Brevard County Oyster Habitat Suitability and Rehabilitation Success Plan

Brevard County Natural Resource Management

Jennifer C.R. Hansen

Table of Contents

Figures

Acknowledgements: We thank the staff of Brevard Zoo's Restore Our Shores Team for their collaboration on forming this document through many conversations, workshop days, and review. Also, we thank Dr. Linda Walters, Dr. Paul Sacks, and Dr. Melinda Donnelly for their review as experts in the field of oyster and living shoreline restoration, and for laying the foundation for the proposed monitoring protocols. Further expert review and input was provided by Anne Birch, Marine Program Manager for The Nature Conservancy, Dr. Vincent Encomio, Florida Sea Grant Agent, University of Florida I.F.A.S. Extension, and Dr. Duane De Freese, Executive Director of the Indian River Lagoon Council and Indian River Lagoon National Estuary Program.

1. ***Preface***

The Indian River Lagoon, Florida, (I.R.L.) is one of 28 estuaries of national significance, authorized in Section 320 of the Clean Water Act as part of the United States Environmental Protection Agency's National Estuary Program. The estuary connects six counties along the I.R.L., spanning 40% of the east coast of Florida. At one time, oyster reefs were a dominant habitat type in many parts of the estuary and an important part of a multi-million dollar commercial shellfish industry. From 1990 to 2015, I.R.L. shellfish harvest declined by 72% in pounds harvested, and 80% in value (Treasure Coast Regional Planning Council, 2016). Much of that economic decline was due to loss of both oysters and clams and declining water quality. The Florida State Wildlife Action Plan (F.W.C. 2012) identified *Crassostrea virginica* as a "taxa of concern" within the species of greatest conservation need, categorizing bivalve reef status as poor and declining. Thirty-two additional species of greatest conservation need, including mammals, birds, reptiles, fish, and invertebrates, were associated with bivalve reefs (F.W.C. 2012). The Indian River Lagoon National Estuary Program (I.R.L.N.E.P.) Comprehensive Conservation and Management Plan – Looking Ahead to 2030 (2019) (C.C.M.P.) called for restoration of filter feeder habitats across a broad spatial distribution in the next 10 years, which would also support I.R.L. biodiversity and improvements to both recreational and commercial fisheries. Oyster restoration directly addresses 5 of the 32 C.C.M.P. vital signs of I.R.L. health identified by the I.R.L.N.E.P.: filter feeders, water quality (nutrient reductions, improved water clarity), biodiversity (habitat provisioning), commercial and recreational fisheries (food web and nursery habitat), and harmful algal blooms (nutrient reduction, direct feeding on H.A.B. species). All five of these vital signs were identified as either critical, requiring immediate, aggressive intervention, or serious conditions threatening long-term lagoon health. There is growing evidence that oyster reef restoration may have positive impacts on shallow seagrass beds in turbid, high-energy systems (Sharma. et al., 2016). The I.R.L. has experienced a catastrophic loss of seagrass coverage since 2011. That loss of seagrass forage is thought to have driven a manatee unusual mortality event in 2020-2021. The I.R.L.N.E.P. and most I.R.L. scientists agree that water quality improvements are urgently needed to restore seagrass coverage to the I.R.L. Restoration of oyster reefs and other filter feeders is an important part of that water quality and habitat restoration strategy.

Rehabilitation projects funded by the Save Our Indian River Lagoon (S.O.I.R.L.) Program target the Central and North I.R.L. and Banana River Lagoon and include the construction of "oyster bars", which are built utilizing various designs, generally including shell cultch and deployed within 60 ft of the Mean High Water Line along natural and hardened shorelines. These projects do not have traditional restoration goals, rather aim to rehabilitate oyster populations once prevalent throughout the I.R.L. for the purpose of improving water quality. When added to the most recent survey of remaining natural reefs mapped in the Sebastian River (Gambordella et al. 2007), the S.O.I.R.L. rehabilitation projects will bring the total oyster habitat to < 1.5% of historic oyster beds mapped in Brevard in the 1970s (Down 1978). Relative to seagrass restoration, this area is only 0.02% of the seagrass coverage target acreage established by Steward et al. (2005). Restoration is essential for sustaining ecosystem services in degraded coastal areas, with larger projects likely to provide the best return on investment (Hernandez et al. 2018). This initial investment by the S.O.I.R.L. Program to bolster local oyster populations will inform strategies for continued restoration in the I.R.L., elucidate habitat selection indices and success criteria (H.S.I.), and facilitate investigations of habitat provisioning and positive feedbacks with adjacent seagrass and shoreline habitats. As the sustainability and ability to effectively provide ecosystem services of different reef types across diverse environmental conditions is unknown (Morris et al. 2019), this H.S.I. and continued monitoring efforts over time will aid in engineering successful living shorelines that restore ecosystem services.

