Chapter 3

Apalachicola Bay

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

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Description of the region

Apalachicola Bay is the largest of several estuarine systems in the panhandle region of northwestern Florida. It is confined hydrologically by a network of four barrier islands and is divided into four sections: St. Vincent Sound, Apalachicola Bay proper, East Bay, and St. George Sound (Fig. 3.1). The system is connected to the Gulf of Mexico through three natural tidal inlets (Indian Pass, West Pass, and East Pass) and one constructed inlet (Sikes Cut, also called Government Cut). The bay is in a transition zone between diurnal tides to the west and semidiurnal tides to the southeast, resulting in a mixed tidal regime with one to five tides daily (Huang 2010, Oczkowski et al. 2011, Huang et al. 2015). Tides can be strongly affected by wind and are normally less than 1 m (3.3 ft) in range. Water currents are tidally driven but can also be strongly impacted by river discharge and winds. Currents generally do not exceed 1 m/s (3.3 ft/s) except in passes and tidal cuts. The system is wide and shallow, with an average depth of 2–3 m (6.5–10 ft), resulting in generally well-mixed and well-oxygenated waters with occasional stratification. Bottom types consist largely of sand and other soft sediments, with hard bottom in the form of historically extensive oyster reefs (Edmiston 2008). Water temperature typically ranges annually from 5–32 °C (41–90 °F). Salinity varies widely spatially and temporally and can range from less than 1 to 33 on the practical salinity scale. Overall water-quality conditions in Apalachicola Bay are excellent, in part because the panhandle region is one of the least populated coastal areas in Florida (Livingston 1984, 2015, Edmiston 2008). This extensive estuarine system provides suitable environmental conditions and large areas of potential habitat for the eastern oyster, *Crassostrea virginica*.

Historically, Franklin County (within which Apalachicola Bay lies) dominated oyster production in Florida, yielding more than 90% of the state's commercial landings and 10% of the oysters sold in the continental United States (Livingston 1984, Havens et al. 2013). The oyster fishery was integral to the lives of many people living in the Apalachicola Bay region. Before 2012, the fishery provided more than 2,500 jobs to nearby coastal communities, often making up to half of their revenue (Havens et al. 2013, Camp et al. 2015). In 2012–2013, the region's oyster fishery and subtidal oyster population collapsed, likely as a culmination of multiple factors including low river flow, high predation, lack of substrate, and poor recruitment (Camp et al. 2015; see below for further discussion about the collapse).

Franklin County is located in the Northwest Florida Water Management District (NWFWMD). Apalachicola Bay receives most of its freshwater inflow from the Apalachicola River, the largest river in Florida in terms of flow. Average seasonal discharge rates range from 570 m^3/s (20,000 ft^3/s) in late summer and fall to 1,800 m^3/s (65,000 ft^3/s) in early spring (Edmiston 2008, Huang 2010). More than 80% of the water in the Apalachicola River comes from the Chattahoochee and Flint rivers (Fig. 3.2), which

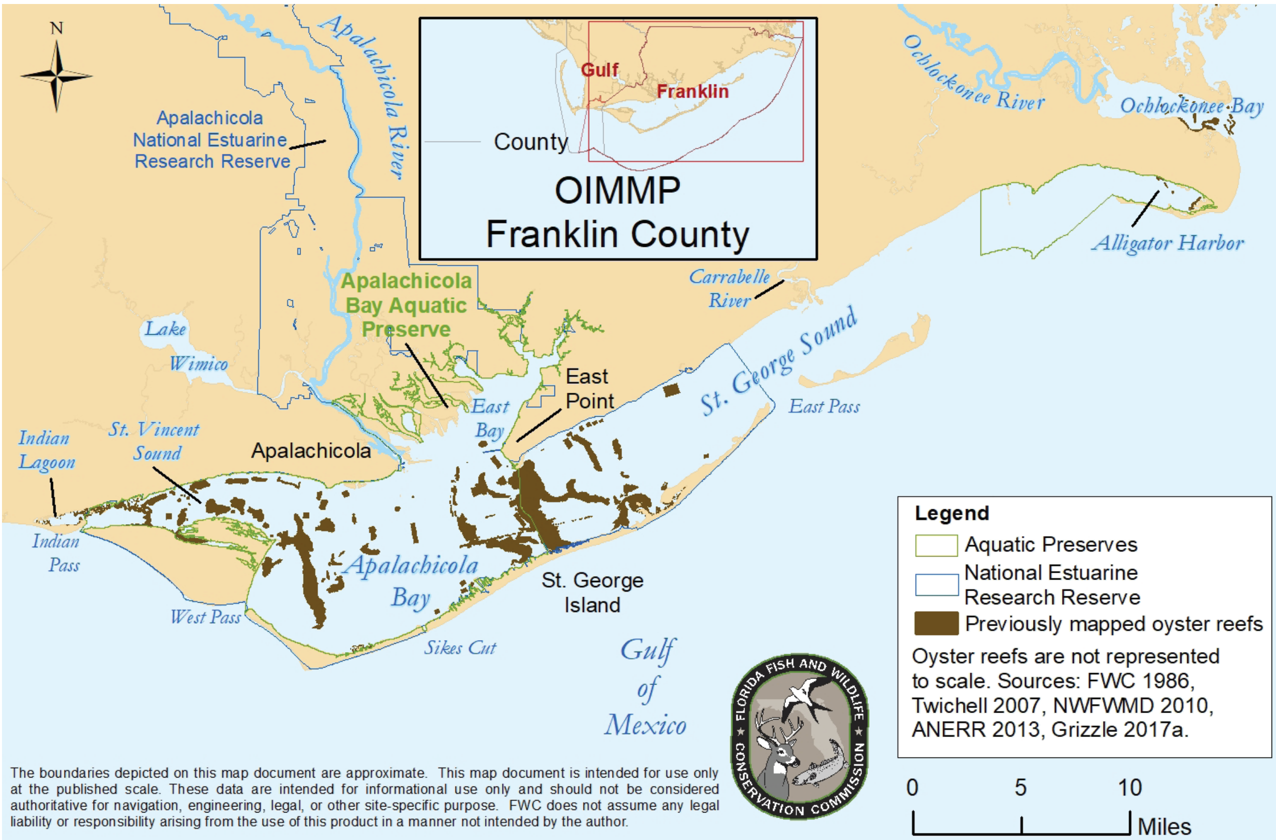

Figure 3.1. Major features of Franklin County and eastern Gulf County, including the Apalachicola Bay estuarine system and oyster reef areas to the west (Indian Lagoon) and east (Alligator Harbor and Ochlockonee Bay). Given the changes in oyster reef distribution in recent years, older maps should be interpreted with caution, as they do not provide information on current reef topography or live oyster populations. Oyster mapping sources for this map include FWC (1986), made from historical data and aerial photographs, years unknown; Twichell et al. (2007), from 2005–2006 side-scan sonar; NWFWMD (2010) from 2009–2010 aerial photographs; ANERR (2013), from 2007 and 2010 aerial photographs; and Grizzle et al. (2017a), from 2012 satellite imagery.

converge at Lake Seminole and the Jim Woodruff Dam at the Georgia state line to form the Apalachicola River. The Chipola River also provides smaller volumes of water as a tributary to the Apalachicola. The watershed of the Apalachicola–Chattahoochee–Flint (ACF) river system encompasses roughly 50,500 km² (20,000 mi²) in Florida, Georgia, and Alabama. More than 7 million people, including many residents of Atlanta, live in the ACF watershed and rely on it as a major source of fresh water for drinking, recreation, and agriculture (Camp et al. 2015). The ACF river system includes 16 dams built to control alluvial flow and prevent flooding (la Cecilia et al. 2016).

Because of its productivity, biodiversity, and water quality, Apalachicola Bay has been designated an Outstanding Florida Water, a State Aquatic Preserve, an International Biosphere Reserve, and a National Estuarine Research Reserve (NERR; Livingston 1984, Edmiston 2008). The Apalachicola National Estuarine Research Reserve (ANERR), which encompasses roughly 1,000 km² (390 mi²), spans the estuary and the lands surrounding the lower Apalachicola River (Fig. 3.1; FDEP 2014). Lands within ANERR are owned and managed by many partners including the Florida Fish and Wildlife Conservation Commission (FWC; Apalachicola River Wildlife Enhancement Area), NWFWMD (Apalachicola River Water Management Area), U.S. Fish and Wildlife Service (St. Vincent National Wildlife Refuge), the Florida Department of Environmental Protection's (FDEP) Division of Recreation and Parks (St. George Island State Park), as well as FDEP's Florida Coastal Office (Apalachicola Bay Aquatic Preserve, Little St. George Island).

Ecology of oysters in Apalachicola Bay

The autecology of oysters in the bay has been reasonably well studied (see summaries in Livingston 1984,

Figure 3.2. Apalachicola–Chattahoochee–Flint River system (watershed boundary source: NERRS 2007).

Edmiston 2008). Spawning occurs mainly from April through October, typically with spring and fall peaks. Growth is continuous and rapid throughout the year, and market size (76 mm [3 in] shell height) can be reached in approximately 18 months (Ingle and Dawson 1953). Prior to the 2012 oyster population collapse, subtidal and intertidal oyster reefs covered approximately 10% of the bay bottom (Kennedy and Sanford 1989, Edmiston 2008). Subtidal reefs cover much more area than those in the intertidal zone; 1,600–4,000 ha (Fig. 3.3; 4,000–10,000 ac) of subtidal oyster bottom had been mapped or estimated in recent decades (Livingston 1984, Twichell et al. 2007, ANERR 2013), compared with approximately 80 ha (200 ac) of intertidal reefs mapped in 2016 (Grizzle et al. 2017a, 2018). The intertidal reefs consist mainly of natural reefs, while the subtidal reefs consist of natural reefs as well as planted reefs, created to support the fishery by the addition of cultch (suitable substrate for settling oyster larvae) including natural shell, fossil shell, lime rock, and other hard materials (Berrigan 1990, Edmiston 2008, FDACS 2015a, 2017).

Based on extensive sonar mapping and field sampling, Twichell et al. (2010) concluded that subtidal reefs in the bay began to develop on the crests of broad, flat sand bars around 400 BCE. Most of these were oriented perpendicular to the long axis of the bay. The early reefs grew vertically and migrated westward, suggesting a net westward transport of sediments in the bay. This model contrasts somewhat with reef development in the Big Bend region to the south, where it is thought that oyster reefs initially developed on nearshore limestone outcrops (Hine et al. 1988). Core and seismic profile data indicate that oyster reefs were more extensive historically and have decreased at their edges due to fine-sediment inputs from the Apalachicola River (Twichell et al. 2010). The present reef size and other characteristics reflect changes in the original spatial patterns resulting from more than two millennia of responses to changes in climate, water quality, freshwater flow, and sediment inputs from both freshwater and marine sources and, more recently, harvest and management practices.

