge base and allow for consistency and continuity. In addition they provide measures to assess oyster reef stability and adjacent habitat stability for assessing if the oyster reef design is appropriate for the selected location; these measures will likely be required by permits. Where numerical success criteria are not relevant, or sufficient local studies are not available, success can be measured compared to a baseline or adjacent community. As in the region-wide success criteria, the density component of the CERP monitoring plan is appropriate for project-specific evaluations (Volety et al. 2009). Additionally, the presence of more than one size class is important for reproductive success, and is considered an important success measure (Oyster Metrics Workgroup 2011, Luckenbach et al. 2005). Although multiple size classes are ideal, a single size class for year one of a project, would be considered successful.

Table 11: CHNEP Goal-Specific Oyster Restoration Success Criteria

	Success Measure	Level I	Level II	Level III	Reference
Reef Stability, Growth and Recruitment					
Primary	Reef Footprint	= Baseline (no undesired expansion due to disturbance)			-
	Reef Relief	= Baseline (after initial settling)	> Baseline (after initial settling)		-
	Density/m^2	0-200	200-800	800-4000	Volety et al. 2009
	Size Structure	1 size class	2 size classes	3+ size classes	OMW 2011
Secondary	Larval Recruitment (spat/m^2)	50-100	100-200	200+	Milbrandt et al. 2012
	Percent Living	20-50%	50-70%	>70%	Jones 2007
Provision of Habitat					
Primary	Oyster Reef Resident Community	Desirable decapods, fish, epifauna and epiphytes present	6-10 decapod species, including mud crabs and porcelain crabs; 6-10 fish species; desirable epifauna and epiphytes present	Biodiversity comparable to natural reefs	Milbrandt et al. 2012, Tolley et al. 2006, Tolley and Volety 2005, Tolley et al. 2005, Glancy et al. 2003
Secondary	Transient Residents	Biodiversity = adjacent non-reef habitat	Biodiversity > adjacent non-reef habitat	Biodiversity comparable to natural reefs	Coen et al. 1999
Water Quality Improvement					
Primary	Water Clarity	= Baseline	Clearer than baseline		Brumbaugh et al. 2006
	Turbidity	= Baseline	Less turbid than baseline		
Adjacent Habitat Protection					
Primary	Adjacent Habitat Stability	Does not cause erosion or degradation of adjacent habitats			-
Secondary	Seagrass	= Baseline	Greater coverage and/or extent than baseline	-	Milbrandt et al. 2012, Brumbaugh et al. 2006
	Salt Marsh	= Baseline	Greater coverage and/or extent than baseline	-	Brumbaugh et al. 2006
	Sediment Stabilization	= Baseline	Greater elevation than baseline	-	Tampa Bay Watch
	Shoreline Stabilization	= Baseline	Extended shoreline (where desired)	-	Brumbaugh et al. 2006

Sarasota County has an ongoing program for measuring percent of living oysters at sites in the northern extent of the CHNEP study area. The success categories included herein are based on Sarasota County's assessment protocol (Jones 2007). Percent living is included as a secondary success criterion for those practitioners that would like to include this measure for consistency with the ongoing Sarasota County program. However, the measure of percent living should be evaluated in context with other measures such as total density, size structure and recruitment.

The success criteria used by SCCF for assessing success of a recent restoration project was also referenced for the larval recruitment, oyster reef resident community and seagrass measures. The SCCF restoration plan set success criteria for first year live oyster recruitment at 50 oysters per m^2, actual recruitment values were greater than 200 per m^2, leading to the range of success values of 50-200+ per m^2 (Milbrandt et al. 2012).

