Chapter 4

Big Bend and Springs Coast

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In:

Oyster Integrated Mapping and Monitoring Program
Report for the State of Florida No. 2

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Description of the region

The northern Gulf coast of peninsular Florida is commonly divided into two segments. The northern segment, from Wakulla County to northern Levy County, is referred to as the Big Bend. The southern segment, from southern Levy County through Pasco County, is called the Springs Coast because of its abundant natural freshwater springs and spring-fed rivers and creeks that discharge into the Gulf of Mexico (Fig. 4.1). Also referred to as the Nature Coast, the region has limited urban development, low coastal pollution, and a lower population density than other coastal regions in Florida, in part due to the lack of extensive beaches (Livingston 1990). Large portions of the coast and nearshore waters are protected in a network of national wildlife refuges, state parks, and aquatic preserves including the Big Bend Seagrasses Aquatic Preserve. Salt marsh, upland forest, and freshwater forested wetlands are the dominant terrestrial habitats in the Big Bend and Springs Coast region. The region is divided among three of Florida's water management districts: Northwest Florida, Suwannee River, and Southwest Florida (NWFWMD, SRWMD, and SWFWMD, respectively; Fig. 4.1).

The coast of the Big Bend and the Springs Coast is characterized by low topography, little wave energy, low sediment supply, and limestone bedrock that lies at or near the land surface (Wolfe 1990, FDEP 2015). These conditions provide ideal habitat for extensive salt marshes and seagrass beds, which are interspersed with tidal flats and oyster reefs. Although the nearshore areas of the Big Bend and Springs Coast are not enclosed by barrier islands, coastal waters up to several kilometers offshore typically have lower salinity than ocean water throughout the year due to freshwater inputs from the Suwannee River, the southern Withlacoochee River, numerous smaller spring-fed rivers, and direct submarine groundwater discharge (Orlando et al. 1993, FDEP 2015). Oysters in this region are more often found in the intertidal areas having greater freshwater input, such as at the mouths of rivers and tidal creeks, as the lower salinity reduces the abundance of marine predators (Hine et al. 1988, Seavey et al. 2011). Oyster reefs in these low-salinity nearshore areas often have higher percent cover and population density than do high-salinity offshore reefs (Bergquist et al. 2006). The eastern oyster (*Crassostrea virginica*) is the most common oyster species; the crested oyster (*Ostrea stentina*) is also found but is much less common (Wolfe 1990).

Offshore reefs often form in linear patterns roughly parallel to the shore, following paleoshorelines (Wright et al. 2005). These offshore reef chains can act as semipermeable dams that slow freshwater flow from rivers, decreasing salinity inshore of the reef and facilitating reef development there (Wright et al. 2005, Frederick et al. 2015, Kaplan et al. 2016). These inshore oyster reefs can also lead to the development of marsh islands with smooth cordgrass (*Spartina alterniflora*; Wolfe 1990). Marsh islands are generally located closer to shore and have higher elevations than sand oyster reefs, which are made up of coarse sand with shell fragments interspersed with oyster clumps (Seavey et al. 2011).

Apalachee Bay

Apalachee Bay (Fig. 4.2), located in the northern Big Bend, receives freshwater inflow from the Ochlockonee,

Figure 4.1. Oyster extent in the Big Bend and Springs Coast region.

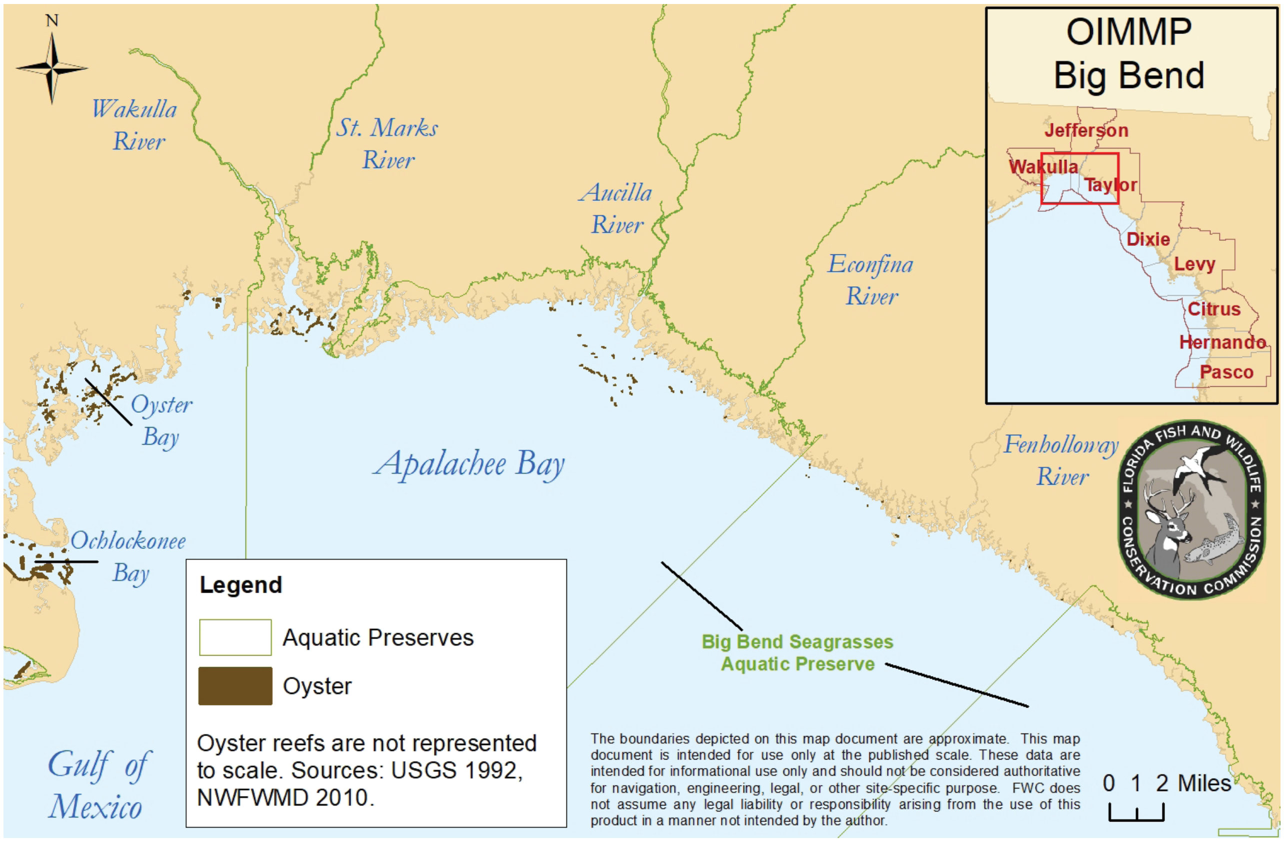

Figure 4.2. Oyster extent in Wakulla, Jefferson, and northern Taylor counties. Oyster mapping sources: USGS (1992), made from 1992–1993 aerial photographs, and NWFWMD (2010), made from 2009–2010 photographs.