Recent work has shown wide spatial variability in live oyster densities on both intertidal and subtidal reefs in the bay. From 1990 to 2015, the Florida Department of Agriculture and Consumer Services (FDACS) annually monitored oyster density and size on selected reefs in the bay from which harvest typically occurred (data summarized in Camp et al. 2015; also see Grabowski et al. 2017). In 2015, monitoring responsibilities shifted to FWC. From 1990 through 2011 (before the 2012 fisheries collapse), total oyster densities fluctuated between approximately 200 and 400 oysters/m^2 (19–37 oysters/ft^2). Intertidal surveys in 2016 by Grizzle et al. (2017a, 2018) found an overall mean of ~400 oysters/m^2 (37 oysters/ft^2) throughout the bay, but the western and eastern portions of the bay differed greatly. In the western bay, the overall mean density of live intertidal oysters was <50 oysters/m^2 (4.6 oysters/ft^2), and many of the reefs were dead. In the eastern bay, the average density was ~1,000 live oysters/m^2 (93 oysters/ft^2; Grizzle et al. 2017a, 2018). Until recently, there was no regular monitoring of intertidal habitats that tracked changes in oyster populations, so natural or anthropogenic changes in these ecosystems were unknown. In late 2019, the Florida State University (FSU) Coastal and Marine Lab began mapping and monitoring intertidal populations as part of their 5-year Apalachicola Bay System Initiative (ABSI, described in further detail below).

Spatial patterns in mortality vary widely across subtidal reefs in Apalachicola Bay (Berrigan 1988, Livingston et al. 2000, Edmiston 2008, Kimbro 2013). For example, Livingston et al. (2000) produced maps of oyster mortality illustrating how variations in river flow and salinity were related to mortality patterns across the bay in 1985 and 1986. Under moderate river flows, oyster mortality

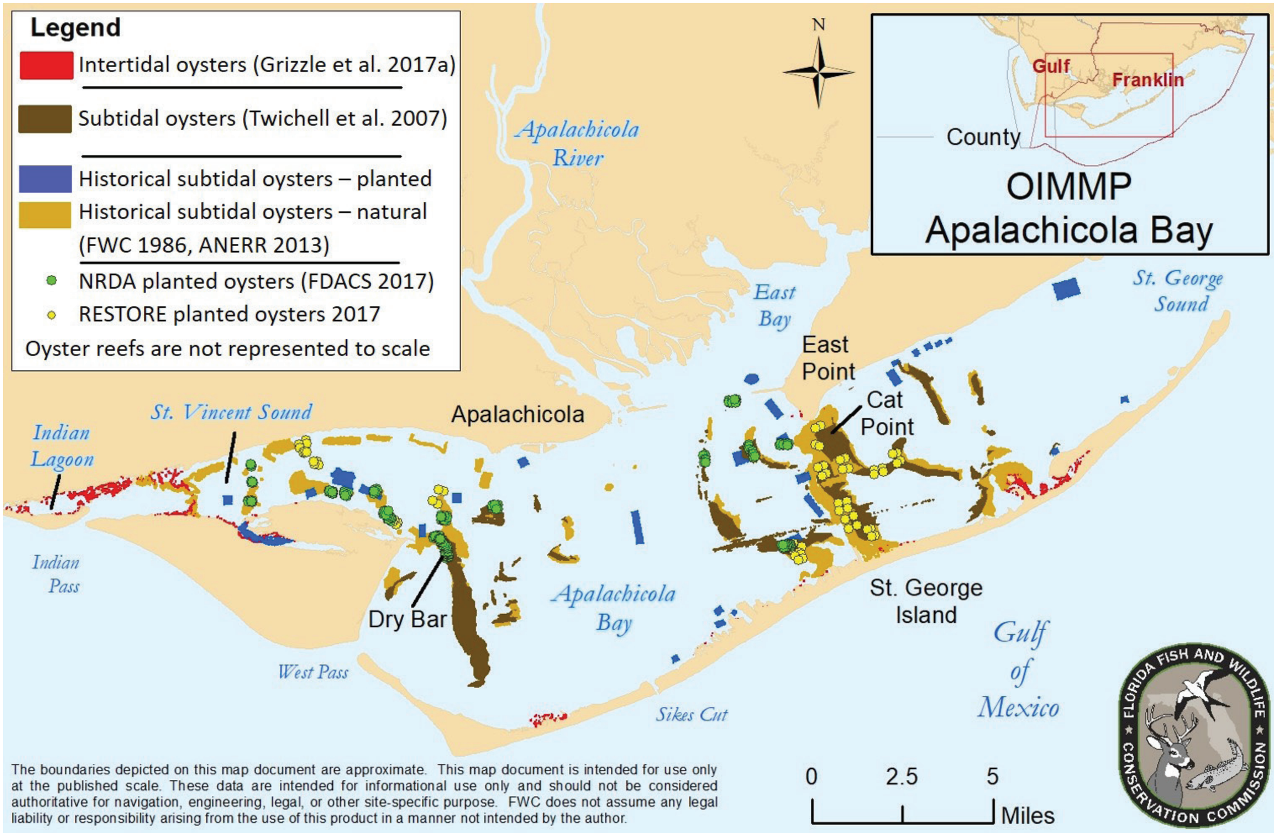

Figure 3.3. Extent of previously mapped natural and planted subtidal reefs and intertidal reefs in Apalachicola Bay. Given the changes in oyster reef distribution in recent years, such older maps should be interpreted with caution, as they do not provide information on current reef topography or live oyster populations. Oyster mapping sources: FWC (1986), made from historical data and aerial photographs, years unknown; Twichell (2007), from 2005–2006 side-scan sonar; ANERR (2013), from 2007 and 2010 aerial photographs; Grizzle (2017a), from 2012 satellite imagery; and FDACS (2017), planting sites from 2015.

was reduced throughout the central portions of the bay. Under low-flow conditions, the area of high mortality in the outer bay increased, particularly near connections to the Gulf of Mexico, possibly because marine predators (such as some gastropods and finfish) move from the Gulf further into the bay system when waters are more saline. Conversely, high river flows, such as during heavy rain events, can result in essentially the opposite result with respect to spatial mortality patterns if salinity falls below the oyster's tolerance threshold (Shumway 1996, Edmiston et al. 2008).

The impacts of storms are more complicated, however, because storm-related factors other than salinity can increase oyster mortality. For example, Hurricane Elena in 1985 produced extreme tides, strong winds, heavy rainfall, and high river discharges that resulted in burial by sediments and other physical damage to reefs in western St. George Sound and eastern Apalachicola Bay (Berrigan 1988, 1990). Oyster production in most areas of the bay dropped 90% following Hurricane Elena, resulting in closures to harvest. Recovery of recruitment and growth was rapid, particularly in areas where cultch had been deployed to replenish lost habitat (Berrigan 1990). Edmiston et al. (2008) reviewed the literature on the impacts of subsequent storms on oysters in the bay, emphasizing that the effects of sporadic events such as hurricanes can vary widely and involve multiple mortality factors. Thus, their effects are not easily predicted.

The spatial distribution of the bay's reefs (Figs. 3.1 and 3.3) is a result of both natural processes and intensive management, which began in the late 1800s (Dugas et al. 1997; see review in Pine et al. 2015). Among the most important of the management actions was the implementation of extensive cultch distribution programs. It was soon recognized that the loss of shell resulting from the harvest itself threatened the sustainability of oyster fisheries throughout Florida because it removed the hard substrate required for larval settlement. Cultch additions to the bay were first recommended around the 1880s (Whitfield and Beaumariage 1977). In 1913, the Florida Department of

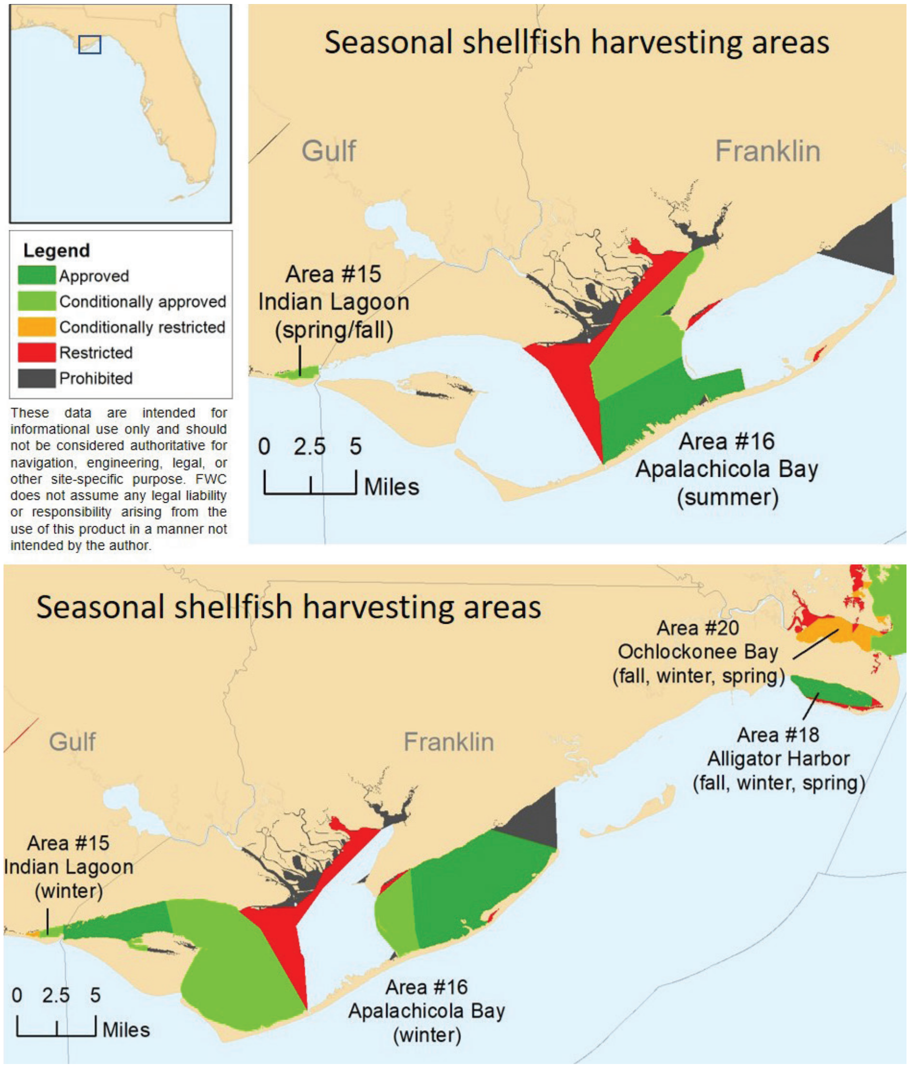

Figure 3.4. Shellfish harvesting areas in eastern Gulf County and Franklin County (Indian Lagoon and Apalachicola Bay were closed to wild harvest in 2020 and will remain closed through 2025. Harvest of aquacultured oysters remains open year-round). Source: FDACS (2021).