The oyster reef resident community success criteria were developed based on the findings of local studies and one study from northwestern Florida. Milbrandt and others (2012) set a target of 10 resident species of invertebrates, and found that actual resident invertebrates were far more diverse. Tolley and others (2005) studying the resident communities of oyster reefs in the Caloosahatchee estuary identified 10 species of decapods and 16 species of fish, similar findings are also reported in Tolley et al. 2005 and Tolley et al. 2006. In northwestern Florida, Glancy and others (2003) compared decapod communities in natural oyster reefs compared to adjacent communities. They found at least 12-13 decapod species, each season, associated with the oyster reefs. Three of these species were found in great abundance in the oyster reef samples and were rarely if ever found in the adjacent communities. These species were the mud crab (*Eurypanopeus depressus*), black-clawed mud crab (*Panopeus herbstii*) and the porcelain crab (*Petrolisthes armatus*). Tolley and Volety (2005) also found an abundance of mud crabs and porcelain crabs associated with the oyster reefs in the Caloosahatchee estuary, as they note the black-clawed mud crab is not found in southwest Florida. The mud crab and porcelain crab appear to be dependent on oyster reef structure (Tolley and Volety 2005), and therefore are included as indicator species. Although these species may not be reliant on live oysters, a sustainable oyster population will continue to provide the structure that they rely upon.

Ultimate success should be a biodiversity comparable to local natural oyster reefs with similar salinity regimes, without the presence of invasive species. Biodiversity sampling is heavily gear dependent. The proposed success criteria are based on small-scale sampling methods (e.g., trays, small lift nets) for ease of implementation; other success criteria values should be considered with the use of different sampling methods. Use of larger nets for sampling would likely result in a higher diversity of fish, and inclusion of larger species (Coen, pers. comm.). Greater biodiversity is also expected under higher salinity conditions (Tolley et al. 2005, 2006).

Implementing monitoring of goal-specific success criteria including oyster reef coverage, density, size class and larval recruitment, to the extent possible, will contribute to evaluating both site-specific and CHNEP area-wide attainment of oyster restoration goals and assist with designing more effective restoration projects in the future. A document entitled “Oyster Habitat Restoration Monitoring and Assessment Manual” has been drafted by a working group to help provide a standardized approach for monitoring oyster reefs. The document is currently going through a review process and when finalized should be used as a key reference for setting success criteria and for designing a monitoring program. The draft document is currently available at www.oyster-restoration.org. This website is also a good resource for up-to-date oyster restoration information.

Oyster Restoration Monitoring and Mapping Needs

Monitoring site suitability and restoration success are essential components of oyster restoration planning, both regionally and for individual projects. Monitoring is essential for evaluating project success and adapting new strategies for enhancing project designs. Documentation of oyster restoration successes and failures can be shared with other practitioners and help achieve greater success in future projects. Using consistent monitoring strategies between projects within the region will also help compare and contrast different restoration strategies, locations and environmental conditions. Monitoring should be conducted before, during and following oyster restoration implementation (Thayer et al. 2005).

Site Suitability Monitoring

Pre-restoration monitoring provides information needed to design a successful project based on the characteristics of the site. Initially it is critical to determine why a healthy oyster population is not currently present at the site. In areas within the CHNEP study area identified by the oyster habitat RSM as highly suitable (80-100%) for restoration, the primary limiting factor is most commonly lack of a suitable substrate for larval oyster settlement. However, other stressors, such as recruitment limitation, water quality and quantity, predation and disease, may also be contributing to a lack of oysters.

Although recruitment limitation has not been a problem in previous restoration projects within the CHNEP study area, there may be localized areas where low recruitment rates occur due to water flow patterns or distance from a spawning population. One to two years of recruitment monitoring is suggested prior to restoration to verify if substrate enhancement alone will be sufficient to restore a population, or if broodstock enhancement may also be necessary (Coen and Luckenbach 2000). Recruitment monitoring in southwest Florida should be conducted between March and October (Volety et al. 2009).

Water quality and quantity should also be evaluated on the local level. The CHNEP oyster habitat RSM takes into account freshwater flow from the three major rivers in the CHNEP study area, but does not attempt to model localized water quality or flow conditions. Water flow should be adequate to replenish food supplies and oxygen, remove waste and moderate water temperature, but not high enough to limit recruitment or to create killing floods (i.e., extended periods of salinity below 3 psu). Areas of run-off can also result in accumulated contaminants in the water that could stress oyster populations (Volety and Tolley 2003), additionally these areas could have higher turbidity levels and higher rates of sedimentation. For regional flow patterns the following references should be consulted: SFWMD 2012, Xia et al. 2010, FDEP 2009, Qui et al. 2007, Bierman 1993, USGS National Water Information System (http://waterdata.usgs.gov/nwis) and DBHYDRO (www.sfwmd.gov).