The content of this H.S.I. is consistent with others in Florida (Barnes et al. 2007; Boswell et al. 2012). For example, the Charlotte Harbor National Estuary Program adopted a suitability model developed in partnership with The Nature Conservancy which scores potential sites by seagrass persistence, aquaculture lease area, boat channels, bathymetry, and tidal river isohalines (Boswell et al. 2012). They noted oyster distribution and survival is controlled by substrate, water flow, salinity, food availability, dissolved oxygen, disease and parasites, contaminants, predators, sedimentation, harvesting, and ocean acidification. Success in the Charlotte Harbor model was defined by self-sustaining populations based on positive net vertical growth, annual spatfall, and presence of multiple size-classes of oysters, rather than population density. They also identified 4 main categories for success: recruitment and growth, habitat provisioning, impacts on water quality, and shoreline protection (Boswell et al. 2012).

2. ***Executive Summary***

In the Indian River Lagoon (I.R.L.), large losses of important foundation ecosystems such as oyster reefs and seagrass beds have occurred (Lapointe et al. 2015). Brevard County has proposed to build 14.5 acres of oyster habitat through the construction of “oyster bars” as part of the Save Our Indian River Lagoon (S.O.I.R.L.) Program to aid in the removal of nitrogen, water filtration to improve water quality, and support ongoing restoration activities set forth by the Indian River Lagoon National Estuary Program (I.R.L.N.E.P.). In order to best manage rehabilitation efforts for the I.R.L., this document summarizes relevant literature from *Crassostrea virginica* oyster reefs in both Florida and elsewhere. Where possible, environmental conditions which uniquely influence oyster rehabilitation projects in the I.R.L. system are explored. Lessons learned from the rehabilitation of 14.5 acres of oyster ecosystems will guide future large-scale restoration of bivalve communities in the I.R.L. To best manage these oyster rehabilitation efforts, this document aims to outline a five-year adaptive management strategy for Brevard County oyster bar projects. The metrics for determining site suitability, success criteria for individual projects, and a monitoring plan, which will feedback into management decisions, are summarized here and further expounded in the following Brevard County Oyster Habitat Suitability and Success Plan.

2.1 Suitability Targets

Summarized below are the indices and targets the Brevard County S.O.I.R.L. Program will use to inform the suitability assessment of each proposed location for an oyster bar rehabilitation project. These may be modified as new scientific and project performance data become available.

Water Quality – Salinity, Temp, D.O.: Sites will target average salinity of 10 to 28 ppt, average annual temperatures of 20 to 30 °C, and near-bottom D.O. concentrations > 4 mg L^{-1}. Oyster bar projects will be built during the spring (March) through early fall (mid-October) to avoid cold shock and capture peak recruitment cycles. Further, areas where significant sediment and/or muck deposition is expected, which could bury oysters and decrease D.O. concentrations, will be avoided.

Depth: Oyster bar projects will be deployed in waters that are at least 30 cm deep during low water season. Ideally, oyster bars would be placed offshore with greater access to higher flows and water depths of at least 0.5 m during low water season. Since the I.R.L. is a shallow, microtidal and wind-driven lagoon-type estuary, shoreline shape and boundary orientation are important considerations related to water flow.

Substrate: A shoreline survey conducted by the University of Central Florida for Brevard County, muck deposits mapped by Florida Institute of Technology, and site visits will be used to determine suitable sediment type. Projects will begin with the addition of hard substrate to encourage oyster settlement. Substrates should be deployed so as to stay in place and persist in the environment for at least two years to capture initial recruitment and establishment of the oyster bar. Ideally, biodegradable options will be explored that will eventually degrade as oysters form bridges (connecting two shells together through new growth) and begin forming their reef structure. Material types can also be chosen to best meet substrate conditions related to sediment type, stability, and transport. Finally, sites will be chosen to avoid seagrass impacts by conducting surveys during the growing season (April through October) immediately preceding bar construction. Areas with persistent seagrass will also be protected by avoiding areas with seagrass reported in at least 14 of 16 survey years mapped by the St Johns River Water Management District (S.J.R.W.M.D.).