Agriculture's Shellfish Division (now within FDACS) conducted the first documented cultching operation when it planted 15,000 barrels of shell. Cultch planting increased substantially around 1925 (P. Zajicek, FDACS, compilation from biennial reports of the Fish Commission, Florida Department of Agriculture Shellfish Division, and State Board of Conservation) and became an even higher priority after 1949, when the Florida State Board of Conservation started an oyster reef restoration program in Apalachicola Bay. In subsequent years, however, funding and available cultch material varied widely (Whitfield and Beaumariage 1977). As of 1977, more than 4 million bushels of shell and rock had been used to cover nearly 400 ha (1,000 ac) of bottom in Apalachicola Bay (Whitfield and Beaumariage 1977), though some of the reported area may have included places that were cultched multiple times. Shell buy-back programs have been implemented to allow dealers to be paid for collected shell, but these programs rely on grants and lack permanent funding. Recent cultch programs have used primarily fossil shell or small limestone rocks (FDACS 2015a, 2015b, 2017).

Oyster harvesting in Apalachicola Bay

Much of the Apalachicola Bay system is classified by FDEP as Class II waters (those designated for shellfish propagation or harvesting) that were conditionally approved or restricted for harvest by FDACS depending on prevailing water quality and seasonal closures (Fig. 3.4). FDACS classifies shellfish harvesting areas using the standards and requirements of the National Shellfish Sanitation Program to ensure that the shellfish are safe for human consumption. Harvesting areas are classified as approved, conditionally approved, restricted, conditionally restricted or prohibited waters. Each classification type reflects the area's suitability for shellfish harvesting based on fecal-coliform data and in some cases toxins such as heavy metals. FDACS routinely monitors shellfish harvesting areas for fecal-coliform bacteria from 82 water-quality stations throughout Apalachicola Bay. The open or closed status of a specific shellfish harvesting area can be obtained from https://shellfish.fdacs.gov/seas/seas_statusmap.htm. Maps of shellfish harvesting areas, aquaculture use zones, and lease areas are also available from https://fdacs.maps.arcgis.com/apps/webappviewer/index.html?id=57f7d4b7d900496d99891f22681c66d0.

Commercial landings data from 1895 through 1984 were reported by the U.S. Fish and Wildlife Service, Florida State Board of Conservation, Florida Department of Natural Resources, or National Marine Fisheries Service, but the FWC's Fish and Wildlife Research Institute took

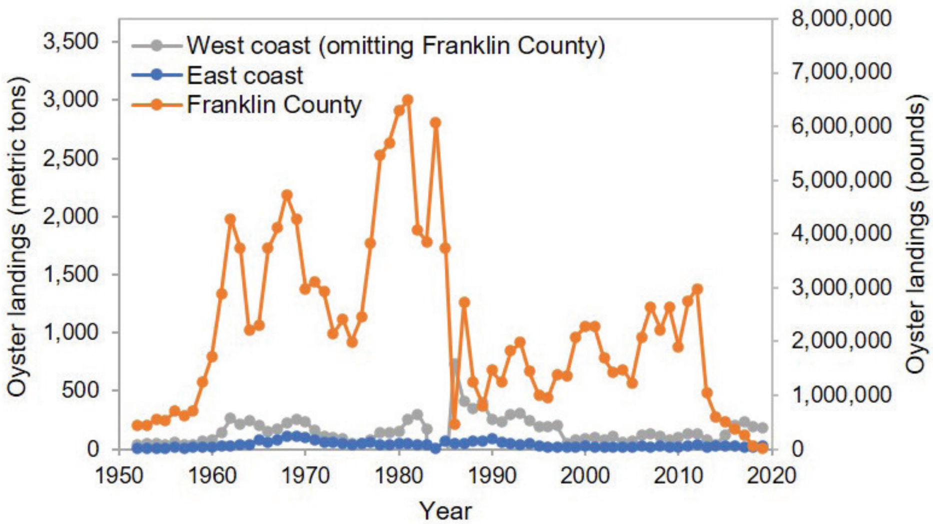

Figure 3.5. Commercial oyster landings for Franklin County and the east and west coasts of Florida. Oyster landings data before 1986 were collected under a voluntary reporting system. Data sources: 1951–1983, Florida Commercial Marine Fish Landings (see Appendix A); 1984–1985, Berrigan (1990); 1986–2019, FWC (2020).

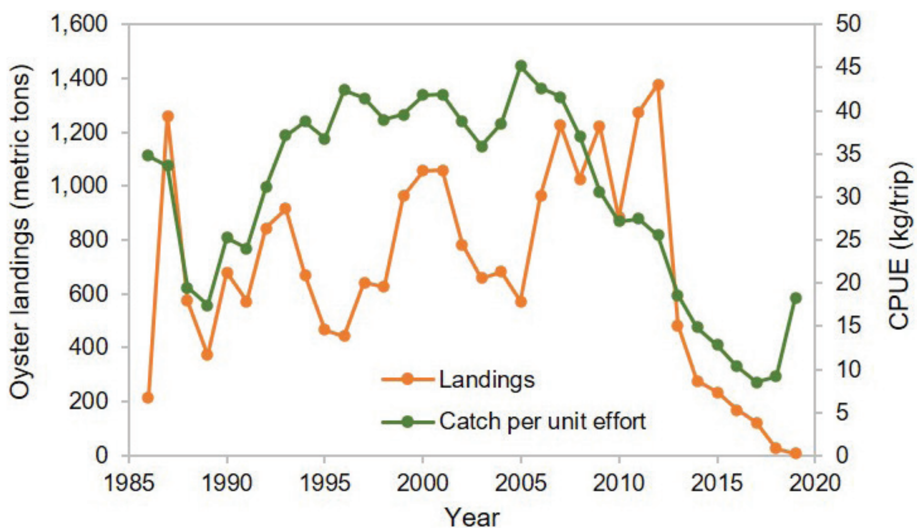

Figure 3.6. Commercial oyster landings and catch per unit effort (CPUE) data for Franklin County since 1986. The higher CPUE in 2019 reflects data from only 460 trips, while the number of annual trips from 2000 through 2017 ranged from 12,700 to 54,000. Data source: FWC (2020).

over these responsibilities in 1985. Since 1986, FWC has recorded the number of trip tickets and landings via a mandatory reporting system (Camp et al. 2015). Earlier, reporting had been voluntary. Despite the mandatory system, Havens et al. (2013) found evidence of unreported harvest and illegal harvest from closed areas that were difficult to quantify and reconcile with reported landings data. Oyster harvest regulations in Apalachicola Bay previously included bag limits, size limits, and spatial closures. A five-year closure was implemented in 2020 to give the oyster reefs time to recover from continued low populations after the 2012 collapse.

Oyster landings from Franklin County (dominated by Apalachicola Bay) fluctuated but increased overall from 1950 through the early 1980s, peaking at 3,000 metric tons (6.6 million pounds) in 1981 (Fig. 3.5). In September 1985, Hurricane Elena caused extensive damage to the bay's oyster reefs, particularly on the east end (Livingston et al. 1999). Many of the reefs that had been the most productive suffered high oyster mortality, loss of cultch, and extensive sedimentation (Berrigan 1990). The bay was closed to harvest for several months for research and distribution of clam shells for substrate (Berrigan 1990). Commercial oyster harvest resumed in May 1986, but with restrictions. Landings were nearly an order of magnitude lower than the prehurricane harvest in 1985. Oyster populations recovered relatively quickly as a result of successful recruitment, cultch distribution, and restricted harvests (Berrigan 1990, Livingston et al. 1999, Pine et al. 2015), but commercial harvests have never returned to the levels recorded before Hurricane Elena (Fig. 3.5).

Landings as well as estimates of catch per unit effort (CPUE) fluctuated but generally increased through the late 1980s and early 1990s (Fig. 3.6). Several hurricanes affected Apalachicola Bay after 1985; impacts to the oyster reefs and the fishery varied depending on storm-related physical disturbances and salinity extremes. In 1994, hurricanes caused record flooding in the region, resulting in near-freshwater conditions in the bay for almost two weeks. While the hurricanes had apparently not physically damaged the reefs, the low salinity caused mortality of 10% to 100% (Edmiston 2008, Edmiston et al. 2008). Oysters at Dry Bar and St. Vincent reefs suffered particularly high mortality. In 2005, Hurricane Dennis caused a 3-m (10 ft) storm surge, but it had little impact on subtidal oyster reefs, as the extra water depth protected them from wave energy (Edmiston et al. 2008). Hurricane Katrina in 2005 did not have a measurable impact on the oysters, but hurricane winds pushed a red tide bloom into the bay, resulting in the closure of oyster harvesting for more than three months (Edmiston et al. 2008). Landings increased substantially after Katrina, but CPUE began to show a steady decline until the most recent collapse, in 2012. Hurricane Michael made landfall in October 2018 as a category 5 hurricane just west of Apalachicola Bay in Mexico Beach. The hurricane caused a 2.1- to 2.4-m (7–8 ft) storm surge in Apalachicola Bay (Beven et al. 2019). The hurricane was not noted to have been detrimental to oysters in the bay, although oyster populations were already low at the time of the hurricane.