Predation and disease should be considered as potential stressors of oyster populations but are not thought by local experts to be the primary limiting factor in oyster reef health in the CHNEP study area. Disease intensity and prevalence is monitored in the Caloosahatchee Estuary on a monthly basis, and data is accessible on the Oyster Sentinel website (www.oystersentinel.org). This data can be used to get a general understanding of the recent and current conditions of oysters in the region, although conditions may vary in others portions of the CHNEP study area.

Table 12 presents a comprehensive list of metrics that should be considered when evaluating site suitability for oyster restoration success. This table could be used by the SWFOWG to develop a standard site assessment form for determining site suitability.

Table 12: Site Suitability Metrics and Considerations

Metric	Time of Year	Considerations
Substrate	Anytime	What type of substrate is present? Will subsidence be a problem? What restoration methods will work best?
Recruitment	Mar-Oct	Is there sufficient recruitment? Is broodstock enhancement needed?
Temperature	Jul-Oct	Do temperatures exceed 32ºC for prolonged periods?
Salinity	June-Oct	Does salinity drop below 3 psu for prolonged periods?
Dissolved Oxygen	Jul-Oct	Are anoxic or hypoxic conditions present for prolonged periods?
Sedimentation	June-Oct	What are the sedimentation rates? Is there the potential for reef burial? What restoration methods will work best?
Water Flow	All Year	Is there sufficient water flow for flushing and food transport? Is water flow too high for successful recruitment?
Predators	All Year	Should shell cultch be used to minimize predation on larvae?
Disease	All Year	Is disease intensity/prevalence a concern?
Wave Energy	Winter	Does the site experience high wave energy? What restoration methods are most suitable?
Boat Traffic	All Year	Is the site in an area of high boat traffic? What restoration methods are most suitable?
Food Availability	All Year	Are there high enough food concentrations?
Water Depth	All Year	What is the water depth range? What is the tidal range?
Adjacent Habitats	Anytime	How will the oyster restoration affect adjacent habitats (positively or negatively)? Will the oyster restoration cause erosion of any adjacent habitats?

Restoration Monitoring

Once a suitable restoration site has been identified and a restoration strategy has been established, the restoration monitoring plan should be developed. A BACR (Before-After-Control-Restoration) design is optimal for statistical analysis of the monitoring data and for providing clearly interpreted results (Thayer et al. 2005). This design includes monitoring prior to restoration and after restoration at both a control site and at the restoration site. The control site would ideally be at a nearby healthy oyster reef that experiences similar environmental conditions, it may not be possible to locate an appropriate control site in some areas.

The specific monitoring design will vary from project to project, and funding will often times dictate the amount of monitoring that can be undertaken. At a minimum, a level of monitoring should be conducted that allows the practitioners to determine if the project is on track for success, or if there is an adaptive strategy that should be implemented in order to lead to success. An example of an adaptive strategy is incorporating broodstock enhancement if recruitment levels are below the established success criteria level. It is important that oyster reef stability and adjacent habitat stability are also monitored to ensure there is no unintended harm to other valued resources.

Table 13 provides a summary of the suggested monitoring methods, frequency and duration for assessing the success of individual projects and region-wide restoration. Additional information on each method is available from the references listed.

Long-term Monitoring

A long-term on-going monitoring program for natural oyster reefs and restored sites is needed throughout the CHNEP study area. A monitoring strategy that expands upon the CERP monitoring program in the Caloosahatchee Estuary would allow for a region-wide assessment of oyster habitat condition. In addition, accurate ground-truthed region-wide mapping using consistent methods is critical to track progress towards achieving the CHNEP oyster habitat restoration goals and estimating the ecosystem benefits of oyster habitats throughout the region. An accurate, repeatable, cost-effective mapping technique should be developed for use in the CHNEP study area to meet this need. The development and implementation of a mapping protocol should occur concurrently with restoration projects. Lessons learned from other mapping studies (e.g., Power et al. 2010, Ross and Luckenbach 2009, Howard and Arrington 2008, O'Keife et al. 2006, Schill et al. 2006, Grizzle et al. 2002, Coen – ongoing study, South Carolina Department of Natural Resources) should be incorporated into a mapping protocol for the CHNEP study area. Some things that should be considered in developing a mapping protocol are:

- Previous and current mapping techniques used within the CHNEP study area.
- Ability to map oysters associated with mangroves.
- Depth to which mapping will be accurate.
- Ability to map both intertidal and subtidal reefs.
- Cost-effectiveness.

The CHNEP will work with its partners to design consistent habitat monitoring and mapping methods throughout the estuaries and implement them cooperatively in the near future as resources allow. The information provided in Table 13 will be used as a starting point for the development of consistent monitoring methods.

Table 13: Guidance on Monitoring to Assess Success Criteria

Success Measure	Methods	Units	Frequency	Duration	Reference
Reef Coverage (areawide)	High Resolution Remote Sensing; GPS/GIS	Acres	5-10 years	Ongoing	Thayer et al. 2005
Reef Footprint (individual project)	GPS/GIS; Hydroacoustics	Square feet, square meters, acres	Annual	2+ years	Thayer et al. 2005
Reef Relief	Chain Transects; Hydroacoustics	Rugosity	Annual	2+ years	Thayer et al. 2005
Living Density	Quadrat (0.1-0.25 m^2)	Live Oysters/m^2	Bi-annual (late fall, early spring)	Regional – Ongoing, Project – 1+ years	Volety et al. 2009; Thayer et al. 2005
Size Structure	Quadrat (0.1-0.25 m^2)	Shell length (cm); # size classes	Bi-annual (late fall, early spring)	1+ years	Milbrandt et al. 2012
Regional Larval Recruitment	Stringer	Spat/shell	Seasonal; monthly	Ongoing	Volety et al. 2009
Project Larval Recruitment	Quadrat (0.1-0.25 m^2)	Recruits/m^2	Bi-annual	1+ years	Thayer et al. 2005
Percent Living/Recently Dead	Quadrat (0.1-0.25 m^2)	Percent	Bi-annual (late fall, early spring)	1+ years	Jones 2007
Oyster Reef Resident Community	Trays; Lift Nets	# of species	Bi-annual	Regional – Ongoing, Project – 1+ years	Milbrandt et al. 2012; Tolley and Volety 2005; Tolley et al. 2005, 2006
Transient Residents	Seine	# of species	Bi-annual	1+ years	Thayer et al. 2005
Condition Index	Meat Weight: Shell Weight	Ratio	Monthly	Ongoing	Volety et al. 2009
Gonadal Condition	Histological Analysis	Scale (0-4)	Monthly	Ongoing	Volety et al. 2009
Localized Water Clarity	Transparency Tube	Centimeters	Monthly	1+ years	Ohrell and Register 2006
Localized Turbidity	Turbidity Meter	NTUs	Monthly	1+ years	Ohrell and Register 2006
Adjacent Habitats	Variable	Variable	Bi-annual	1+ years	Brumbaugh et al. 2006

Steps Toward Attaining CHNEP Oyster Habitat Restoration Goals

The following is a brief summary of some of the key components necessary for attaining the region-wide CHNEP oyster habitat restoration goals.

Build Partnerships: A large-scale restoration project, such as a region-wide oyster restoration, requires wide spread support and a diversity of skills. The Southwest Florida Oyster Working Group provides a forum within which to continue building partnerships for implementing projects. The group, consisting of members from government agencies, non-profits, academia and the private sector, provides a strong knowledge and skills base for designing successful restoration and research projects. In addition the group would benefit by identifying civic groups that might be passionate about oyster restoration, and be interested in volunteer opportunities. Reaching out to the commercial and recreational fishing communities may be of particular benefit for gaining community support, knowledge about existing and historic oyster reefs and support on the water. (Brumbaugh et al. 2006)