Wakulla, St. Marks, Aucilla, Econfina, and Fenholloway rivers and numerous small creeks. Apalachee Bay is a broad, shallow embayment with an average depth of 1.5–3.0 m (5–10 ft) and an average salinity of 30 on the practical salinity scale (FDEP 2015). A zone with moderate salinity (15–25) extends about 8 km (5 mi) offshore during months of high freshwater flow (Nelson 2015). Tidal range in the bay is 0.75 m (2.5 ft). Oyster reefs are found in the moderate- and low-salinity (5–15) areas near the mouths of creeks and rivers (Fig. 4.2; Nelson 2015). A large portion of Apalachee Bay is included within the Big Bend Seagrasses Aquatic Preserve, the boundaries of which extend up the coastline and navigable tributaries to the tidal mean high-water line (Fig. 4.2; FDEP 2015). The coastline is largely undeveloped, and the river systems, salt marshes, seagrass beds, and oyster reefs have relatively little human impact compared with those in other regions of Florida (FDEP 2015, SRWMD 2017). An exception is the Fenholloway River, located outside the Big Bend Seagrasses Aquatic Preserve, which was once classified by the Florida Department of Environmental Protection (FDEP) as a Class V water body (i.e., designated for industrial use), because it received point-source pollution from the Buckeye Foley pulp mill, mining companies, and the city of Perry's wastewater treatment plant (FWC 2004). Water quality in the river has improved in recent decades, and the river was upgraded in 1998 to Class III (designated for fish consumption, recreation, and maintenance of fish and wildlife). Nevertheless, water-quality concerns and the need for environmental monitoring remain (FDEP 2012, 2015). Oysters are sparse at the mouth of the Fenholloway River, although the available oyster maps throughout Apalachee Bay may underestimate oyster extent (Fig. 4.2).

Deadman Bay

Farther south, the Steinhatchee River and several of its tidal tributaries discharge into Deadman Bay, a broad embayment with an average depth of 2.2 m (7.3 ft) (Fig. 4.3; FDEP 2015). Surface and subsurface freshwater discharge flows into Deadman Bay, creating an average salinity of 26 within the bay. Oyster reefs are most common near the mouth of the Steinhatchee River and in nearby tidal creeks (Figure 4.3).

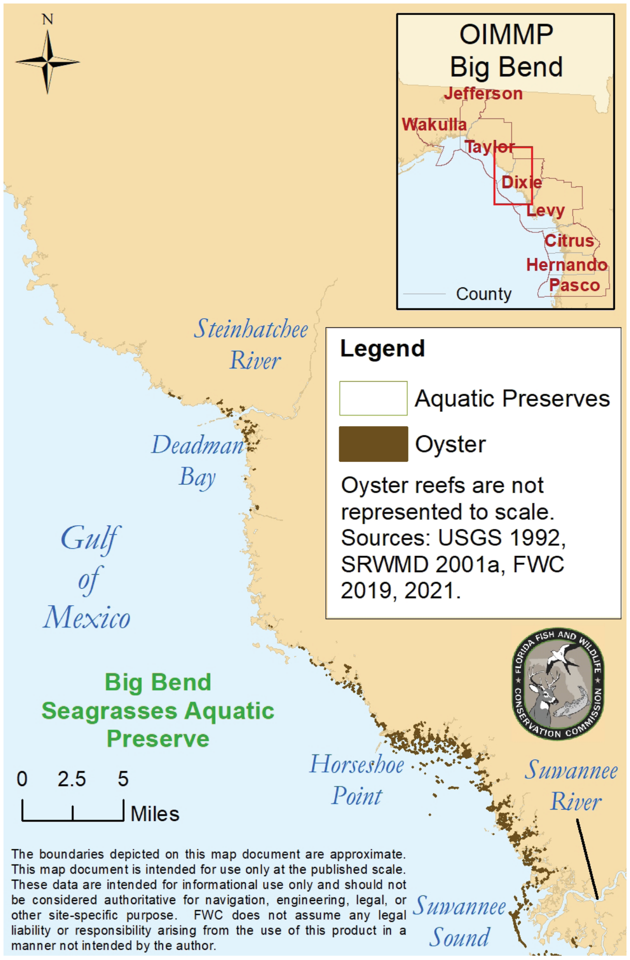

Figure 4.3. Oyster extent in southern Taylor and Dixie counties. Oyster mapping sources: USGS (1992), made from 1992–1993 aerial photographs; SRWMD (2001a), from 2001 photographs; FWC (2019) from 2011–2019 imagery; and FWC (2021), from 2017–2021 imagery.

Suwannee Sound

The Suwannee River begins in Georgia and provides the largest freshwater source to the Big Bend (FDEP 2015). Suwannee Sound, which extends roughly from Horseshoe Point to Cedar Key, has an average salinity of 16 (and a range of 1 to 26) due to freshwater input from the Suwannee River (Figs. 4.3 and 4.4; FDEP 2015, Frederick et al. 2015). Moderate-salinity (15–25) waters extend about 8 km (5 mi) offshore (Nelson 2015). Suwannee Sound contains oyster reefs scattered among marsh islands and historically hosted extensive linear offshore oyster reefs (Fig. 4.5). Evidence from the past 150 years suggests that many offshore, inshore, and nearshore oyster reefs migrated landward, and some offshore reefs were largely lost (Fig. 4.5; Seavey et al. 2011). An aerial-photograph assessment of oyster habitat trends in the Suwannee Sound region revealed a 66% net loss of oyster reef area from 1982 through 2011 (Seavey et al. 2011). The loss was greater in high-salinity offshore reefs (88% areal loss) than in nearshore (61% loss) and inshore reefs (50% loss). In an assessment of oyster count data for 2010–2018 in the Big Bend region (same areas as in Seavey et al. 2011), Moore et al. (2020) found a continuing decline in intertidal oyster counts. Oyster reef collapse resulted in the erosion (~7 cm [2.8 in] annual loss in elevation) of many high-density, high-relief oyster reefs and conversion to low-relief tidal flats dominated by sand and scattered shells (Seavey et al. 2011). In some cases, oyster reef collapse led to an apparent increase in reef area as eroded shell spread across a wider expanse of substrate. This apparent expansion was temporary. Oyster spat that settled on loose shell were not capable of long-term survival or shell accretion. When the collapsed oyster reefs lost substrate, the surface available for settlement was limited. Aerial photographs showed declines in oyster acreage in the 1980s and 1990s, and oyster reef collapse was reported after 2000 (Seavey et al. 2011). Because offshore barrier reefs help protect inshore reefs from wave action and create lower-salinity conditions, the collapse of offshore oyster reefs led to further oyster collapse inshore (Frederick et al. 2015, Kaplan et al. 2016). The loss of offshore reefs has also resulted in a decline of offshore, high-tide roost habitat available to American Oystercatchers (*Haematopus palliatus*; Brush et al. 2017).

The decline in oyster reefs may be linked to some combination of the effects of increased salinity and ongoing harvest pressure. Seavey et al. (2011) noted that months with low discharge from the Suwannee River have increased in frequency, and, as a result of increased use by humans, total river discharge has declined relative to the amount of rainfall. When oysters are exposed to high-salinity water for longer periods or more often, they suffer from the increased occurrence and intensity of disease, predation by marine species, and parasitism (White and Wilson 1996, Camp et al. 2015a). Supporting the importance of Suwannee River outflow to oyster abundance, Moore et al. (2020) found a significant positive relationship between live oyster counts in Suwannee Sound and Suwannee River discharge from the previous year. In addition to reduced freshwater flow, oysters in Suwannee Sound have been the basis of substantial commercial fisheries. In 2017–2019, landings from Suwannee Sound have exceeded those from all other regions of Florida, but Moore et al. (2020) did not find that commercial fishery trips or landings improved the model explaning declining oyster populations in the region. The relative importance of and interaction among the confounding factors of salinity, predation, disease, and