Hydrodynamics – Flow, Wave Exposure, Sedimentation, and Food Access: Site selection will avoid areas that have significant impediments to flow, such as deep within a cove or canal that have obvious signs of water stagnation. Areas where obvious sediment trapping is occurring will be avoided, such as along accreting shorelines. Access to larval supply will also be influenced by local hydrodynamics.

Natural Recruitment: Oyster rehabilitation will target areas where there is either evidence of prior oyster recruitment and/or a source population within 3 km (Anderson et al. 2019). As part of the proposed adaptive management strategy, the need for seeding and/or reseeding oyster bar projects will be determined based on survival of initial populations, investigations of discrete environmental events (i.e. major storms and hurricanes, water quality fluxes, or harmful algal blooms), and evidence of poor recruitment years (lack of recruitment and survival across multiple sites).

2.2 Adaptive Management and Success

Metrics summarized below will be utilized in deciding the overall success of oyster bar projects. When incorporated into a multi-year timeline, these targets will elucidate discreet events from project failures and allow for response and adaptation.

Density: Previous studies have defined live oyster reefs as those with >10 live oysters m^{-2} (Theuerkauf et al. 2017). Minimum success included 10 (Powers et al. 2009) to 15 oysters and 15 g dry weight m^{-2}, covering at least 30% of rehabilitated area (Allen et al. 2011)

Recruitment: Evidence of recruitment in at least one of two survey years (Powers et al. 2009) with oyster spat defined as settled individuals < 25 mm (Wang et al. 2008) and recruits defined as those that survive to between 10 and 25 mm.

Size Class Distribution: Presence of two distinct size classes (Allen et al. 2011).

Seeding: If projects include the addition of live oysters at deployment, they will be added at a density of approximately 100 oyster m^{-2} to the top layer. The baseline size for these oysters will also be recorded and continued monitoring will help to show initial impacts on survival, such as salinity shock (Anderson et al. 2019), extreme low water, storm events, or sedimentation. Survival for the first 6 months to 1 year will be calculated as the total number of live oysters >40 mm divided by the initial number of seed oysters deployed, with a target of at least 50%

survival. Once new recruits reach the size of the seeded oysters, survival of the seed population can no longer be differentiated; however, the total population can continue to be evaluated based on density and size class targets (Baggett et al. 2014).

In order to allow for adaptive management, after two to three years the degree of success in meeting interim targets will be determined along with potential causes if targets are not met (Allen et al. 2011). At this time decisions can be made, such as seeding or re-seeding a project to mitigate against discreet events such as a poor recruitment year or storm event (Allen et al. 2011). For example, if the project meets the Minimum Success Targets for density and recruitment, but not the Sustaining Success Targets, then reseeding the project may be appropriate (Allen et al. 2011). In the case of regular wave energy or storm-specific damage severely degrading the integrity of a project, every effort to make repairs and replace materials as needed will be made. Once a project has met the success targets, it will be deemed complete with no further action or reporting necessary. If all efforts to mitigate for discreet events have been completed but metrics still are not met, a project may be deemed a failure. A complete failure to meet rehabilitation goals can be defined as a lack of recruitment over multiple cycles, high mortality of seed stock after two optional replenishments, and degradation and burial before the population can establish. However, additional ecosystem services such as habitat provisioning supporting biodiversity, and adjacent habitat protection may continue. Removal will be discussed with relevant agencies if this stage is reached. The potential to allow projects to remain based on additional restoration goals of the National Estuary Program can be assessed during these discussions utilizing goals supported by the I.R.L.N.E.P. and targets adopted by the Charlotte Harbor National Estuary Program.

2.3 Monitoring Summary

Task Description: Monitoring of a representative subset of oyster bar projects will be conducted at baseline and annually for a period of three years. Monitoring frequency and duration is subject to change if requested by Brevard County Natural Resources Management Department and dependent on adaptive management needs.

Key Personnel: Researchers from University of Central Florida's Coastal & Estuarine Ecology Lab will study a subset of these projects to answer specific questions. This monitoring will be more frequent and in-depth. Brevard County Natural Resources Management staff and/or Brevard Zoo Restore Our Shores staff will monitor the remaining subset of projects. This monitoring will collect information related to success targets.