Raise Awareness: Raising awareness will in part happen by developing a more diverse group of partners, but outreach to the media, school groups and others is also important to reaching a wider audience. Press releases, highlighting the benefits of oyster restoration in relation to large-scale issues (e.g., habitat conservation, water quality, water management), should be distributed as part of all restoration projects. A good base of partners will aid in making more media contacts. (Brumbaugh et al. 2006)

Secure Permits: Input from permitting agency staff on this plan was intended to reduce the time and effort it will take to receive permits for oyster restoration projects that follow the guidance herein. However, since each project will be unique, practitioners are strongly encouraged to engage in discussions with permitting agencies early on in the process of designing and implementing a project, if at all possible prior to submitting a permit application. See the Regulatory Permitting Considerations section for more information.

Secure Funds: Funding for restoration projects is available on a competitive basis from government agencies and non-governmental organizations. Each funding opportunity has specific criteria for who can apply, maximum dollar amount awarded, amount of leveraging (i.e., match) required and project benefits/goals. A proposal backed by a diverse partnership is likely to be more competitive for funding because they are able to bring more to the table, such as diverse skills, volunteers and matching funds. Diverse partnerships also increase the number of funding opportunities available, as some opportunities are limited to certain types of applicants. (Brumbaugh et al. 2006)

Monitor and Map: The development of a region-wide oyster monitoring program that expands upon the CERP Caloosahatchee estuary program will enable the CHNEP to evaluate oyster conditions throughout the region. In combination with the development of a region-wide mapping program the CHNEP will be able to evaluate progress toward the oyster restoration goals. The Southwest Florida Oyster Working Group should serve as a forum for developing partnerships for designing, obtaining funding and implementing these programs.

Fill Knowledge Gaps: As projects are implemented CHNEP partners are encouraged to help fill the knowledge gaps about oyster restoration in southwest Florida. Thoughtfully designed monitoring programs will allow for practitioners to determine success of an individual project, while also making comparisons between various project designs. Some of the knowledge gaps identified while drafting this plan include:

- Historical oyster reef density and distribution in CHNEP study area.
- Current oyster reef density and distribution in CHNEP study area.
- Current abundance of non-reef oysters (e.g., mangroves and seawalls).
- Comparison of intertidal and subtidal (3-6 ft. and >6 ft.) oyster restoration sites in SW Florida.
- Appropriate methods for contouring existing water quality data.
- Biodiversity of resident and transient species associated with oyster reef communities in SW Florida.
- Quantification of ecosystem services provided by oyster habitat in SW Florida.
- Distribution and abundance of oyster larvae throughout the CHNEP study area.
- Relationship between smalltooth sawfish and oyster reefs.

Recommended Oyster Restoration Areas for Each CHNEP Estuary

Table 14 represents the recommendations of the SWFOWG in regards to specific restoration areas within the highly suitable restoration areas (as defined by RSM scores ≥ 0.8) of each estuary region.

Table 14: Recommended Restoration Areas by Estuary

Estuary Region	Comments	Recommended Restoration Areas
Dona & Roberts Bays	Oysters end at intersection with Fox Creek and are most abundant east of US 41; Blackburn Canal hydrology may affect success of oyster restoration.	East of US 41
Upper & Lower Lemon Bay	SWFWMD Coral Creek restoration should benefit water quality and oyster habitat.	All Tributaries
Gasparilla Sound-Cape Haze	Avoid manatee birthing area in Turtle Bay.	South side of Cape Haze
Tidal Myakka River	There are lots of healthy oysters in this area; additional substrate may be added west of the 776 bridge.	West of 776 bridge, Tippecanoe Bay
Tidal Peace River	Environment is suitable for restoration at least up to the I-75 bridge.	Northwest of Punta Gorda Isles, Alligator Bay, behind Hog Island
Charlotte Harbor West Wall & East Wall	The citizen's group, CCA, is interested in oyster restoration in this area.	Add fringing reefs near islands north of Pirate's Harbor
Charlotte Harbor Proper	Oyster bars were present north of Bokeelia historically; boat traffic should be considered.	Sandbars to the north of Bokeelia
Pine Island Sound	Locations of existing reefs – northwest of York Island, near MacKeever Keys, near Regla Island, underneath mangroves outside of Tarpon Bay's shallow cut, east of the north end of Buck Key, south of Demere Key, Captiva Rocks, near fish houses west of Pineland, between Cayo Costa and Cabbage Key.	Add substrate near existing reefs.
Matlacha Pass	Restoration within Pine Island Creek may conflict with American Crocodile habitat. Water quality related to Ceitus Canal should be considered.	Shallow areas outside of the channel, north of the powerlines
San Carlos Bay	An extensive reef was present historically on the south side of Fisherman Key.	Add substrate near existing reefs and at sites of historic reefs.
Tidal Caloosahatchee River	Killing floods limit suitable areas to those downstream of Peppertree Point; with improved management of water releases oyster restoration could occur further upstream.	Additional substrate near previously restored, successful reefs
Estero Bay	Higher quality oyster habitat is near Estero River and Spring Creek. High flows from the Imperial River and Mullock Creek reduce the quality of habitat in these areas. High flows from Mullock Creek also flow up Hendry Creek, reducing salinities.	Hell Peckney Bay, Hurricane Bay, around Estero River, around Spring Creek