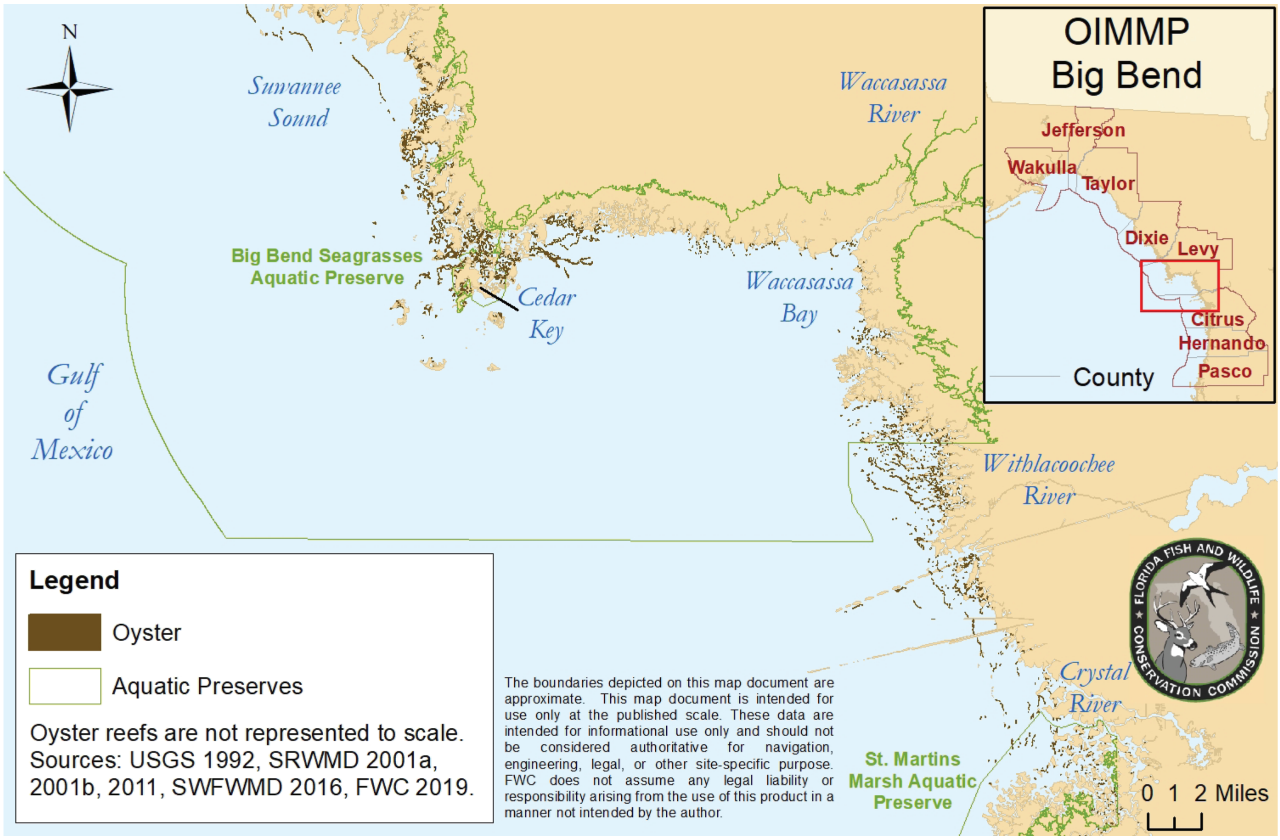

Figure 4.4. Oyster extent in Levy and Citrus counties. Oyster mapping sources: USGS (1992), made from 1992–1993 aerial photographs; SRWMD (2001a, 2001b), from 2001 photographs; SRWMD (2011), from 2010–2011 photographs; SWFWMD (2016), from 2016 photographs; and FWC (2019), from 2011–2019 imagery.

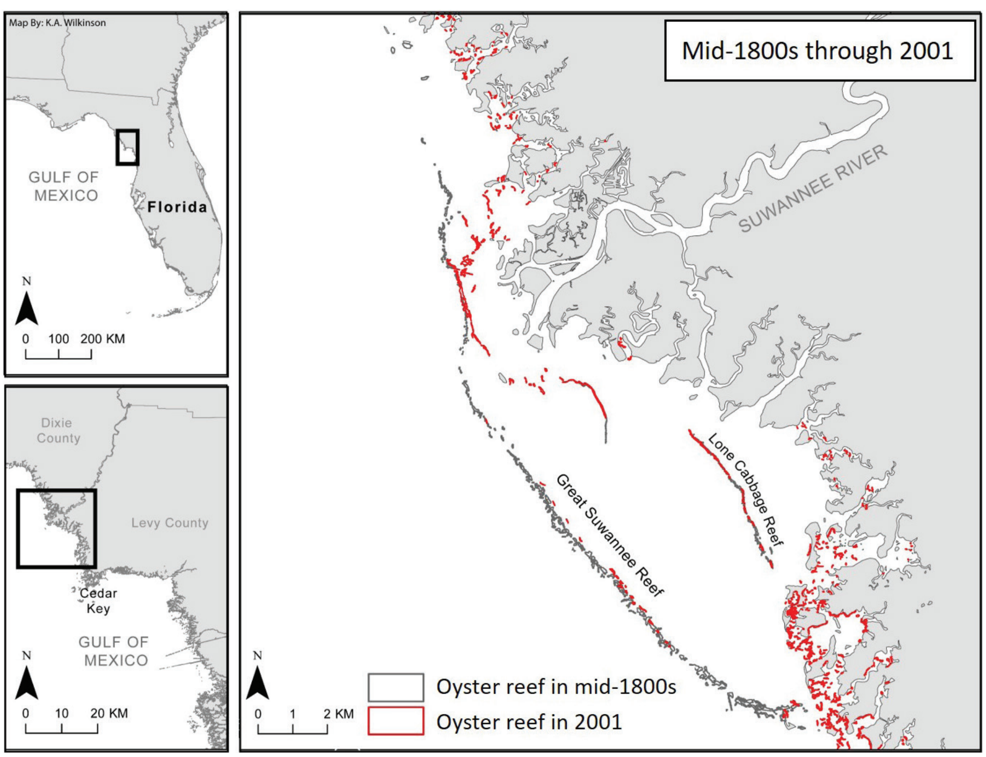

Figure 4.5. Oyster reef extent in Suwannee Sound in the mid-1800s (gray) and 2001 (red). Map by Krystan A. Wilkinson. Data sources: Raabe et al. 2004 (made from 19th century topographic sheets), SRWMD 2001a (made from 2001 photographs). Note that the increase in oyster extent along the coast in 2001 may reflect an increase in mapping effort in these areas.

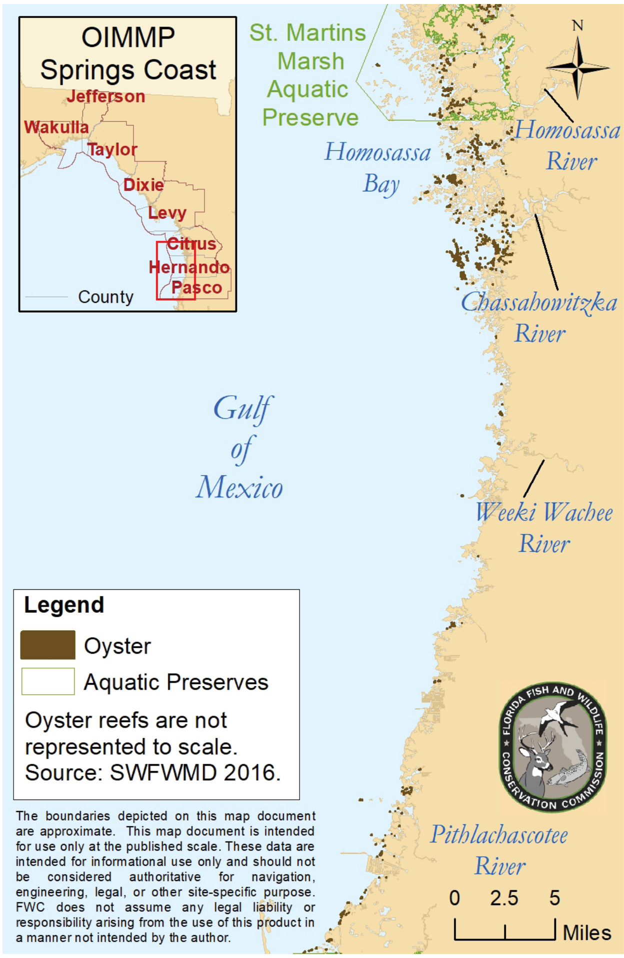

Figure 4.6. Oyster extent in Citrus, Hernando, and Pasco counties. Oyster mapping source: SWFWMD (2016), made from 2016 aerial photographs.

harvest on oyster decline is complex, but research into this trend is the subject of several studies ongoing in the region (see Monitoring section below).