Methods: Oyster bar monitoring data will be collected by emptying or visually inspecting the rehabilitation unit (shell bags, gabions, mats, etc.) that is being utilized at the project site. For each unit this will include: total number of live oysters, shell length of first 50 haphazardly selected live oysters to look at size class distribution, numbers of live oysters impacted by live boring sponge, and enumeration of boxed oysters. If an oyster bar is seeded with live oysters, a baseline will be established, and a monitoring event within the first 6 months will be conducted to determine survival of the seeded oysters prior to the size classes merging. If rehabilitation units are removed for monitoring they will be reattached once monitoring is complete. A minimum of five units per monitoring site will be emptied for material types where this is possible.

Rapid visual census data will include observing rehabilitation units while in place, noting information such as: the presence or absence of bridge formation, presence/absence of algal overgrowth, sediment accretion on top of the oyster bar, and condition/integrity of units.

Rapid abiotic data collection (salinity, air, and water temperatures) will occur at all monitoring sites on all monitoring dates at depths equivalent to those occupied by the oysters. After deployment, baseline monitoring will occur, followed by annual monitoring to determine if success targets related to adaptive management are being met. Unit integrity/substrate placement will be tracked after named storm events as needed through the duration of the project. Refer to the remainder of the "Brevard County Oyster Habitat Suitability and Success Plan" for greater detail on monitoring and adaptive management.

Deliverables: Annual report detailing monitoring completed will be submitted electronically to relevant state and federal permitting agencies (Florida Department of Environmental Protection, S.J.R.W.M.D., and/or U.S. Army Corps of Engineers) for review by February 28th of each year for the duration of the project, if requested.

3. *Introduction and Background*

Oysters serve as a keystone species in estuaries and coastal waters, forming large biogenic reefs (Luckenbach et al 1999). These reefs provide a suite of ecosystem services including improvements in water quality (Newell et al. 2002; Grizzle et al. 2008), creating habitat for fish and invertebrates (Peterson et al. 2003), shoreline erosion protection (La Peyre et al. 2014; Weaver et al. 2017), sediment stabilization and reductions in total suspended solids (Grizzle et al. 2008; Reidenbach et al. 2013), resilience to and protection from sea level rise (Ridge et al. 2017), and nutrient sequestration and denitrification (Kellogg et al. 2013; Chambers et al. 2018; Locher et al. 2020). Oysters are sessile, benthic organisms, which are sensitive to natural and artificial changes and are beholden to their environment for the delivery of resources and the removal of waste products, and therefore serve as a good indicator species of estuary health (Barnes et al. 2007).

Globally, an estimated 85% of oyster reefs have been lost (Beck et al. 2011). In the Indian River Lagoon, Florida, (I.R.L.) large losses of important foundation ecosystems such as oyster reefs and seagrass beds have occurred (Lapointe et al. 2015). In 1895 in a report to Congress, oysters in the Indian River Lagoon were noted as being a "prominent fishery" (Brice 1897). Oyster beds were described in the lagoon near Titusville, south of Rockledge, 0.5 mi north of Fort Pierce, and along the shore for a few miles running north from St. Lucie, with catch taken near Titusville, Cocoa, Eau Gallie, and Fort Pierce (Wilcox 1896). In 1966, oysters were found between Eau Gallie and Sebastian totaling 447 acres (Futch 1967). As late as the 1970s, the eastern oyster, *Crassostrea virginica*, was one of only four species of mollusk found in all seven subregions of the Indian River Lagoon and was listed as a "characteristic species" (Mikkelsen et al. 1995).

From 1970-1975 an aerial mapping project was undertaken in Brevard County to quantify underwater features including seagrass and oyster beds (Down 1978). At the time of this mapping effort, regions in the North and Central Indian River Lagoon (figure 1) were listed as Class 2 Shellfish propagation and harvesting waters. Utilizing aerial photography, the signature for oyster beds was calibrated to areas of dense stands of oysters relatively clear of seaweed fouling and in waters less than one meter deep. This resulted in an approximate 2,500 acres of oyster habitat mapped throughout the Central I.R.L. (Down 1978, maps copied in Appendix A). This shellfish area was the most economically productive harvesting area of the county at the time, with about 82 oyster leases, and was described as "a major contributor of a total of 4,087,686 pounds of shellfish harvested in Brevard County waters in 1975" (Down 1978).