Apalachicola Bay was not directly affected by the Deepwater Horizon oil spill in 2010 (Grabowski et al. 2017). The fishery remained open—unlike those in large areas of Texas, Louisiana, and Alabama—and the resulting shortage of oysters initially led to an increase in oyster harvesting and prices for oysters from Apalachicola Bay (Camp et al. 2015, Pine et al. 2015, Grabowski et al. 2017). Out of concern for possible future closures, the oyster harvesting season in Apalachicola Bay was opened early. While oyster harvesting is usually prohibited Friday through Sunday, harvesting was also allowed on weekends during that time (though no changes were made with regards to size limits or daily bag limits) (FWC 2013). Despite the extended season, oyster landings in 2010 were slightly lower than those in 2009 and 2011 (Figs. 3.5 and 3.6), perhaps in part due to declining prices or fishers making use of BP's Vessels of Opportunity program for alternative employment (Crabbe 2010). Concern about the safety of post–oil spill Gulf oysters led to a decline in demand and oyster prices (Sumaila et al. 2012, Camp et al. 2015), though there has been no evidence that the oil spill had contaminated seafood harvested from Apalachicola Bay (Havens et al. 2013).

2012–2013 collapse of the oyster fishery

Oyster landings from Apalachicola Bay began a marked decline in 2012, dropping from 1,378 metric tons (3.0 million pounds) in 2012 to only 483 metric tons (1.1 million pounds) in 2013, followed by seven years of unprecedented low landings (Figs. 3.5 and 3.6). Fishery-independent sampling data collected by FDACS showed a sharp decline in oyster density on subtidal reefs (results summarized in Camp et al. 2015). The density of oysters on subtidal reefs fell below 100 oysters/m² (9 oysters/ft²) during 2012 and 2013, a marked decline from 200–400 oysters/m² (19–37 oysters/ft²) found from 1990 through 2011. A spatially extensive sampling program conducted in 2016 by FWC found live oysters at only 66 of the 161 stations sampled on mapped reefs, and the overall average live oyster density at those stations was only 17 oysters/m² (1.5 oysters/ft²). Fishery-independent sampling by FWC from 2015 to 2019 showed that oyster densities fluctuated between 0 and 156 oysters/m² (0–14 oysters/ft²). Most of that sampling found oyster densities below 50 oysters/m² (4.5 oysters/ft²) (Parker et al. 2020).

The cause of the 2012–2013 fishery collapse has been linked to a combination of events. The conclusions of Camp et al. (2015), paraphrased in the following summary, provide a plausible scenario linking five likely contributing factors: 1) low river flow led to increased salinity in Apalachicola Bay for a multiyear period, which caused 2) an increase in oyster parasites, marine predators, or pathogens, leading to 3) increased oyster mortality, particularly among juveniles, resulting in 4) recruitment failures (over several years), possibly worsened by shell removal by fishing or environmental events, finally leading to 5) collapse of adult oyster populations.

Numerous studies, including those by Wilber (1992), Wang et al. (2008), Oczkowski et al. (2011), and Fisch and Pine (2016), have assessed the role of river discharge in the long-term dynamics of oyster harvest from the bay, confirming the importance of freshwater discharge to the ecology, production, and harvest of oysters, but also underscoring the complex nature of the relationship. Unfortunately, sufficient data to fully support factors 2 and 3 above are not available because diseases, parasites, and predators were not monitored before the collapse; very high densities of boring sponges and predators, however, have been observed in the bay since the collapse (Fig. 3.7, Camp et al. 2015). Camp et al. (2015; also see Fisch and Pine 2016) also discuss research that reached similar conclusions for earlier fishery collapses in Apalachicola Bay and other parts of the state. Fisch and Pine (2016) did not find a significant correlation between oyster CPUE and river discharge between 1987 and 2013. They posit that this lack of a relationship may be a result of the changes in reporting requirements for fishery landings, the lack of a proportional relationship between CPUE and oyster populations, impacts of hurricanes, and changes in ecosystem dynamics in the bay. Overfishing is not thought to have directly contributed to the 2012–2013 collapse, in the

Figure 3.7. Oyster drills (*Stramonita haemastoma*), 3–6 cm (1–2 in.) long, and their egg cases crowd a concrete block left for one month to monitor oyster spat settlement in Apalachicola Bay in 2018 (photo credit: Nicole Martin).

Recent research has provided new perspectives on the temporal and spatial dynamics of oyster populations in Apalachicola Bay, as well as the complexity of the fishery and its importance to the region's economy and communities. Fisch and Pine (2016) focused on the complexities of the relationship between freshwater discharge and oyster landings. Camp et al. (2015) and Pine et al. (2015) explored the relationship between ecological and social issues, focusing on management strategies that should be considered to enhance resiliency in the fishery. Kimbro et al. (2017) and Pusack et al. (2018) demonstrated the potential importance of predation as related to freshwater discharges to the bay in oyster population dynamics.

Legal battles over water rights have been ongoing between the states of Florida, Alabama, and Georgia since the 1980s. After the 2012–2013 collapse, the State of Florida sought to have the U.S. Supreme Court apportion water rights in the ACF watershed. The State of Florida argued that Georgia's water policies negatively affected Apalachicola's oyster fishery, resulting in the collapse of the oyster population and the loss of many of the ecosystem services that oysters provide. Florida stated its concern that upstream water use will continue to increase as urban and agricultural demands for water grow in Georgia, inhibiting the recovery of the fishery. In 2014, the U.S. Supreme Court agreed to hear State of Florida v. State of Georgia over the appropriation of water from the ACF basin. In 2017, the court-appointed special master recommended that the court side with Georgia because Florida had failed to prove that a water-consumption cap could have averted the fishery collapse (Lancaster 2017). In June 2018, however, the court declared that the special master had applied too strict a standard in requiring Florida to prove its case and ordered reconsideration of the case (Florida v. Georgia 2018, Pittman 2018). The new special master released a report in favor of Georgia in December 2019 (Kelly 2019, Fowler 2020). In April 2021, the Supreme Court dismissed the case, stating that Florida had not provided sufficient evidence to show that the oyster fishery collapse was caused by overconsumption of water by Georgia (Florida v. Georgia 2021).

Little research has dealt with the substantial ecosystem services such as habitat provision for reef-associated

sense that recruitment was not limited by harvest (FWC 2013, Pine et al. 2015), but the fishery might have exacerbated the collapse indirectly, through the removal of shell substrate (Camp et al. 2015, Pine et al. 2015).

The fishery collapse resulted in a request by the State of Florida for a federal fisheries disaster declaration. The request was granted in 2013 by the U.S. Secretary of Commerce, enabling the use of federal funds to support the community in the aftermath of the collapse (Havens et al. 2013). These funds, as well as funding from the Florida Department of Economic Opportunity, led to the Apalachicola Bay Fishery Disaster Recovery Project Plan, which called for restoration of oyster habitat, monitoring of oyster resources, vocational training for affected oyster fishers and their communities, and upgrades to processor facilities. Continuing low harvests and low oyster density in monitoring data led the FWC to issue an emergency order in July 2020 to close the recreational and commercial oyster fisheries. In December 2020, commissioners voted unanimously to keep the fisheries closed through the end of 2025.

fauna, including the ecologically and economically valuable fish and invertebrate species, shoreline protection, and water filtration that Apalachicola Bay's oyster reefs provide (Coen et al. 2007, Grabowski and Peterson 2007). In addition to oyster landings and economic impacts, the 2012 fishery collapse also resulted in a loss of some portion of these ecosystem services. The collapse thus had ecological as well as economic and social effects. In their assessment of long-term changes in water filtration by oyster reefs in 13 estuaries in North America, zu Ermgassen et al. (2013) found that only Apalachicola Bay showed an increase in filtration capacity. Their assessment, however, was based on 1990–2010 data, collected before the 2012 collapse (see Table 1 in zu Ermgassen et al. 2013). It is reasonable to assume that other ecosystem services provided by the bay's oyster reefs have also greatly diminished since 2012, but this research has yet to be addressed.

Finally, a recent result of the Apalachicola Bay oyster fishery collapse is increased harvests in the Big Bend region of Florida. In 2016, yields from the Big Bend equaled those from Apalachicola Bay (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). There has also been an expansion of interest in off-bottom oyster aquaculture in Franklin County, in which oysters are grown in cages suspended in the water column, where they are safer from some predators and less vulnerable to sedimentation or hypoxia (Reiley 2018).

This shift is similar to changes occurring in other estuaries, where traditional oyster fisheries that have failed or become greatly diminished are being supplemented with aquacultural practices. As of January 2021, FDACS was administering 56 shellfish aquaculture leases in Apalachicola Bay (49 water-column and 7 in-perpetuity bottom leases). This includes a high-density lease area, known as an aquaculture use zone, on the western end of Apalachicola Bay in an area locally known as 4 Mile (38 leases).

Indian Lagoon

Located at the westernmost edge of Apalachicola Bay, Indian Lagoon (Fig. 3.1) is within the borders of Gulf County and is not part of ANERR. The lagoon is bounded by Indian Pass peninsula and opens to St. Vincent Sound to the east and to the Gulf of Mexico to the southeast at Indian Pass. The lagoon is shallow with a bottom of fine organic sediments (FDEP 2014), and most oyster reefs in the lagoon are intertidal (Fig. 3.3; Grizzle et al. 2017a). Oysters from Indian Lagoon make up most of the landings from Gulf County, which were at substantial levels during the 1960s and 1980s but have been at record low levels since 1990 (Fig. 3.8). As of January 2021, FDACS was administering two water-column oyster aquaculture leases in Indian Lagoon.

Eastern Franklin County

Oyster reefs are also found in Alligator Harbor and Ochlockonee Bay in eastern Franklin County (Fig. 3.1). Alligator Harbor is a barrier-spit lagoon partly enclosed by Alligator Point peninsula. It has a mean low-water depth of approximately 1.2 m (4 ft) (FDEP 2018). Salinity is similar to that in the Gulf of Mexico due to negligible freshwater input. There are some small areas of dense intertidal and subtidal oyster reef in the eastern end of the harbor, as well as some scattered larger reefs and oyster growth associated with salt marshes (Fig. 3.1; FDNR 1986, FDEP

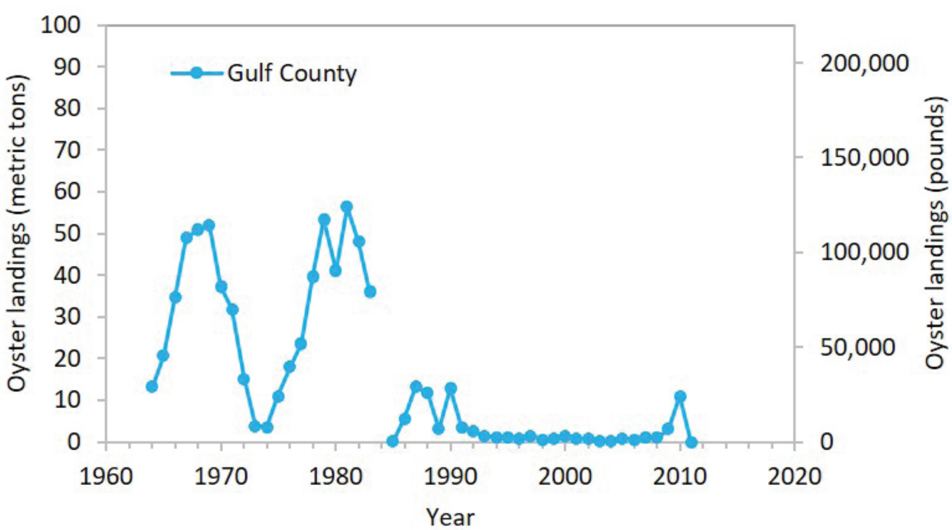

Figure 3.8. Commercial oyster harvest from Gulf County (Indian Lagoon). Data sources: FWC (2020) and Florida Commercial Marine Fish Landings (see Appendix A).