Restoration actions that include the addition of substrates resistant to erosion may mitigate reef collapse. This was tested through a small restoration project (Frederick et al. 2015), which led to a larger restoration effort using limestone boulders to restore a portion of Lone Cabbage Reef in Suwannee Sound. In addition to providing substrate for oyster settlement, the boulders caused waters on the landward side of the reefs to have a slightly lower salinity than waters on the seaward side of the reef at some river discharge levels (Frederick et al. 2015, Moore and Pine 2020).

Springs Coast

The Springs Coast (Figs. 4.4 and 4.6) receives freshwater outflow from groundwater seeps and spring-fed rivers including the Crystal, Homosassa, Chassahowitzka, Weeki Wachee, and Pithlachascotee rivers (Hine et al. 1988). This region also receives significant amounts of tannic freshwater flow from the mostly surface-fed southern Withlacoochee River. Oyster reefs are found mostly inshore among marsh islands, but occasionally offshore as linear reefs that fringe the shoreline. Mid-19th-century surveys of the Springs Coast indicate that oyster reefs were more abundant at the mouths of these spring-fed rivers than today and at some locations extended up to 5 km offshore (Fig. 4.7; Bache 1861, Raabe et al. 2004). Offshore oyster reefs still exist in Crystal River and in Withlacoochee, but they have been widely fragmented; in the case of Crystal River, they extend half their historic distance into the Gulf of Mexico (Fig. 4.7). At other rivers, such as the Chassahowitzka and Weeki Wachee rivers, only remnants of historic offshore reefs are evident in the numerous shoals dominated by sand and scattered shell that extend across river mouths (Hesterberg, pers. obs.). Spatial analysis comparing the historical distribution of oyster reefs near the Crystal River with the best modern maps indicates a net landward movement of oyster habitat over the past 150 years (Fig. 4.7). Water discharge from the Crystal River is driven by discharge from springs, which is largely impacted by rainfall (which has declined since 1970) and, to a lesser extent, by groundwater withdrawals (SWFWMD 2015). Sea-level rise and reduced freshwater flow also cause increases in coastal salinity, as has been seen in the past decade in the Crystal River and the associated Kings Bay (SWFWMD 2015). The spatial loss of the outermost oyster reefs near the Crystal River might be due to diminished freshwater outflow, as has been found in Suwannee Sound (Seavey et al. 2011, Moore et al. 2020), but, as for Suwannee Sound, the relative importance of oyster harvest and increased salinity (and its presumed associated increases in oyster predation and disease) to oyster population dynamics in the Springs Coast is not well understood.

Archaeological excavations of prehistoric (1,500–1,000 ybp) shell middens at sites near the Crystal River suggest that oyster shell height has declined by one-third over the past two millennia (Hesterberg et al. 2020), and maximum shell height has been sharply truncated at approximately 120 mm (4.7 in). These results are in stark contrast to shell heights as great as as 188 mm (7.4 in) found in the middens. Large oysters disproportionately contribute to increased water filtration, reproductive output, and shell budgets compared to smaller oysters (Riisgård 1988, Powell and Klinck 2007, Mroch et al. 2012, Mann et al. 2014). Thus, shifts in oyster size structure suggest a reduction in ecosystem services for reefs

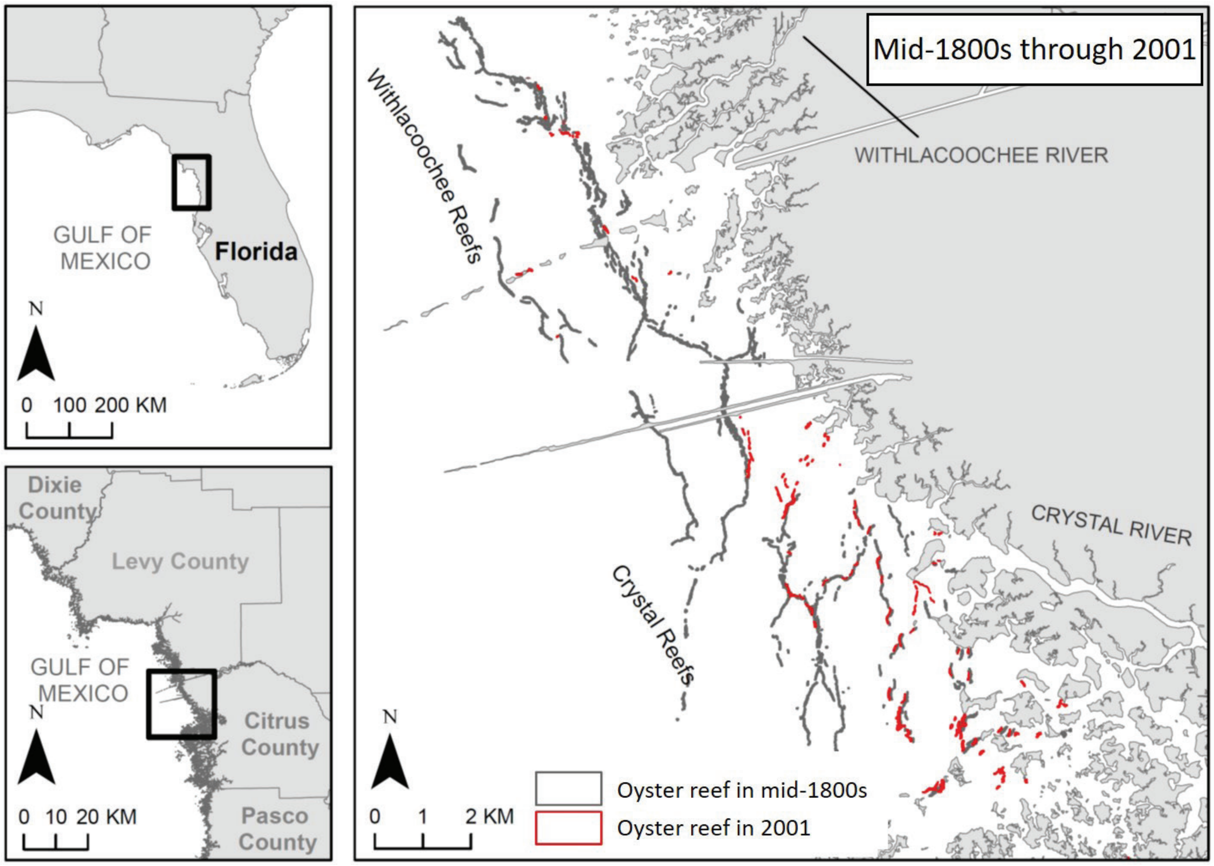

Figure 4.7. Oyster reef extent offshore of the Withlacoochee and Crystal rivers in the mid-1800s (gray) and 2001 (red). Map by Stephen Hesterberg. Data sources: Raabe et al. (2004), made from 19th-century topographic sheets, and SRWMD (2001a), made from 2001 photographs.

that have existed for thousands of years (Grinnell 1971, Wright et al. 2005). Geochemical profiles of oyster shells found in the Crystal River middens also generally have heavier carbon-isotope values, typical of oysters from higher-salinity waters (Hesterberg et al. 2020), suggesting that at one time the largest oyster size classes were found on outer reefs and that restoration of outer reef habitats may be key to the restoration of oyster size and life-history demographics.