Several decades later, the Florida Fish and Wildlife Conservation Commission (F.W.C.C.) undertook a large-scale oyster mapping program, the results of which were reported in 2019 (Parker et al. 2019). They concluded that the majority of oysters for the Brevard County portion of the I.R.L. were located within the tributaries (Parker et al. 2019). In Brevard, much of the mapping effort focused on the Sebastian River. This area was mapped using Real-Time

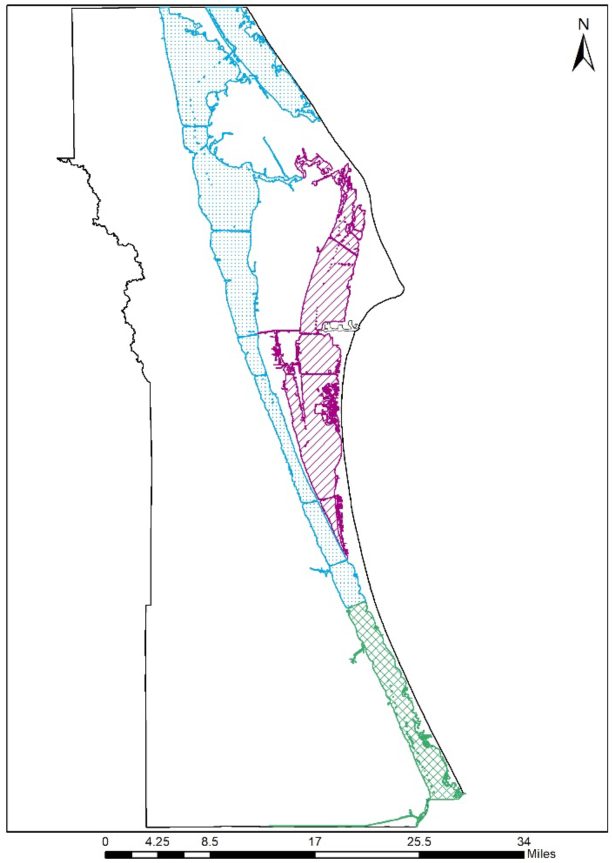


Figure 1 Map of the Brevard County portion of the Indian River Lagoon showing the Banana River Lagoon (purple slants), North I.R.L. (blue dots), and Central I.R.L. (green crosshatch) sub-lagoon boundaries.

Kinematic GPS in 2005-2006 by the Florida F.W.C.C. Fish and Wildlife Research Institute and Golder Associates. In Sebastian River, 133 reefs were mapped covering 21.7 acres comprising of reef patches ranging from < 10 m^2 to > 5,000 m^2, with one > 18,000 m^2. Most were located in subtidal, shallow water < 2 m. Mean and peak densities were < 200 and 600 oysters m^{-2}, respectively, and live proportions of oysters on reefs ranged from 0 - 1, with a mean of 0.78 (Gambordella et al. 2007). By examining shell heights on relic (dead boxed oysters having paired shells) versus live assemblages, Gambordella et al. (2007) concluded that the historic center of the oyster population had moved from up-river to the mouth. They also noted that the small size of live oysters compared to relic shell heights indicated that the population was going through a recovery from a previous collapse.

Targets for oyster restoration work were developed by the Oyster Metrics Workgroup in the Chesapeake Bay, which outlined quantifiable goals that can be translated to the management of the oyster bar projects in Brevard County. For the Chesapeake on a tributary scale, their suggested goal was to restore 8-16% of the historic habitat (Allen et al. 2011). While we know oyster populations were described throughout the Brevard County portion of the Indian River Lagoon, we do not have estimates of the acreage of oyster populations for each sub-lagoon. However, estimates of oyster bottom between 447 to 2,500 acres by Futch (1967) and Downs (1978) were predominantly located in the Central I.R.L. Therefore, in the Central I.R.L., 8% of the 1960's and 1970's acreage is 36-200 acres. This list is far from comprehensive as there is anecdotal evidence of oyster harvest in local oral histories throughout the entire Indian River Lagoon (In Progress Paul Sacks, U.C.F.).