2018). Few data are available on the condition of these reefs (FDEP 2018), but they are included in FSU's ABSI intertidal monitoring effort, so information on population dynamics, reproduction, recruitment, and disease will be available in the future. Areas east of Apalachicola Bay are still open to standard commercial harvest limits of 20 bags/day/vessel. Clam aquaculture was established in 2002 in Franklin County, and off-bottom oyster aquaculture was approved on leases in Alligator Harbor Aquatic Preserve in 2015. As of January 2021, FDACS was administering 67 shellfish (oyster and clam) aquaculture leases in the Alligator Harbor Aquaculture Use Zone.

The University of Florida Institute of Food and Agricultural Sciences (UF/IFAS) intermittently monitored water-quality parameters including nutrient and chlorophyll *a* concentrations and water clarity near these shellfish harvesting areas from 2002 through 2012; monitoring was discontinued in 2012 due to a lack of funding (FDEP 2018). FDEP's Central Panhandle Aquatic Preserve (CPAP) resumed this monitoring program in 2016. In 2019, CPAP also established two autonomous data-logger sites in Alligator Harbor, providing continuous monitoring of selected abiotic water-quality parameters at these locations.

Ochlockonee Bay receives freshwater flow from the Ochlockonee River. The watershed of this river covers 6,412 km² (2,476 mi²), including parts of southern Georgia and the city of Tallahassee (NWFWMD 2017). Human population in the watershed is steadily increasing, and with population growth come concerns for proper wastewater and stormwater management. Ochlockonee Bay includes extensive seagrass beds and coastal salt marshes. Salinity in the bay varies with river flow, and the water column is often stratified (NWFWMD 2017). Salinity has remained sufficiently low in the upper half of the bay to protect oysters there from key predators (Kimbro et al. 2017).

Threats to oysters in Apalachicola Bay

Several recent reports provide a comprehensive analysis of the relationship between Apalachicola Bay's oyster fishery (and, indirectly, its oyster populations) and various environmental factors, thus providing an overview of threats to oysters (Camp et al. 2015, Pine et al. 2015, Fisch and Pine 2016, Kimbro et al. 2017, Pusack et al. 2018). From those reports, five of the most important factors are described below (and in some cases in sections above).

- **Altered hydrology:** Water withdrawals and other changes in the hydrology of the ACF river system represent a threat to oysters that has been at the center of debate and litigation for decades. A network of dams in the ACF river system alters freshwater flow rates, sediment delivery, and erosion patterns for the Apalachicola River and Bay. When this altered hydrology is coupled with low precipitation and urban and agricultural demand for fresh water, the resulting low freshwater flow and high salinity make oysters more vulnerable to dermo (a disease caused by the protist *Perkinsus marinus*), and high salinities increase incidence of predators such as the stone crab (*Menippe mercenaria*) and southern oyster drill (*Stramonita haemastoma*) (Livingston et al. 2000, Kimbro et al. 2017, Pusack et al. 2018).
- **Parasites:** In addition to predators and dermo infections, oysters must also cope with parasites such as the boring sponge, boring clam, and polychaetes. These parasites damage the oysters' shells, which provides access to pathogens, possibly resulting in death. Weakened shells also leave oysters more vulnerable to predators (Havens et al. 2013).
- **Sea-level rise:** The combined impacts of decreasing freshwater inflow and rising sea level will undoubtedly lead to more frequent instances of high salinity in the region. Even with modest increases in sea level, more saline water will enter the bay through East Pass, which will push river discharge toward the west with tidal currents (Huang et al. 2015). Cat Point is expected to experience greater increases in salinity than is Dry Bar, as freshwater flowing from the Apalachicola River is pushed westward, toward Dry Bar (Huang et al. 2015). While most oysters in Apalachicola Bay are subtidal, the intertidal oysters will face increased submergence times as a result of sea-level rise. Solomon et al. (2014) found that shell height and recruitment are greatest at high rates of submergence for intertidal oysters in Apalachicola Bay. However, these submerged-reef elevations also had the highest rates of sedimentation, which can smother reefs. Whether intertidal habitats become buried or submerged or remain intertidal will depend greatly on the oyster population dynamics and shell budget of the reef (Waldbusser et al. 2013, Rodriguez et al. 2014).
- **Hurricanes and tropical storms:** Hurricanes can negatively impact oysters and may cause erosion of reef substrate, sedimentation and burial of reefs, and extreme salinity changes (Edmiston et al. 2008). Hurricanes also redistribute shell off the reef, where it can be buried and lost in fine-grained sediments (Twichell et al. 2010). Storms often bring heightened pollutant and nutrient loads with terrestrial runoff, which can feed algal blooms (including red tide) and lead to hypoxia (Edmiston et al. 2008).

- **Harvesting:** The effect of harvest on a fishery is generally assessed by its impact on reproductive potential and recruitment. Pine et al. (2015) found that decline in the oyster population of Apalachicola Bay was linked to high juvenile mortality rather than to lack of recruitment due to harvesting. According to FWC fishing regulations, no more than 5% of harvested, unattached oysters may be undersize and no more than 15% of attached oysters may be undersize (FWC 2021). Undersize oysters must be culled immediately and returned to the reef from which they were harvested. If these limits are not honored or enforced and too many undersize oysters are harvested, it can drive down the size of individuals in a population. Since oysters are protandrous sequential hermaphrodites (adults change from male to female; Thompson et al. 1996), removing sublegal animals could reduce the number and size of females in the population. Finally, removal of shell substrate faster than the oysters can replace it can result in substrate limitation, a significant cause of poor recruitment. Fishing without shell replacement (as well as illegal fishing not complying with regulations) greatly reduces the chance that populations will recover (Havens et al. 2013).

Oyster reef mapping and monitoring efforts

Historical oyster mapping

Oyster maps for Apalachicola Bay date to the work of Franklin Swift, who conducted a comprehensive survey in 1895–1896 for the U.S. Commission of Fish and Fisheries and published a detailed map based on 75,000 manual sounding points (Swift 1897). This map represents the modern starting point for the knowledge of the distribution of natural reefs in the bay before the start of extensive cultch-planting programs.

U.S. Geological Survey geophysical mapping of subtidal oysters

Following Swift (1897), another comprehensive survey of Apalachicola's subtidal reefs did not occur until 2005–2006, when the U.S. Geological Survey used interferometric multibeam bathymetry, side-scan sonar, and seismic-reflection techniques to create detailed maps of oyster reefs (Fig. 3.9; Twichell et al. 2007). Data were collected using an outboard-propelled boat, which was used to survey depths greater than 2 m (6.5 ft); an autonomous

Figure 3.9. Composite map of the surficial geology of Apalachicola Bay using 2005–2006 sonar-based mapping (figure from Twichell et al. 2007).

surface vehicle was used to survey depths between 0.75 and 2 m (2.5–6.5 ft). Approximately one-third of the total bottom area of the bay was not surveyed due to very shallow or very deep water, and they did not survey St. Vincent Sound. This effort characterized the relationship between oyster reefs, bay floor morphology, and how the reefs likely developed in the long term (Twichell et al. 2010; see discussion in Ecology section above). Shapefiles from these surveys are available for download at https://catalog.data.gov/dataset/benthic-habitats-and-surficial-geology-of-apalachicola-bay-florida-2006-geodatabase.

FDACS compilation

The FDACS Division of Aquaculture compiled mapping data from Twichell et al. (2007) with information on cultch locations (Fig. 3.10). The reefs shown on the FDACS map are mainly subtidal, though some of the nearshore reefs are likely intertidal. This map is likely the most comprehensive map available that differentiates between natural and constructed or restored oyster reefs in the bay. The FDACS compilation and Twichell et al. (2007) focus on subtidal oyster reefs (Figs. 3.9–3.10) and provide only spatial data (i.e., no information on oyster reef condition is indicated or implied).

Intertidal reef mapping by the University of New Hampshire and The Nature Conservancy

Until recently, intertidal oyster reefs in Apalachicola Bay were largely neglected in most mapping efforts, because subtidal reefs were more abundant and were the target of harvesting. The University of New Hampshire (UNH) and The Nature Conservancy (TNC) developed new maps in 2017 for oyster reefs in Apalachicola Bay and assessed the potential of high-resolution satellite imagery for mapping and monitoring (Grizzle et al. 2017a, 2018). The project used both high-resolution GeoEye satellite imagery from Grizzle et al. (2015) and ground truthing to assess the position and size of oyster reefs. One hundred reefs were sampled, and oyster density was analyzed. This study concluded that most of the oyster reefs on the