Oyster harvesting

Numerous shell middens along the Big Bend and Springs Coast indicate that oysters have been harvested in this region for at least 1,400 years (Dean et al. 2004, Sassaman et al. 2013). Commercial harvest of oysters began in the Big Bend area in the late 1800s (Dawson 1955, Arnold and Berrigan 2002). Annual yields along the Big Bend and Springs Coast varied throughout the 1900s and peaked in the 1980s before declining significantly in the 1990s (Fig. 4.8). This decline can be partly attributed to the Florida Department of Agriculture and Consumer Services' (FDACS) closing some shellfish harvesting areas in 1987 due to the presence of fecal coliform bacteria and to a shift in in the community away from harvest of mullet and wild oysters in the 1990s and the development of hard-clam aquaculture programs in the region (Colson and Sturmer 2000). FDACS monitors several shellfish harvesting areas in Wakulla, Dixie, Levy, and Citrus counties (Fig. 4.9; FDACS 2021). The current status (open or closed) of shellfish harvesting areas is available from https://shellfish.fdacs.gov/seas/seas_statusmap.htm. Maps of shellfish harvesting areas, aquaculture use zones, and lease areas are available from https://fdacs.maps.arcgis.com/apps/webappviewer/index.html?id=57f7d4b7d900496d99891f22681c66d0.

Several of the areas with productive oyster reefs in the Big Bend are often closed to commercial harvest due to water-quality concerns (FDEP 2015). Since the collapse of the Apalachicola oyster fishery in 2012, there has been increased focus on the Big Bend fishery. Although oyster harvests in the Big Bend are far smaller than the peak yields of the 1980s (Fig. 4.8), they are increasing. In 2016, commercial oyster landings for both the Big Bend

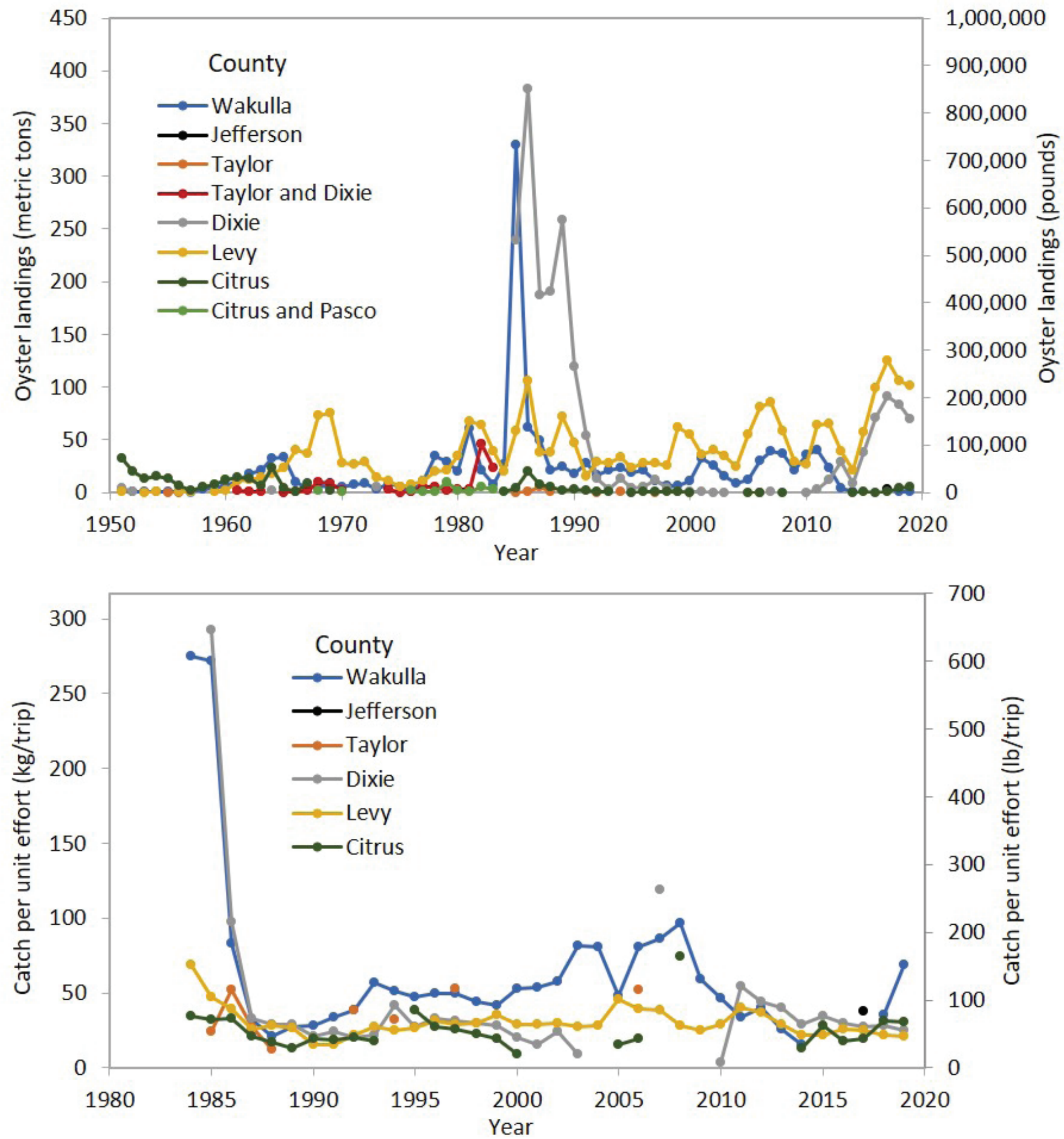

Figure 4.8. Commercial harvest yields of oyster meat (top) and catch per unit effort (bottom) from counties in the Big Bend and Springs Coast region. Oyster landings before 1986 were collected under a voluntary reporting system. Data source: summary of Florida commercial marine fish landings (see Appendix A) and FWC (2020).

and the previously dominant Franklin County were both 170 metric tons (375,000 pounds; FWC 2020). In 2017, commercial oyster landings for the Big Bend increased to 219 metric tons (483,000 pounds), surpassing the Franklin County yield of 122 metric tons (268,000 pounds; FWC 2020). Oyster landings for the Big Bend in 2018 and 2019 continued to surpass yields in Franklin County (FWC 2020). The role of harvest in structuring the distribution and viability of oyster reefs in the Big Bend is unclear, and it is uncertain if the effects of fishing on the predominantly intertidal reefs along the Big Bend are comparable to the effects of fishing on subtidal oyster reefs of Apalachicola.