While it is valuable to have an historic context, it is also important to note that determining the historical reference for any restoration project can also be misleading (zu Ermgassen et al. 2016). Depending on when data are available, the "historical" map may represent a shifted baseline as degradation in habitat and overfishing would have already occurred (Gambordella et al. 2007). Even the Wilcox (1895) report describing the location and harvest amounts of oysters in the I.R.L., suggested fishing pressures, saying "conditions are very favorable for the expansion of the oyster industry…, while under present conditions it is only a question of time when the natural supply will become exhausted". Due to the nature of change within an environment, restoration cannot be solely based on the historic distribution as some areas may no longer represent suitable habitat. Rather, the historic record can add context and highlight the potential for the system (zu Ermgassen et al. 2016). Further, suitable habitat for improved success may be better at alternative nearby locations, rather than specific historical sites. Therefore, in addition to estimating aerial extent, restoration efforts may also target the ecosystem services, such as total tons of nitrogen removed in order to meet maximum nitrogen load constraints (zu Ermgassen et al. 2016). Brevard County has proposed rehabilitation of oyster populations in the I.R.L. through construction of 14.5 acres of oyster bars, with the aim of providing nutrient removal benefits through filtration and denitrification. This acreage is expected to reduce total nitrogen by approximately 25,000 lb. TN yr^{-1} (S.O.I.R.L. 2021 Plan Update). These are not traditional restoration projects as the main goal is improvement of water quality, therefore we use the term "rehabilitation" when referring to oyster bar projects as they effectively serve to rehabilitate oyster populations that were once prevalent throughout the I.R.L. In this way, oyster bar projects are also not restricted to natural shorelines, allowing utilization of the predominantly hardened shorelines in Brevard County.

Oyster reefs remove nitrogen from the system through assimilation in tissues and shells, burial in sediments surrounding oyster reefs, and conversion through denitrification (zu Ermgassen 2016). Kellogg et al. (2013) compared denitrification rates associated with oyster reefs from various studies in the Chesapeake Bay and found an average rate that equates to 0.04 lb. TN m^{-2} yr^{-1}. Seasonal changes in these cooler waters led to decreased denitrification rates in the winter months. In 2017, a study conducted for Brevard County on restored intertidal oyster bars in the warmer waters of the Mosquito Lagoon measured denitrification rates of 0.1 lb. TN m^{-2} yr^{-1} and sequestration in shells and tissues of 0.43 lb. TN m^{-2} (Schmidt and Gallagher 2017).

In order to best manage oyster rehabilitation efforts for the I.R.L., this document aims to outline a five-year adaptive management strategy for Brevard County oyster bar projects. This includes metrics for determining site suitability, success criteria for individual projects, and a monitoring plan, which will feedback into management decisions. The habitat suitability section outlines control variables for oyster recruitment and growth with the planned target metrics for ranking sites. In the performance and success criteria we propose the goals and timeline for determining success of an individual oyster bar site as “minimum” and “sustaining” success targets. Finally, the monitoring section will address potential methodology and target values for assessing success and adaptive management related to the outlined project goals and site fidelity, as well as oyster productivity. Throughout this plan, literature is referenced for natural and restored, intertidal and subtidal oyster populations throughout the geographical range of *C. virginica*. The Indian River Lagoon is a relatively shallow estuary with very low tidal forcing and predominantly subtidal oyster populations in the sub-lagoons bordered by Brevard County, which guides how proposed targets and monitoring protocols can be applied to this system.

4. ***Oyster Habitat Suitability Indices***

4.1 Water Quality

Water quality is one of the most important controls in oyster habitat suitability and success. Salinity, temperature, and dissolved oxygen concentrations affect the duration larvae remain as veligers in the water column (Baker and Mann 1992), influencing recruitment as well as acting as a stressor for adult oysters (Patterson et al. 2014). As sessile organisms, oysters cannot escape environmental stressors that persist, and therefore additional considerations of habitat quality are important.

Data from St. Johns River Water Management District (S.J.R.W.M.D.) water quality monitoring stations and the O.R.C.A. Kilroy stations are available and will be used to examine current and multi-year trends in water quality parameters. Data can be analyzed for the nearest station to a proposed site or across multiple stations within entire sub-lagoons.

4.1.1 Salinity

S.J.R.W.M.D. contracted a study to develop salinity targets for the Sebastian River in order to calculate and control discharges. To increase biodiversity and utilize oysters as an indicator species, salinities of 10 to 28 ppt were recommended, with salinities < 6 ppt allowable for only 2 weeks and < 2 ppt for no longer than 1 week (Estevez and Marshall 1992). During spawning, salinity should remain above 10 ppt, with optimal growth for spat at 12.5 to 20 ppt (Estevez and Marshall 1992; Burrows et al. 2005). A habitat suitability model developed for the Caloosahatchee Estuary in Southwest Florida listed similar optimal salinity ranges for *C. virginica* of 10 to 20 ppt for adult oysters and 15 to 25 ppt for larvae, with a cited settlement peak range of 25 to 29 ppt (Barnes et al. 2007). For pilot studies conducted in Brevard County, monthly monitoring data from state/local governments with records covering 1996-2013 were used to determine sites where mean salinity ranged between 10 to 28 ppt (Anderson et al. 2019).