Cost Estimates for Attaining CHNEP Oyster Restoration Goals

Table 15 is provided as general guidance for the cost of the materials needed for implementing various types of restoration projects, and some estimate of staff and volunteer time for implementation. Due to variability between projects, estimates do not include time/money needed for obtaining funds, securing permits, or monitoring. Another highly variable cost, which is not included, is boat usage. Many volunteer/community based projects are able to solicit the donation of boat use, so this is often not a large expense for those projects. Whereas projects delivering loose cultch via a barge will have much higher costs in boat use, the cost of which will vary dependent on distance of the project from a staging site. When comparing the various methodologies one should also consider the scale of the project.

Table15 specifies a restoration unit for each methodology based on the project size from which the estimates were made. The cost of materials is scaled up for a comparison of cost per acre of restoration. However the time estimates are not scaled up, as with the larger projects time-use may become more efficient and not have a linear relationship with project size. Material costs for the oyster restoration methods range from \$3,000 per acre (0.004 km^2) for loose fresh shell to \$605,000 per acre (0.004 km^2) for Reef Balls™. The average cost per acre for materials for the most conventional methods is \$54,500 per acre (0.004 km^2).

Funding Opportunities

A recent study of the economics of oyster restoration found that "oyster reefs, when restored and managed as a resource rather than a commodity, can provide billions of dollars' worth of value to the national economy" (Stokes et al. 2012). The growing realization that oyster restoration is not only valuable for the oyster harvesting industry, but offers wide-spread ecological benefits is driving an increase in funding opportunities. Table 16 provides a summary of those opportunities that are generally available on a yearly basis.

> **"For oyster reef restoration to be fully incorporated into coastal management plans, it needs to meet four main challenges. First, projects need to provide policymakers and funders with reliable data about reef design and effectiveness. Second, restoration efforts need to be coordinated and the technologies used to scale. Third, the innovation already taking place needs to be encouraged so that oyster reef restoration can be an effective strategy to meet a variety of goals for coastal areas. Fourth, adequate funds need to be available. While the first three challenges seem to depend entirely on the fourth, in fact each challenge is part of a cycle. Already, progress in all of these areas has generated practical support for oyster reef restoration." (Stokes et al. 2012)**