Threats to oysters in the Big Bend and Springs Coast

- **Altered hydrology and salinity:** Decreased freshwater input and consequent higher salinity could impact many of the oyster reefs in the Big Bend and Springs Coast region. Many aspects of oyster biology are strongly influenced by local salinity patterns, including abundance, growth, predation, parasitism, disease, recruitment, and reproduction (Bergquist et al. 2006, La Peyre et al. 2013, Miller et al. 2017). Evidence of the effects of increased salinity on oyster reefs can be seen

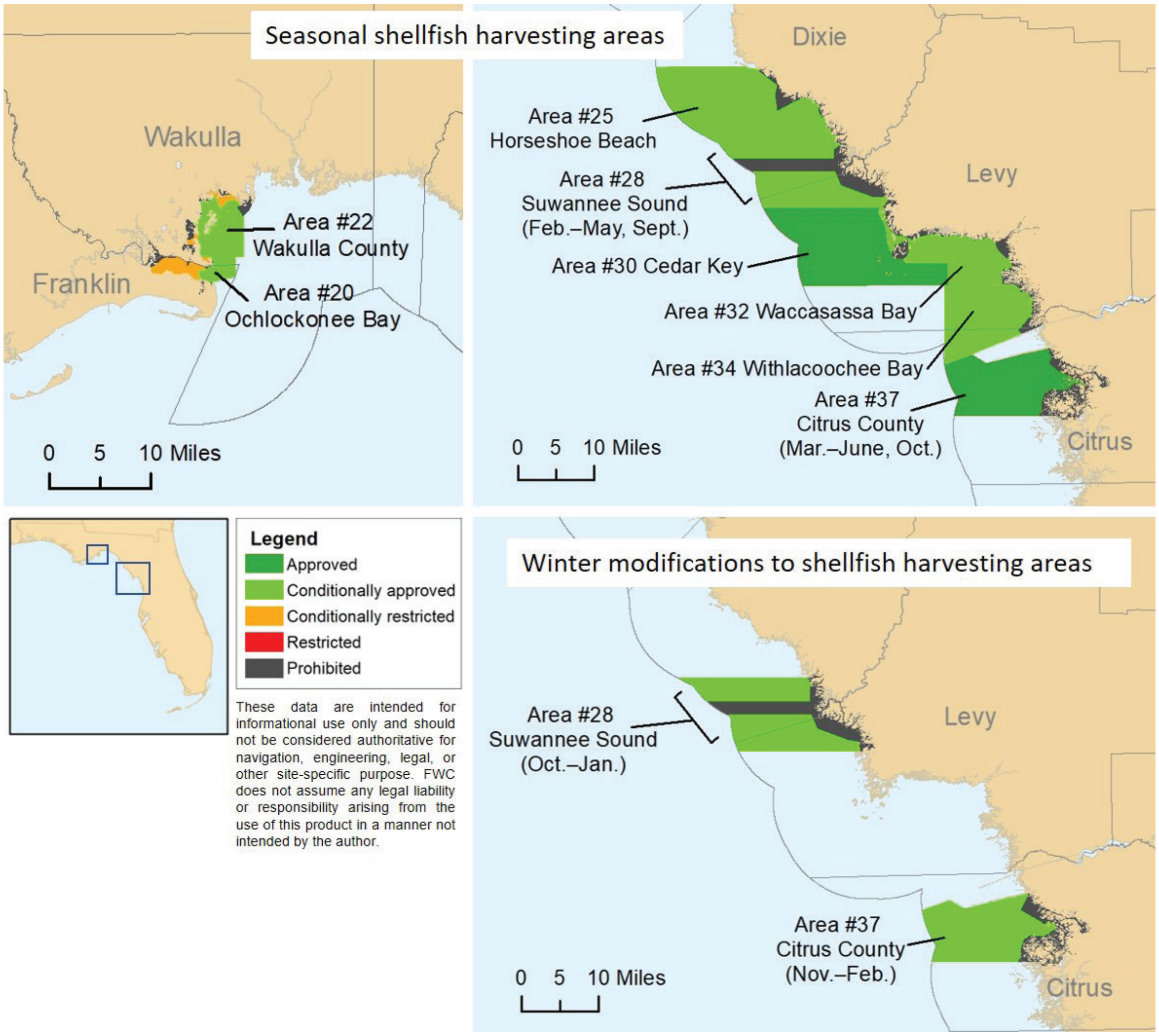

Figure 4.9. Shellfish harvesting areas in the Big Bend and Springs Coast. Data source: FDACS 2021.

in the preferential loss of offshore reefs and the net landward migration of remaining oyster reefs (Seavey et al. 2011; Figs. 4.5 and 4.7) and in the lower oyster densities found in years following low levels of river discharge (Moore et al. 2020). It is unclear to what extent diminished freshwater input results from direct human use versus long-term climatic drivers. The Atlantic Multidecadal Oscillation has been linked with declining rainfall on the Big Bend and Springs Coast since 1970, but human population and demand for fresh water have also increased during this time (Kelly and Gore 2008, SWFWMD 2015).

- **Sea-level rise:** Cedar Key sea level rose an average of 2.23 mm (0.09 in.) per year (22.3 cm/8.76 in. per 100 years) from 1914 to 2020 (NOAA 2021) (Cedar Key tide gauge; NOAA 2020), increasing the risk of exposure of oysters to parasites and predators as salinity and tidal immersion have increased (Seavey et al. 2011). Oyster reefs accrete vertical elevation over time and thus can decrease the length of time spent immersed by tides (Rodriguez et al. 2014), but this requires a healthy reef, including large, long-lived individuals that can contribute ample shell to reef accretion at rates equal to or exceeding sea-level rise (Waldbusser et al. 2013). Thus, if managers expect oyster reefs to keep pace with accelerating sea-level rise, they must try to maximize oyster body size on reefs and keep other stressors, such as temperature and salinity, below thresholds that impact individual performance or mortality.

- **Thermal stress:** Extended periods of elevated water temperature can cause oyster mortality through oxygen limitation (Forster et al. 2012, Waples and Audzijonyte 2016) and disease intensification (Petes et al. 2012). Temperatures above 28 °C (82 °F) can cause stress and mortality in eastern oysters, especially when combined with other stressors (La Peyre et al. 2016, Rybovich et al. 2016, Southworth et al. 2017). High temperatures disproportionately affect larger marine individuals, as oxygen diffusivity decreases and disease intensity increases with body size (Forster et al. 2012, Waples and Audzijonyte 2016). Thus, these stresses may contribute to a trend toward smaller oyster sizes over time (Daufresne et al. 2009, Sheridan and Bickford 2011, Waples and Audzijonyte 2016). Such morphometric shifts have been observed on oyster reefs affected by thermal effluent near Crystal River; thermally affected reefs had size structures similar to those of unaffected reefs but lacked the largest oyster size class (Lehman 1974). The direct effect of elevated temperatures on size distributions in oyster populations has not been shown experimentally, and the interplay between disease, predation, parasites, and harvesting with environmental variables such as tidal height and climate remains extremely complex.

- **Harvest and lack of adaptive, robust management strategies:** Management strategies for oyster resources focus on a combination of size limits, bag limits, and seasonal closures to protect human health. It is not known how effective these regulations are in protecting oyster recruitment and growth from increasing fishing effort. Given the documented decline of oyster reefs in the region (Seavey et al. 2011, Moore et al. 2020), the concern that increased landings will result in high effective mortality is justified. Unlike Apalachicola Bay, where most of the oyster resources are found on subtidal oyster reefs, the Big Bend is characterized by large expanses of intertidal reefs. The population dynamics of intertidal reefs along the Big Bend and Springs Coast are not well understood, and there is need for formal stock assessments or other measures of oyster-harvest rates relative to oyster production. This creates additional challenges for managing potentially exploited oyster reefs in the Big Bend and leads to the need for strategic, location-specific management strategies (further details provided below in the Recommendations for Management, Mapping, and Monitoring section).