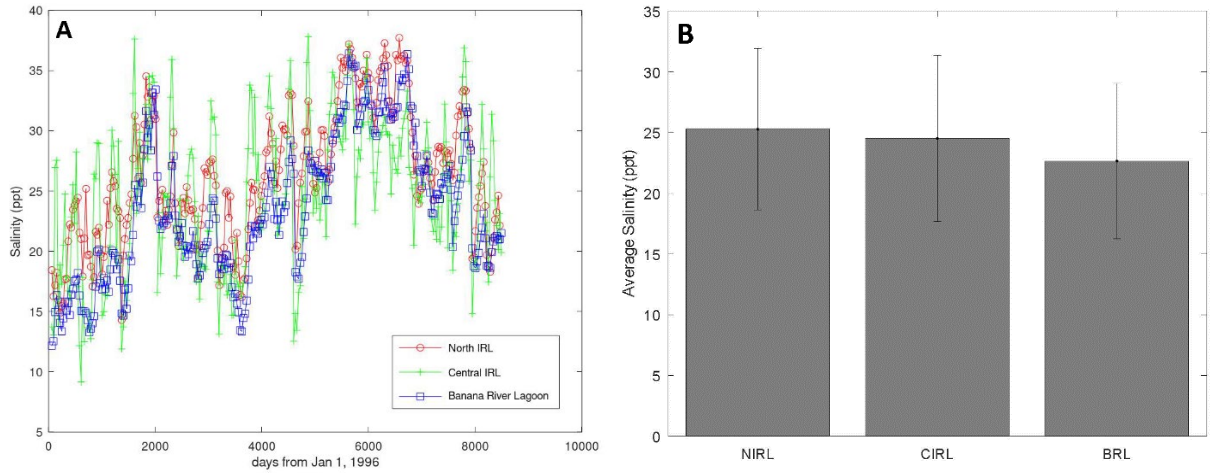


Figure 2 A. Time series of water salinity in the Indian River Lagoon by basin, North (red circles), Central (green +), and Banana River Lagoon (blue squares) averaged monthly from multiple stations within each sub-lagoon from January 1996 through October 2019. **B.** Average salinity over available time series for each sub-lagoon (error bars represent standard deviations). Raw Data Source: St. Johns River Water Management District