Table 15: Cost Estimates of Supplies by Restoration Methodology

Method	Location/ Source	Restoration Unit	Materials	Material Costs/ Unit	Cost/ Acre	Volunteer Hours/Unit	Staff Hours/ Unit	Additional Considerations
Bagged Cultch (2-bags high)	Florida (City of Naples)	0.01 acres (400 ft^2)	5 tons of fossilized shell ($29/ton), 2 1000' mesh rolls ($80/roll)	$303	$30,300	110-150	20-60	permitting, travel, boats, staging sites
Bagged Cultch Research Project (1 bag high)	Clam Bayou on Sanibel Island (SCCF)	0.16 acres (637 m^2)	100 tons of fossilized shell delivered ($25/ton), other materials (mesh, tubes, buckets, monitoring trays, tools, calipers)	$13,265	$82,906	752	1,000-1,500	permitting, travel, boats
Loose Fresh Shell	Florida (GSMFC 2012)	1 acre	250 cubic yards of fresh shell ($12/cubic yard)	$3,000	$3,000	-	80-200 (dependent on barge size)	permitting, travel, barge, staging sites
Loose Fossilized Shell	Florida (GSMFC 2012)	1 acre	250 cubic yards of fossilized shell ($26.95/cubic yard)	$6,738	$ 6,738	-	80-200 (dependent on barge size)	permitting, travel, barge, staging sites
Oyster Mats	Mosquito Lagoon, Florida (TNC)	0.10 acre (approx. 2,500 mats)	23 rolls mesh (XV1020) 100,000 50lb test cable ties, 450 5g. buckets whole oyster shell, 7,500 weights, 10,000 120lb test cable ties, drill presses etc.	$17,800	$178,000	3750-7500	1,110-1,500	permitting, travel, boats for supply haul and volunteers, staging sites
Reef Balls™		0.03 acres (100 x 15 ft)	165 - 2' high, 3' wide cement balls ($100/ball and delivery)	$18,150	$605,000	75-100	20-60	permitting, travel, staging site
Precast Concrete 'Oyster Grates'	Mosquito Lagoon, Florida (TNC)	0.10 acre (approx. 2,500 grates)	Limestone/stone/ sand/cement/oyster shells	$37,500	$375,000	20-50	500-1000	permitting, travel, boats for supply haul and volunteers, staging sites

Note: This table provides a rough estimate of the cost of materials, volunteer time needed and staff time needed for the implementation of different types of restoration projects. Time estimates do not include permitting, monitoring, report writing etc. Each project will vary dependent upon location, goals of project, types of volunteers, permit requirements etc. Prices are based on estimates obtained in 2012. Monitoring costs should be comparable between restoration types.

The development of this plan offers a step toward being more competitive for grant funding by demonstrating a regional approach. It also puts the CHNEP partners in a position to compete for larger funding opportunities, such as those that were available through the American Recovery and Reinvestment Act. It was through those funds that Martin County was allotted $4 million to conduct oyster restoration in the St. Lucie River.

The USACE is the largest federal stakeholder in Chesapeake Bay oyster restoration, having restored over 250 acres (1 km^2) by 2002 (NRC 2004). Developing a partnership with the USACE may help secure additional federal funding in the future. By continuing to build partnerships through which projects are implemented in support of this plan, sharing lessons learned and demonstrating success, the CHNEP will be able to even more effectively raise support for additional funding. Continued coordination with the permitting and funding agencies is key to being able to take advantage of all available funds for oyster habitat restoration.

Community Stewardship Opportunities

Partnering with community groups brings immediate value to a project through contribution of volunteer hours, which can be an important source of leverage for grant funds. But these partnerships also add value through educating the volunteers, gaining media support and getting wide-spread community support; benefits that are invaluable to a large-scale restoration effort. Dependent on individual skills, volunteers can contribute to many aspects of projects, but independent of skill-level several restoration methodologies draw heavily upon volunteer labor. These types of volunteer opportunities are great for both high school and college students to gain hands-on experience with estuarine ecology. Some students may be able to use such volunteer opportunities to meet program requirements for volunteer hours or independent research (e.g., requirements for the International Baccalaureate Program).

Bagging fossilized shell and assisting with transporting and placing bags has been demonstrated time and again to be a well-received volunteer activity for scout troops, school groups, civic groups and individual citizens (Milbrandt et al. 2012, Hadley and Coen 2002, City of Naples, FGCU). The oyster mat methodology also provides an array of opportunities for volunteer participation, including: transporting oyster shell, drilling shells, cutting mat fabric, making mats and deploying mats, to name a few (Birch and Walters 2009). The mat making in particular is a great activity that can be used as a teaching tool and taken into classrooms, nursing homes, civic meetings or most any venue (Figure 11). The Brevard Zoo, in cooperation with TNC, has developed such an outreach program through which oyster mats are made while the importance of oyster restoration is spread throughout the community. Another common volunteer activity is oyster gardening, which requires volunteers to maintain caged or bagged oysters until they are ready to spawn. Typically, these oysters are then transplanted to restoration sites. This technique has been used in areas where broodstock enhancement is identified as a limiting factor (Brumbaugh et al. 2000a, Brumbaugh et al. 2000b).