Oyster reef mapping and monitoring efforts

The compilation of data used to create the oyster maps in this report is available for download at http://geodata.myfwc.com/datasets/oyster-beds-in-florida.

NWFWMD oyster mapping

The most recent NWFWMD land use/land cover (LULC) map that included a separate oyster reef layer was from 2009–2010 (NWFWMD 2010). Oysters were mapped following the Florida Land Use and Cover Classification System (FLUCCS), which includes a category for oyster bars (FLUCCS 6540; FDOT 1999). While more recent NWFWMD LULC maps, from 2012–2013 and 2015–2016, are available, oyster bars were not mapped in those years. NWFWMD geographic information system (GIS) files are available for download at https://www.fgdl.org/metadataexplorer/explorer.jsp.

SRWMD oyster mapping

In 2001, the SRWMD conducted a thorough seagrass- and oyster-mapping project in the Suwannee Estuary from Horseshoe Cove to Cedar Key using 1:24,000-scale, true-color aerial photography (SRWMD 2001a, Patterson 2002). The boundaries of oyster reefs were digitized with guidance from a photointerpretation key created for this effort that differentiated between oyster reefs, patchy oyster reefs, and remnant oyster reefs. Twenty random locations were visited in the field to verify classification accuracy; overall mapping accuracy was 100% (Patterson 2002).

Also in 2001, the SRWMD completed a seagrass- and oyster-mapping effort in Waccasassa Bay using 1:24,000-scale, true-color aerial photography (SRWMD 2001b). Classifications were completed using FLUCCS categories, which included a category for oyster bars (FLUCCS 6540; FDOT 1999). The minimum mapping unit was 0.25 ac (0.1 ha).

The most recent SRWMD LULC map that includes a separate oyster reef layer was from 2010–2011 (SRWMD 2011). Oysters were mapped using FLUCCS categories (FDOT 1999). While more recent SRWMD LULC maps, from 2013–2014 and 2016–2017, are available, oyster reefs were not mapped in those years. SRWMD GIS files and all corresponding reports for the 2001 seagrass- and oyster-mapping efforts are available for download at https://www.mysuwanneeriver.com/319/Data-Directory.

SWFWMD oyster mapping and surveys

Since 2007, the SWFWMD has mapped oyster habitat as part of the Springs Coast Seagrass Mapping Program on a four-year cycle. While the primary objective is to map seagrass, other habitats including oysters reefs, tidal flats, hard bottom, and attached algae are also mapped. Mapping conventions are based on a modified FLUCCS classification system (FDOT 1999). Maps are created from photointerpregation of aerial imagery which is collected at an altitude of 2,700 m (9,000 ft) specifically for the purpose of mapping seagrass. The winter flight window is based on multiple factors including water clarity, sky conditions, tide, and sea state. Mapping of oyster habitat is based on image signatures and does not consider the quality of oyster reefs. Accuracy assessment and ground-truthing operations focus only on presence or absence of oyster habitat; therefore, dead and living oysters are mapped together under a single classification code. The most recent maps available at the time of this report publication were completed in 2016 (SWFWMD 2016). The 2020 maps will be released in September 2021. SWFWMD shapefiles are available for download on the district website at https://data-swfwmd.opendata.arcgis.com/.

SWFWMD river surveys and feasibility studies

SWFWMD conducted oyster surveys in the Homosassa and Chassahowitzka rivers as part of the process for determining acceptable minimum flows and levels for the rivers. Oyster surveys were conducted as part of mollusk-community assessments in the Chassahowitzka River in 2007 (Estevez 2007) and the Homosassa River in 2008 (WAR 2010). More detailed oyster surveys were conducted in late 2017–early 2018 for the Homosassa, Chassahowitzka, and Withlacoochee rivers to evaluate minimum flows and levels and to identify opportunities for oyster restoration projects.

In May 2019, Environmental Science Associates completed a feasibility study for SWFWMD for living-shoreline projects in the Crystal and Homosassa rivers (ESA 2019). The purpose was to model conditions to create a site-selection matrix of factors believed to influence oyster growth and reef establishment. Factors such as salinity, substrate type, and exposure to wave energy were considered. Additionally, this project used the matrix to identify potential oyster-enhancement sites in each system and develop conceptual design plans, including cost estimates for each location. This project involved an intensive monitoring effort that included both location and quality of existing oyster habitat.

1992 Panhandle Big Bend seagrass and oyster mapping project

In 1992–1993, the U.S. Geological Survey (USGS) National Wetlands Research Center completed an extensive mapping effort of seagrass extent from Anclote Key, north of Tampa Bay, to Perdido Bay on the Florida–Alabama state line (USGS 1992). Aerial photos were collected at a scale of 1:24,000 in December 1992 and early 1993. Oysters were mapped if reefs were located near seagrass beds. This project was not specifically designed to provide a complete oyster reef data set, but the data set fills gaps for areas of Apalachee Bay for which no other maps are yet available.

Florida Fish and Wildlife Conservation Commission (FWC) oyster mapping

Two mapping efforts (FWC 2019, 2021) have been conducted by FWC's Oyster Integrated Mapping and Monitoring Program (OIMMP) in the Big Bend. FWC (2019) focused on previously unmapped intertidal oyster reefs located in tidal creeks and nearshore waters located north and south of the Suwannee River. This effort was intended as a supplement to existing oyster maps for the area (SWFMD 2001). Imagery used for photointerpretation of oyster reefs included Landsat imagery and Florida Department of Transportation mosaics. A total of 1,126 previously unmapped oyster reefs were identified. Twelve percent of the reefs identified were ground truthed, with a mapping accuracy rate of 99%. This mapping effort did not distinguish between the extent of live and dead patches of oyster reef.

FWC (2021) focused on oyster reefs from Horseshoe Point to Deadman Bay and created maps designed to identify unmapped oyster reefs and to replace outdated maps for the area. A total of 532 areas were identified from imagery as potential reefs; 34% of these areas were ground truthed with a mapping accuracy of 82%. Only live reefs (and not areas of shell or patchy oyster clusters) were classified as oyster reefs during ground truthing. The final map of 444 oyster reefs was refined based upon ground truthing.

FWC oyster monitoring and mapping

FWC's Molluscan Fisheries Program conducts long-term oyster population monitoring for resource assessment and management in several estuaries in Florida. Population monitoring includes assessing oyster density, condition, recruitment, reproductive status, dermo disease (*Perkinsus marinus*) prevalence and intensity, predatory gastropod density, quantity of available substrate, and water quality. FWC is expanding monitoring and mapping activities into the Suwannee Sound area in mid-2021 as part of a multiyear project funded by the National Fish and Wildlife Foundation (NFWF). With declining harvests from Apalachicola Bay in the years following the collapse of the oyster fishery, the Suwannee Sound region has seen an increase in harvest (Fig. 4.8), raising concerns of possible overfishing in the area. The mapping and monitoring components of the NFWF project will improve understanding of the state of the oyster resource in Suwannee Sound and allow for the development of a shell budget model that will inform resource management.

FWC will also begin work as part of a grant from the Florida Trustee Implementation Group in July 2021. This project will expand mapping and monitoring activities in Suwannee Sound and Withlacoochee Bay aiming to assess and fill critical data gaps and ultimately develop a GIS-based habitat suitability index for oysters to inform oyster restoration efforts along the Gulf coast. The index and statewide trends derived from all ongoing FWC oyster monitoring will be made publicly available through the OIMMP web page, increasing the resources available to anyone interested in future oyster restoration efforts in Florida.