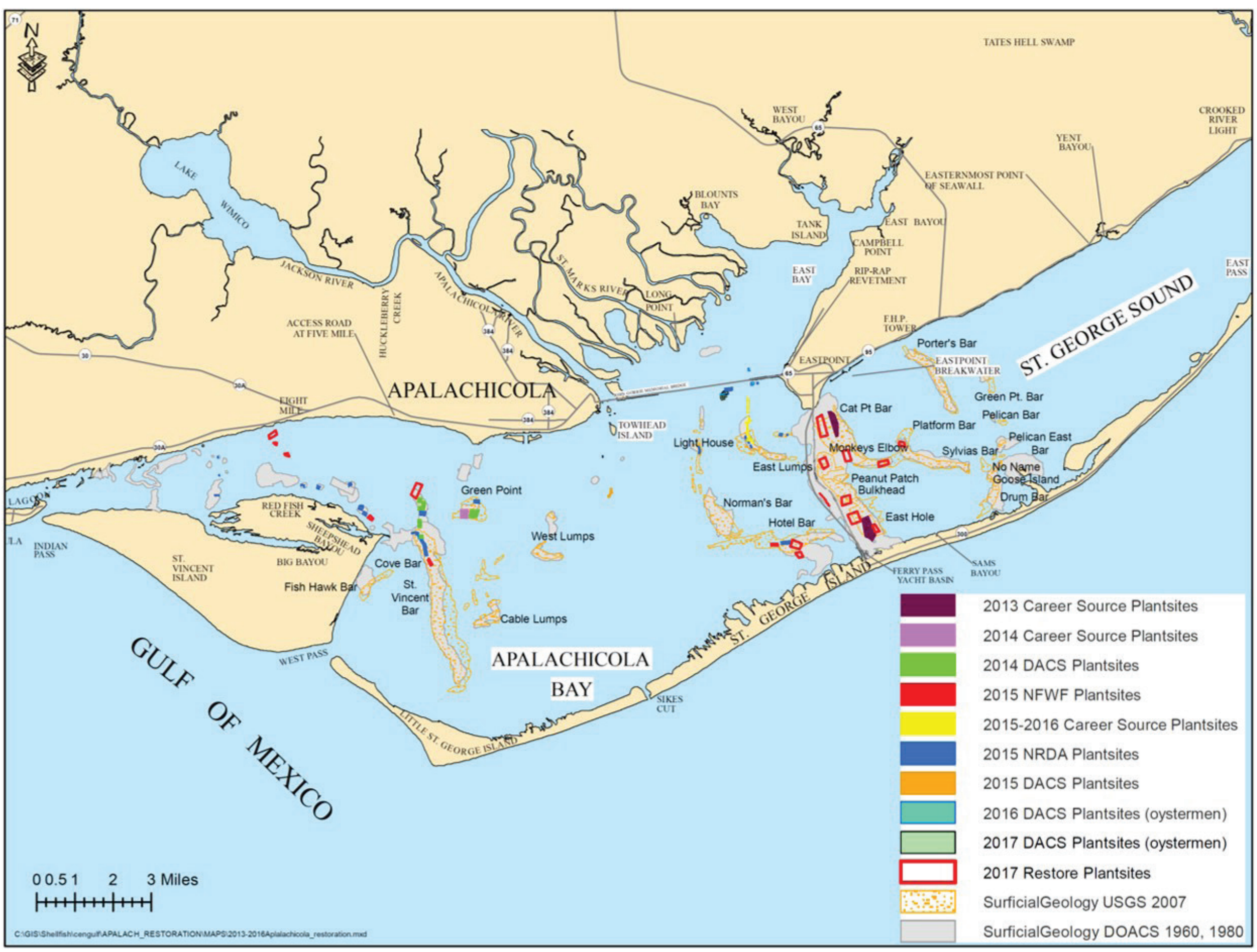

Figure 3.10. Composite map from FDACS showing natural reefs and cultching plantsites in Apalachicola Bay.

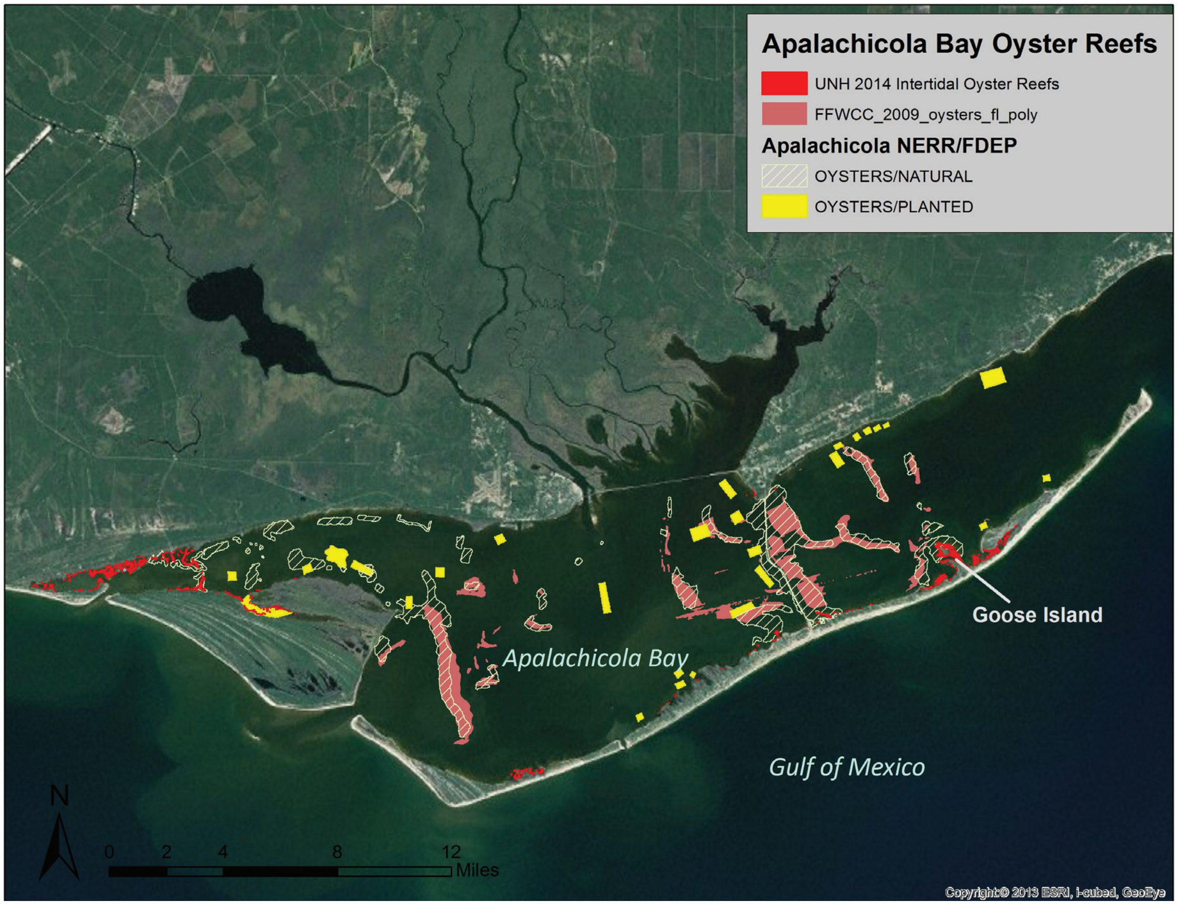

Figure 3.11. Composite map of intertidal and subtidal oyster reefs. UNH 2014 intertidal oyster reefs were mapped using 2012 satellite imagery (Grizzle et al. 2015, 2017a); FFWCC (FWC) 2009 layer compiled data from Twichell (2007) and historical data; Apalachicola NERR/FDEP data set from 2007 and 2010 aerial photographs and historical data sets (ANERR 2013). Figure from Grizzle 2017a.

western side of the bay consisted of dead shells, indicative of a recent mass mortality, with little recent recruitment. Ground truthing indicated a classification accuracy of 77–97% in the interpretation of satellite imagery. A total of 777 reefs were mapped, covering 78.5 ha (194 ac) of bay bottom.

Figure 3.11 is a composite map that combines most of the data from the subtidal maps mentioned above with the intertidal oyster reefs mapped by Grizzle et al. 2017a. This compilation and the FWC compilation (Fig. 3.1 and discussed below) represent the most comprehensive maps available showing the shape, size, and location of the major oyster reefs in Apalachicola Bay. Spatially detailed data are available on the condition of subtidal reefs, and some information is available on intertidal reefs mapped by the University of Central Florida (UCF) and UNH (see data in Grizzle et al. 2015, 2017a, 2017b, 2018) and subtidal reefs (Grizzle et al. 2020).

Intertidal reef mapping by the University of Central Florida

Researchers from UCF (Melinda Donnelly, Linda Walters, Stephanie Garvis, and Joshua Solomon) used Landsat imagery from 2012 (USGS) of Apalachicola Bay to map locations of intertidal oyster reefs. After initial mapping, ground truthing was used to evaluate the accuracy of the imagery interpretation. Field observations were conducted at 100 random locations (50 oyster, 50 nonoyster) in summer 2013 (96% accuracy). A total of 603 intertidal reefs were identified, covering approximately 80 ha (198 ac); the majority of intertidal reefs were found near natural shorelines on lands managed by St. George Island State Park and St. Vincent National Wildlife Refuge. Mapping was supported by a grant from the National Oceanic and Atmospheric Administration (NOAA). Shapefiles are available by contacting Melinda Donnelly (Melinda.Donnelly@ucf.edu).

Northwest Florida Water Management District oyster mapping

The most recent NWFWMD land-use/land-cover (LULC) map that included a separate oyster reef layer is from 2009–2010 (NWFWMD 2010). Oysters were mapped following the Florida Land Use and Cover Classification System (FLUCCS), which included a category for oyster bars (FLUCCS 6540; FDOT 1999). Mapped oyster reefs in Gulf and Franklin counties included intertidal oysters in Indian Lagoon, Alligator Harbor, and Ochlockonee Bay (Fig. 3.1). While NWFWMD LULC maps from 2012–2013 are available, oyster bars were not mapped in those years. NWFWMD shapefiles are available for download at http://www.fgdl.org/metadataexplorer/explorer.jsp.

Apalachicola National Estuarine Research Reserve mapping and monitoring

ANERR mapped land cover and benthic cover in the reserve using high-resolution imagery from 2007 and 2010 (ANERR 2013). The minimum mapping unit was 0.02 ha (0.05 ac). Subtidal oyster reef extent was compiled by Twichell et al. (2007), and a lower-resolution data set of benthic communities was compiled using infrared photographs by the GIS group at FWC's Florida Marine Research Institute (since renamed Fish and Wildlife Research Institute) (FWC 1986). The ANERR shapefile is available from http://cdmo.baruch.sc.edu/get/gis_index.cfm.

Monitoring within ANERR includes its System-Wide Monitoring Program, which began in 1992 and monitors water quality at Cat Point, East Bay, and Dry Bar in a study of the effects of changing river flow on the environmental variables at those sites. More water quality stations were added at Pilot's Cove in 2015, Little St. Marks in 2016, and the East River in 2020. Since 2002, sampling for nutrient and chlorophyll *a* concentrations has been conducted monthly at 11 sites throughout the bay, Apalachicola River, and offshore. ANERR also has a weather station that has collected meteorological data in East Bay since 1999. All these data are available at http://cdmo.baruch.sc.edu/.