Table 16: Oyster Habitat Restoration Funding Opportunities

Agency	Name	Total Amount	Award Ceiling	Goal	Eligibility	Website
US Fish & Wildlife Service (USFWS)	The Multistate Conservation Grant Program	$6,000,000	$1,000,000	Fish & Wildlife Resources	State, public and private institutions of higher education, nonprofits	http://wsfrprograms.fws.gov/
USFWS	Sport Fish Restoration Program	dependent on income	-	Sport Fish Restoration	State Fish & Wildlife Agencies	http://wsfrprograms.fws.gov/
USFWS	National Coastal Wetlands Conservation Grant Program	$20,500,000	$1,000,000	Conservation of Coastal Wetland Ecosystems	State	http://wsfrprograms.fws.gov/
USFWS	Coastal Program	-	-	Region 4 - shoreline restoration and protection	State and local agencies, nonprofits, other?	www.fws.gov/coastal/
TNC and NOAA Restoration Center	Community-based Restoration Matching Grants Program	-	$250,000	Marine and coastal habitat restoration - focus on shellfish	Public, private, tribal governments, non-profit	www.habitat.noaa.gov
Southeast Aquatic Resources Partnership (SARP)/NOAA Projects	Community-based Restoration Program	$215,000	$100,000	Protect shorelines, create fish habitat	NGO's, municipalities, schools, states, tribal governments	www.southeastaquatics.net
SARP-NFHAP-USFWS	Aquatic Habitat Restoration Program	-	$75,000	Restore or enhance aquatic habitat via on the ground modification	-	www.southeastaquatics.net

Table 16: Oyster Habitat Restoration Funding Opportunities (cont.)

Agency	Name	Total Amount	Award Ceiling	Goal	Eligibility	Website
Fish America and NOAA Restoration Center	Community-based Habitat Restoration Projects	$1,000,000	$75,000	Citizen-driven fisheries habitat restoration	Non-profits, educational institutions, state, local government	www.fishamerica.org
NOAA Restoration Center	NOAA Coastal and Marine Habitat Restoration National and Regional Partnership Grants	$10,000,000	$1,000,000	fisheries habitat restoration	Colleges, universities, non-profits, for profits, U.S. Territories, and state, local and Indian tribal governments	www.habitat.noaa.gov
NOAA Fisheries Service	Estuary Habitat Restoration	$7,000,000	$1,000,000	Cost effective estuary habitat restoration	-	www.era.noaa.gov
Gulf of Mexico Foundation and NOAA	Gulf of Mexico Community-based Restoration Partnership	$500,000	$100,000	Citizen-driven habitat restoration	-	www.habitat.noaa.gov
National Fish and Wildlife Foundation	Five Star Restoration Program	-	$40,000	Wetland, riparian and coastal habitat restoration	Any public or private entity	http://www.nfwf.org
National Fish and Wildlife Foundation	Keystone Initiatives	-	-	Marine and coastal - US shellfish sustainability	-	www.nfwf.org
FDEP	Coastal Partnership Initiative	-	-	promote the protection and effective management of Florida's coastal resources at the local level	Local Government - can partner with other entities	www.dep.state.fl.us/cmp/grants/index.htm

Beyond the initial restoration event volunteers can offer assistance with monitoring (Hadley and Coen 2002). As has been demonstrated by other programs within the CHNEP study area (e.g., Charlotte Harbor Volunteer Water Quality Monitoring, Volunteer Shoreline Survey) a committed and trained volunteer team can allow for a level of monitoring that otherwise would not occur due to budget constraints.

Figure 11: Pictures of Oyster Mat Making by Volunteers (Pictures courtesy of the Brevard Zoo)

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