Historical habitat maps

Raabe et al. (2004) digitized 19th-century topographic sheets in a grid-based format to create georeferenced historical habitat maps of oyster reefs and coastal vegetation along the Big Bend and Springs Coast. The resulting map had an accuracy of ±8 m (26 ft) and showed marked shoreline erosion and landward migration of habitats. The open-file report and shapefiles of the historical habitats are available for download at https://pubs.usgs.gov/of/2002/of02-211/, enabling comparison with the habitats' present locations (Figs. 4.5 and 4.7). The use of historical topographic surveys to create habitat maps is not without complication, as these surveys sometimes had incomplete coverage due to the complexity of the shoreline and time-consuming nature of the effort (Raabe et al. 2004). Additionally, oysters in open water that presented navigation hazards were more likely to be mapped than were intertidal oysters adjacent to the shoreline.

Oyster restoration and monitoring in the Suwannee Sound

Recent research in the Suwannee Sound has focused on oyster population status (Seavey et al. 2011), the influence of oyster reefs on salinity (Kaplan et al. 2016), use of oyster reefs as bird habitat (Frederick et al. 2016, Brush et al. 2017), and effectiveness of restoration (Frederick et al. 2016, Moore and Pine 2020). In 2017, the National Fish and Wildlife Foundation funded a multiyear project designed to restore the degraded Lone Cabbage Reef in Suwannee Sound. At present, a georeferenced database of these efforts is being developed, and this reef will be the subject of intensive elevation surveys as well as mapping and monitoring of oyster coverage to evaluate the restoration project. Information on the project is available from https://wec.ifas.ufl.edu/oysterproject/ and https://lcroysterproject.github.io/oysterproject/.

University of Florida modeling and management project

An oyster modeling and management effort by UF, anticipated to be funded for 2021-2023, focuses on assessing oyster population dynamics and fisheries stock assessments, valuation of oyster economic aspects, efficacy of alternative management strategies, and stakeholder support for revised management decision-making. The population modeling is intended to provide the best possible assessment of the current state of the oyster fisheries in Suwannee Sound, given the available data and the role of fisheries in population dynamics. The modeling will consist of applying modern stock-assessment methods to models designed to take into account the oyster's life history (e.g., inclusion of specialized, shell-based recruitment functions). Critically, model developing will be made with input from local oyster-fishery stakeholders. Information from assessment models will be transferred into simulation models to evaluate the likely and unlikely responses on oyster populations and fisheries to present and future management actions. The anticipated outcome of the work will be a revised approach to governing wild oyster harvest that meets both stakeholder and agency needs. Contact Ed Camp, edvcamp@ufl.edu, for further details.

NOAA Mussel Watch

The National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends Program has monitored pollutants in bivalves through the Mussel Watch program across the coastal United States since 1986. Monitoring locations in this region include Black Point at Cedar Key, West Pass on the Suwannee River, and Spring Creek on Apalachee Bay (Kimbrough et al. 2008). High levels of arsenic and mercury have been found in oysters on the Suwannee River (Kimbrough et al. 2008).

Recommendations for Management, Mapping, and Monitoring

- Continue traditional mapping and ground truthing of oyster reefs to evaluate ongoing changes in oyster condition and reef location (FDEP 2015). Reconstructing the historical distribution of oyster habitat from aerial photographs and nautical charts could also prove useful for establishing reference conditions and elucidating the causes of habitat loss.
- Update oyster reef maps for Apalachee Bay, for which most reefs have not been mapped since 1992.

- Monitor both the extent and the quality of oyster reefs (i.e., monitor their ability to provide desired ecosystem functions and remain resilient in the face of the threats identified earlier). Although mapping the spatial distribution of oyster habitat is valuable, oyster monitoring must extend to factors other than the reefs' aerial extent, which can increase due to reef collapse and therefore mask declines in habitat quality (Seavey et al. 2011, zu Ermgassen et al. 2013).
- Quantify oyster population size structure to rapidly provide a snapshot of reef health, as large oysters are disproportionately important for reproductive output and shell budgets and they provide information about a habitat's capacity to withstand stressors. The presence of large individuals can also indicate a reef's ability to cope with the threats outlined earlier, including salinity and thermal stress, overfishing, and sea-level rise. Diminishing body size has also been suggested as an early indicator of population collapse (Clements and Ozgul 2015, Clements et al. 2017). Given the limited time and resources available for monitoring, the size structure of oyster populations should be emphasized in future assessments, because it is both important and easy to quantify (Woodward et al. 2005).
- Continue large-scale oyster reef restoration and habitat protection in the Suwannee Sound and expand to other sections of the coast as steps toward achieving regional conservation goals. Substrate-focused restoration efforts on Suwannee Sound oyster reefs have proved successful in improving oyster densities and reducing salinity inshore of the reefs, allowing for mitigation of some impacts of reduced freshwater flows (Frederick et al. 2015, Kaplan et al. 2016). But the long-term effectiveness of adding shell material to promote oyster reef growth is uncertain, given the oyster population stock status and limited availability of cultch. If this restoration method proves successful, other viable locations, such as the Withlacoochee, Crystal, Homosassa, and Chassahowitzka rivers, should be considered for restoration.
- Continue monitoring restoration sites to assess their effectiveness (Moore and Pine 2020). Conduct further studies to determine if it is more effective to restore larger areas of low-relief habitat or small areas of high-relief habitat.
- Conduct further research into how positive shell budgets can be maintained naturally on oyster reefs. For harvested reefs, this may necessitate examining fishery practices including how and where culling takes place and determining survival rates of culls. It may also require implementing harvest limitations to allow for the accumulation of shell material through natural mortality processes on extant reefs.
- Consider new fishery-management strategies that integrate changing climate, fluctuating oyster fishing effort, and widespread anthropogenic changes in order to reduce the risk of resource collapse (Geselbracht et al. 2007, Camp et al. 2015b). The 2012 collapse of the Apalachicola oyster fishery and subsequent increase in oyster harvest in the Big Bend region have created a need to re-evaluate oyster fishery policies in the region. While size regulations, bag limits, and seasonal closures may once have promoted sustainable fisheries, there is need to consider new strategies. These strategies could include watershed-scale management and reef resilience, maintenance of positive shell budgets, and promotion of diverse size–age structure on remaining reefs (Quiros et al. 2017). Better enforcement is also needed to address harvesting below minimum size limits and returning culled oysters to their reefs of origin. Experimental management policies that might be considered include limited entry, rotational harvest of wild oyster areas (with long fallow periods, individual fishing quotas (IFQs), and the development of Territorial Use Rights for Fisheries (TURFs; Prince et al. 1998), which, through leases, transfer to individual fishers the rights to specific bottom areas. This could promote innovative modes of reef conservation and restoration by providing TURF holders the incentive to better manage their individual resource, though it would also require changes in the legal governance structure. Finally, the growing oyster aquaculture industry should be viewed as a new alternative for providing direct benefits to oyster harvesters and local communities and reducing harvest pressure on wild oyster resources.
- The efficacy of the different management strategies and restoration projects proposed above must be evaluated in terms of both ecological and socioeconomic sustainability, including model-based, stakeholder, and empirical experimentation.

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Big Bend Seagrasses Aquatic Preserve
https://floridadep.gov/rcp/aquatic-preserve/locations/big-bend-seagrasses-aquatic-preserve

FDACS shellfish harvesting areas, aquaculture use zones, and lease areas
https://fdacs.maps.arcgis.com/apps/webappviewer/index.html?id=57f7d4b7d900496d99891f22681c66d0

U.S. Fish and Wildlife Inventory and Monitoring Network Southeast Region
https://www.fws.gov/southeast/national-wildlife-refuges/inventory-and-monitoring/

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