ANERR has also collaborated with multiple researchers for large-scale studies of oyster populations in relation to physical parameters within Apalachicola Bay. Petes et al. (2012) examined oyster mortality in relation to salinity, temperature, and presence of dermo. They found that oysters suffered more disease-related mortality in high-salinity conditions, especially during warmer months, and that vulnerability was size specific; larger oysters were the most susceptible. Kimbro et al. (2017) studied the effects of salinity on predation rates by the oyster drill on oysters in Apalachicola Bay; Pusack et al. (2018) further studied the impacts of predator density on predation rates. Kimbro et al. (2020) studied restoration success in relation to habitat structure and predation.

Environmental Sensitivity Index maps

Environmental Sensitivity Index (ESI) maps depict coastal-zone natural resources and are designed for use in damage evaluation, prevention, and clean-up for oil spills. Areas are mapped on a scale of sensitivity based on potential exposure, biological productivity, and ease of cleanup. ESI maps depict the locations of oysters and several other shellfish species in low, medium, and high concentrations. These concentration categories are subjective and based on the opinion of local experts. Oyster mapping data for northwest Florida were published in 1995 (RPI 1995). More information and ESI mapping data can be found at http://ocean.floridamarine.org/esimaps/.

FWC oyster map compilation

FWC has compiled many of the maps described above to create a comprehensive oyster map for Apalachicola Bay (e.g., Fig. 3.1). Data sets include those from FWC (1986), Twichell (2007), NWFWMD (2010), ANERR (2013), and Grizzle (2017a). The compilation is available for download at http://geodata.myfwc.com/datasets/oyster-beds-in-florida.

Apalachicola Bay System Initiative

FSU's ABSI program has multiple scientific objectives including mapping and monitoring of intertidal and subtidal habitats, researching the reasons that the oyster populations have not recovered after the 2012–2013 fishery collapse, and creating decision-support tools that resource managers can use to develop science-based management and restoration plans. Franklin County intertidal oyster areas were mapped in 2020 by the Duke University Marine Robotics and Remote Sensing Lab using its quad-copter drone. Image mosaics and digital terrain models were produced for Indian Lagoon, East Cove, the Carrabelle River, the FSU Coastal and Marine Laboratory, and Alligator Harbor. These data were used to identify five long-term intertidal monitoring sites in each area and an additional series of sites that are used for random sampling in the spring (after first recruitment) and fall (after second recruitment peak). Five quadrats

(0.25 m²) are haphazardly deployed and their contents removed for assessment of live and dead adults, juveniles, predators, disease, reproduction, and condition index. Monthly surveys include subsampling 10 animals from each of five quadrats at each site for analysis of condition index, reproduction, and disease. These methods follow FWC's protocol for subtidal sampling, so ABSI intertidal data can be readily compared with FWC's subtidal data. ABSI is also developing procedures for the use of drones to perform periodic surveys of intertidal habitats for assessment of live oyster density and distribution.

To gain a broader perspective on habitat type and associated oyster populations, ABSI began working with a local oysterman to sample subtidal habitats using tongs. These surveys collect six tong samples per site and measure volumes of total material, rock, shell, and oysters. Boxes (recently dead oysters with intact shells) and predators are counted and live oysters are classified by size. From these surveys it has become clear that reef habitat is severely depleted, and only a few areas seem to have sufficient habitat to support a significant oyster population. The ABSI will supplement subtidal mapping by FWC and UNH by identifying smaller high-value target areas for high-resolution topographic and subtidal mapping. Understanding how habitat topography has changed since the fishery collapse will inform restoration efforts.

Modeling efforts in Apalachicola Bay

A series of studies have been published concerning the modeling of multiple abiotic parameters in Apalachicola Bay. Several directly relate their findings to the oyster population. Models include oyster population as a function of freshwater input (Livingston et al. 2000), wind effects on salinity (Huang et al. 2002), impacts of sea-level rise on salinity (Huang et al. 2014), oyster growth rate as a function of hydrodynamic models (Wang et al. 2008), and impacts of sea-level rise on salinity and oyster growth (Huang et al. 2015). Singh et al. (2015) modeled the impact of climate variability on baseline flow in the ACF river basin.

ABSI also has several hydrodynamic modeling components, which will combine to provide information on the interaction of river discharge and water flowing into the bay from the Gulf of Mexico. The high-resolution model will be used to identify larval dispersal patterns in the system under different scenarios and can aid restoration planning. To assist the modeling efforts, seven additional data loggers have been deployed in the ABSI area to augment those deployed by ANERR. These are located near the passes (Indian Lagoon, West Pass, Sikes Cut, and East Pass), the miles (between St. Vincent Island and the mainland) and in areas to the east of the St George Island Causeway. A habitat-suitability model for oysters in the ABSI area is also being developed in concert with the mapping and hydrodynamic models.

A modeling effort by UF, funded for 2021 through 2023, is focused on assessing oyster population dynamics and fishery stock assessments, valuation of oyster economic aspects, and efficacy of alternative management strategies. The population modeling is intended to provide the best possible assessment of the state of the oyster population in Apalachicola Bay. The modeling will seek to place the current stock biomass and recent fishing in historical context and to infer the effect of fishing on past and future population dynamics via stock assessment. Simulation models based on the assessment model will be used to evaluate alternative management strategies, including fishery regulations and restoration actions. All work is being developed in cooperation with ABSI and conducted in coordination with FWC. Contact Ed Camp, edvcamp@ufl.edu, for further information.

Fishery Disaster Recovery Project

The initial efforts for the recovery of Apalachicola Bay following the collapse of the oyster fishery in 2012–2013 were a collaboration between the Florida Department of Economic Opportunity, FDACS, FDEP, and FWC. In 2015, FWC assumed responsibility for the twice-a-year oyster density and size monitoring that had been carried out by FDACS since 1990. The monitoring component included pre– and post–commercial season surveys of oyster density at 15 oyster reefs located throughout the bay. In addition, monthly measures of larval settlement rates were recorded at those reefs. The monitoring component also included a fishery-independent survey of oysters throughout Apalachicola Bay (mentioned in the Ecology section). Survey locations were randomly selected from areas deemed likely oyster habitat based on shapefiles and data sets. A total of 161 stations were sampled, and results indicate that many areas considered potential oyster habitat have experienced substantial loss of settlement substrate. Funding for this project ended in 2020, and summary results can be found in the project's final report (Parker et al. 2020). FWC will continue to carry out semiannual surveys of oyster densities from these locations as a part of state-funded population monitoring and will continue monitoring larval settlement rates as part of Apalachicola Bay Oyster Reef Restoration Phase II (both described below).

FWC oyster population monitoring

In July 2015, the State of Florida provided funding for establishment of an annual monitoring program for Apalachicola's commercially fished oyster reefs for fishery-management purposes. The FWC program conducts monthly measures of oyster condition, dermo prevalence and intensity, reproductive development, and incidence and severity of shell pest infestations. The FWC program will continue to conduct the twice-a-year surveys of oyster density previously funded by the Fishery Disaster Recovery Project, as described above.

Apalachicola Bay restoration mapping and monitoring

Many cultch plantings have taken place in Apalachicola since 2013 (Fig. 3.10). Several of these cultch plantings have been subsequently mapped or monitored by various agencies.

- **Natural Resource Damage Assessment (NRDA) cultch planting and monitoring:** One such cultch-placement project was funded by a Gulf Coast Ecosystem Restoration Council grant (GCERC 2016) and is a continuation of a Deepwater Horizon NRDA Phase III Early Restoration project and National Fish and Wildlife Foundation (NFWF) project. The project involved the placement of suitable cultch on depleted oyster reefs to promote oyster colonization. The coordinates and description of these restoration efforts can be found in the project report (FDACS 2017). Approximately 19,000 m^3 (24,840 yd^3) of fossilized oyster shell were deposited on an estimated 50 ha (124 ac) of depleted oyster reefs in Apalachicola Bay in fall 2015 (FDACS 2017). Site selection and cultch placement were coordinated through FDACS. FDEP is monitoring the success of this restoration effort.
- **Apalachicola Bay Oyster Restoration Project:** This cultch-restoration project extended from 2014 through 2021 and was funded by oil-spill reparation funding through the NFWF. It was a collaboration between FWC, UF, FDACS, and UNH. The initial component of the project was overseen by FDACS and involved the placement of fossil shell at three experimental sites in Apalachicola Bay in 2015. At each of those experimental sites five 2-ac parcels were delineated and cultched at different shell densities (0, 100, 200, 300, and 400 yd^3/ac) to identify optimal shell density for future restoration efforts. The coordinates and description of cultching efforts can be found in FDACS's final report summarizing its component of the project (FDACS 2015b). In 2016, UNH and Substructure Inc. conducted acoustic mapping and ground truthing of the experimental sites (Grizzle et al. 2017b). From 2015 through 2019, UF monitored oyster health and condition. Details and results of the oyster health monitoring can be found in UF's final report (Kane and Lindsay 2019). FWC monitored oyster and predator densities as well as oyster size distribution on each of the parcels from 2015 through 2019 (Parker and Davis 2019).
- **Shell-budget model development:** In 2019, FWC began developing a sampling protocol and collecting data for a shell-budget model in cooperation with the University of New Orleans as part of the Gulf-wide Saltonstall-Kennedy Grant Program. This approach uses a model to gauge the impact of multiple variables on changes in the amount of shell on oyster reefs. Other Gulf states have begun to use their own similar models as valuable tools for managing their oyster fisheries. Initial model simulations indicate that net shell gains on oyster reefs in Apalachicola Bay are not possible without cultch placement (Soniat 2020). To assist with the development of a shell-budget model, UNH and Substructure Inc. conducted acoustic mapping and ground truthing of about 650 ha (1,600 ac) in the central portion of the bay and identified candidate areas for restoration (Fig. 3.12; Grizzle et al. 2020). FWC selected six 0.2-ha (0.6-ac) areas near monitoring sites for mid-2021 cultch placement. FWC will continue to monitor these sites through the end of 2025 as a part of the Apalachicola Bay Oyster Reef Restoration Phase II project described below.
- **Apalachicola Bay Oyster Reef Restoration Phase II:** The most recent cultch-restoration project, funded by NFWF, was initiated in 2020 and is funded through the end of 2025. The project aims to restore as much as 400 ha (1,000 ac) of oyster reef in the bay. Initial mapping and ground truthing implemented to identify possible restoration sites were carried out from January through May 2021 and covered an area of more than 2,400 ha (6,000 ac) by UNH and Substructure Inc. FWC is conducting quarterly monitoring on oyster and predator density on selected areas before and after cultch placement. FWC is also continuing the monthly larval recruitment monitoring that began as a part of the Fishery Disaster Recovery Project (see above) and is monitoring sedimentation rates in six locations throughout the bay. FWC is working with stakeholders to inform cultch-placement efforts and to work toward a revised fishery-management plan in anticipation of the fishery's reopening (Estes 2020).

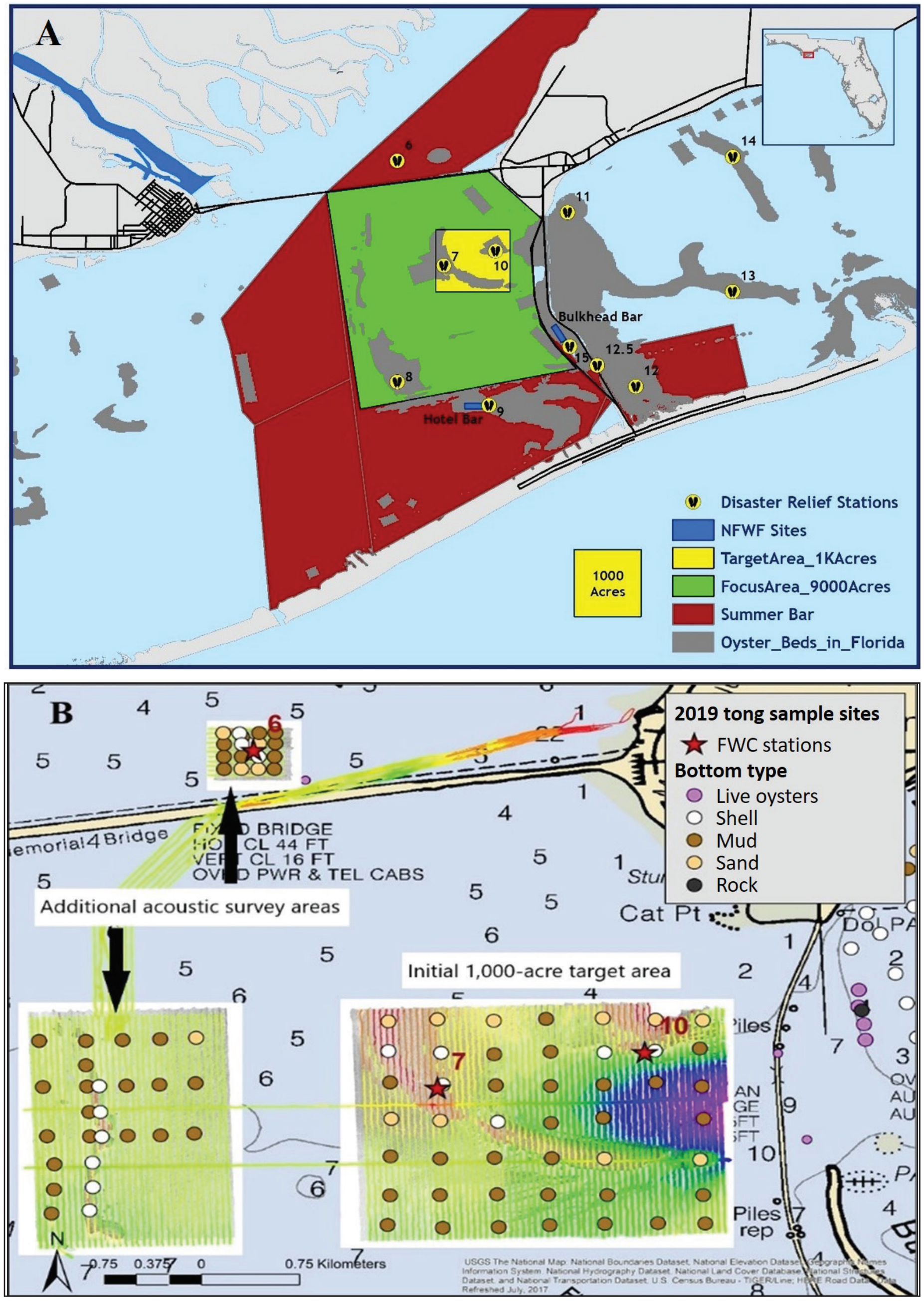

Figure 3.12. Primary survey area in Apalachicola Bay (A) and acoustic survey results showing depth at low water (blue color indicates a depth of ~3 m, red indicates a depth of ~1 m) with ground-truthing sites shown in color-coded circles (B). Figure from Grizzle et al. (2020).

- **Habitat structure and restoration success study:** In a separate study on cultched oyster reefs, Kimbro et al. (2020) monitored oyster size and survival on three 0.4 ha (1 ac) reefs with either no added shell, moderate structure (152 m³/200 yd³ shell added), or high structure (306 m³/400 yd³ shell added). With the use of predator-exclusion cages, they found that predation was greatest on the reef with no added shell but similar between the two culched reefs. Oyster larval supply did not vary among the three reefs, but oyster density was higher on the shelled reefs. Oyster drills were more likely to be found at sites during times with high salinity and high temperature (Pusak et al. 2019).

Disease monitoring

The prevalence and intensity of dermo in the eastern oyster were monitored from 2005 to 2015 in several locations in Apalachicola Bay by the Oyster Sentinel, established by Thomas Soniat at the University of New Orleans. Monitoring locations and data are available from https://oystersentinel.cs.uno.edu/. Monitoring included water temperature and salinity. At present, dermo is being monitored in intertidal habitats by the ABSI group and in subtidal habitats by FWC.

Contaminant monitoring

Oyster samples from Cat Point Bar and Dry Bar in Apalachicola Bay are included in NOAA's Mussel Watch program, which monitors sites around the United States for organic and inorganic pollutants. Data are available from https://products.coastalscience.noaa.gov/collections/ltmonitoring/nsandt/default.aspx. Oysters from Apalachicola Bay contained moderate levels of arsenic and mercury (Kimbrough et al. 2008). The ABSI project is collaborating with scientists at Florida Agricultural and Mechanical University to assess levels of organic pesticides and heavy metals at 12 stations in the Apalachicola Bay and River, and a time series of contamination will be created using three sediment cores taken in the main basin.

Recommendations for mapping, monitoring and management

- Conduct periodic and extensive mapping of subtidal and intertidal reefs that is practical, sustainable, and coordinated in both project design and areal coverage. Portions of intertidal and subtidal reefs have been mapped recently, as funding has allowed, as separate studies following project-specific protocols.
- Monitor the condition of the bay's oyster reefs, including reefs harvested before closure and those that were not traditionally harvested. The resulting data should be coupled with mapping programs and environmental data to improve understanding of spatial and ecological relationships between the bay's oyster reefs and environmental variability.
- Continue research to support development of a science-based and stakeholder-supported oyster habitat restoration plan. Ongoing research is aimed at assessing optimal densities for deployment of fossil shell, but research is also needed on where cultch should be placed, the types of substrate (e.g., fossil shell, recycled seasoned shell, other, more durable, substrates) that are most effective, and how to deploy the material. Continue oyster reef restoration and associated monitoring efforts, which help to determine where and what type of restoration is most effective and allow for adaptive managment during large-scale restoration projects.
- When commercial harvest reopens, better manage the fate of oyster shell removed during harvest. The importance of adequate hard substrate for larval settlement, and thus long-term sustainability of oyster reefs, has long been recognized (Swift 1898). Cultch-distribution programs have been conducted in Florida by FDACS, but they lack permanent funding, having to rely on nonrecurring grants. These programs have focused on Apalachicola Bay and, more recently but to a lesser extent, St. Andrew and Pensacola bays. While the importance of cultch programs to oyster management has been well established (Pine et al. 2015), questions remain with respect to details in program design (Havens et al. 2013).
- Investigate management needs and social issues related to salinity and minimum river-discharge requirements for Apalachicola Bay. Increased salinity as a result of reduced river discharges to the bay and sea-level rise is a major threat to oysters in this region, but also one of the most difficult to address. Although there has been a substantial amount of research on how oyster populations respond to increasing salinity, including research in Apalachicola Bay, research is also needed on how to address such complicated social issues from a management perspective.
- Continue research on the ecological role of and services provided by oysters in Apalachicola Bay. The bay's oysters have historically been managed almost entirely as a resource for human harvest, but oyster reefs also provide habitat, improve water quality through filter-feeding, and are components of the estuarine food web. More information is particularly needed on ways in which oyster harvest practices affect these ecological functions and on ways to optimize ecosystem functionality in a heavily harvested estuary.
- Further explore the role of oyster aquaculture in the bay. Oyster farming and oyster fishing are not mutually exclusive, but the tradition in Apalachicola Bay has historically not included aquaculture. Oyster farming is becoming increasingly common in other Florida estuaries, such as nearby Apalachee Bay and Alligator Harbor (FDEP 2018; Reiley 2018). The use of Territorial Use Rights for Fisheries (TURFs; Prince et al. 1998), in which oysters are harvested from areas leased to individual oyster farmers rather than from common-use public reefs (Havens et al. 2013, Camp et al. 2015), should also be explored. Individual leases help prevent unsustainable fishing practices and shell removal, and they encourage stewardship of reefs for long-term use, such as the distribution of cultch to replace lost substrate.
- Enhance community outreach with partnerships in research, policy development, and education. The most effective policies will be those that result from a broad support base and are responsive to changes and new knowledge. Buy-in from all stakeholders, especially the fishing communities whose livelihoods have historically relied on the harvest from the oyster reefs of the Apalachicola Bay area, is crucial to achieving stable, long-term management of a healthy Apalachicola Bay ecosystem and fishery.

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General references and additional regional information

Apalachicola Bay Aquatic Preserve
https://floridadep.gov/rcp/aquatic-preserve/locations/apalachicola-bay-aquatic-preserve

Apalachicola National Estuarine Research Reserve
https://apalachicolareserve.com/

Apalachicola River Wildlife and Environmental Area
https://myfwc.com/recreation/lead/apalachicola-river/

Commercial oyster fishing regulations
https://myfwc.com/fishing/saltwater/commercial/oysters/

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

St. Vincent National Wildlife Refuge
https://www.fws.gov/refuge/st_vincent/

St. George Island State Park
https://www.floridastateparks.org/parks-and-trails/dr-julian-g-bruce-st-george-island-state-park

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