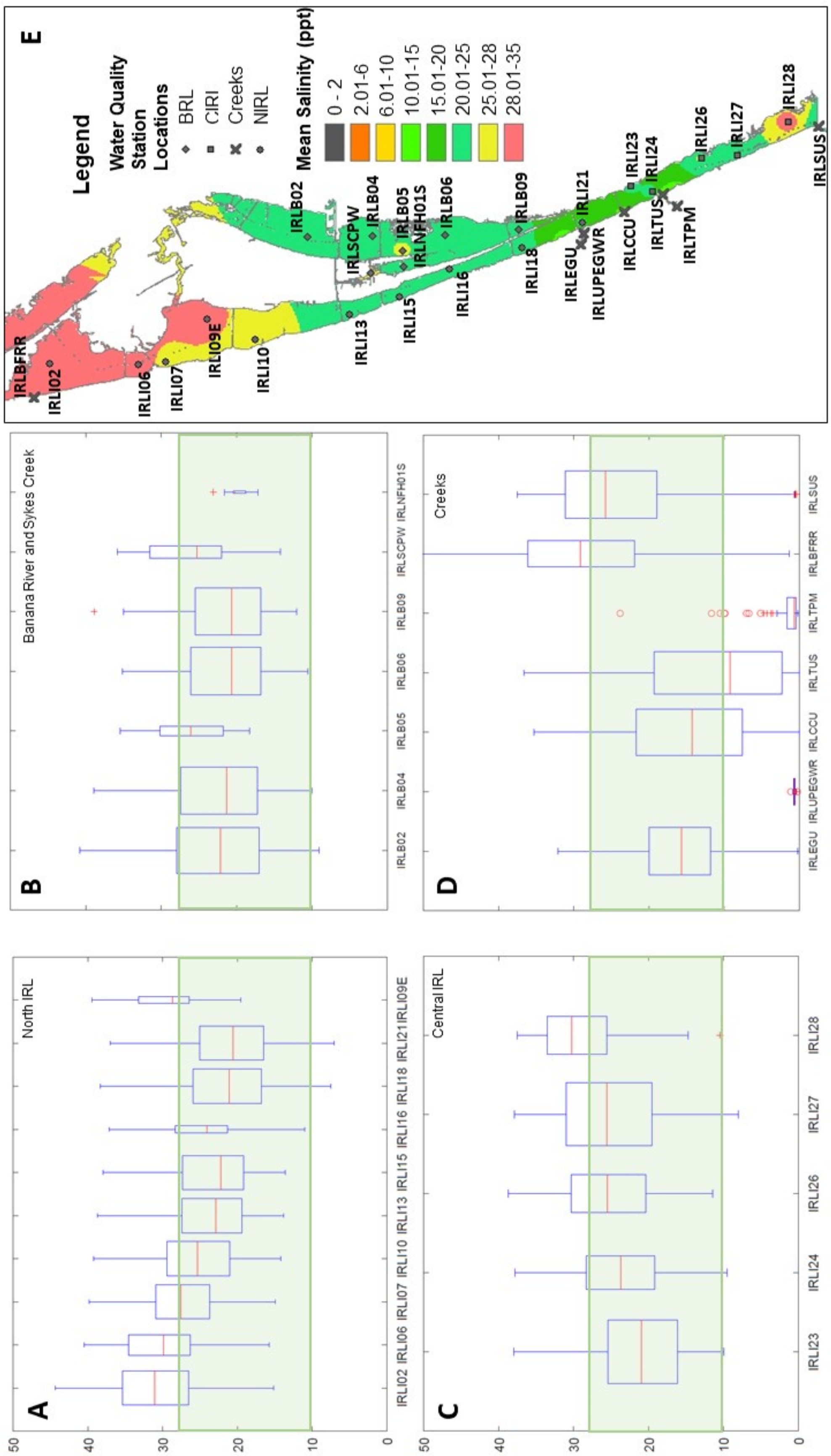
In Brevard County, water movement in the I.R.L. is predominantly wind-driven (Shen et al. 1990) and lacks a significant tidal signal (Smith 1987); therefore, oyster populations are predominantly subtidal. As subtidal oysters cannot utilize low tide to escape predation pressure, instead, relatively low salinities provide this refuge [< 15 ppt (Coen and Luckenbach 2000), < 20-25 ppt for a predation strength of 0.5 (Kimbro et al. 2017)]. However, when floods that drastically reduce salinities (< 6 ppt, Estevez and Marshall 1992) for more than 30 days occur, oyster mortality can reach 100% (summarized in Allen and Turner 1989). Anecdotal evidence from local watermen in Brevard County has suggested that oyster reefs were present along freshwater outflows. This likely is due to predation relief in the relatively depressed salinities compared to the main I.R.L. While utilizing oysters to filter stormwater outfalls could be desirable, the potential for greater fluctuations in dissolved oxygen concentrations, sedimentation, and salinity should be considered. Initial Brevard County oyster projects that are currently being monitored suggest survival and recruitment may be more limited at canal sites, where larval transport from the lagoon and circulation rates are likely limited, freshwater input maybe high, and fluctuations in salinity were greater (U.C.F. January 2020 Abridged S.O.I.R.L. Monthly Monitoring Report, Appendix B).

Monthly water column salinity data collections reported by S.J.R.W.M.D. analyzed over a 23-year period indicates that the percentage of available data with salinities < 10 ppt were only 0.07, 0.54, and 0.19 % for the North, Central, and Banana River sub-lagoons, respectively (figure 2, 3). Further, the percent of data < 10 ppt were always less than 1 % of the available data per station, while the percentage of available data with salinity > 28 ppt were 34.83, 34.98, and 22.12 % for the North, Central, and Banana River sub-lagoons, respectively. These data are highly variable by station within each sub-lagoon, suggesting that though low salinities are likely not a limiting factor for oysters in this area, high salinities may be an important factor in site selection depending on location. Therefore, the salinity map and boxplots presented in figure 3 are utilized to target appropriate salinity ranges. While the temporal resolution is not great enough to capture weekly trends, the minimal frequency of low salinities indicates most of the lagoon is above the minimum threshold for site selection. However, higher temporal resolution data can inform how discreet events influence interpretation of success and adaptive management.

Target:

- *Average salinity of 10 to 28 ppt*

Figure 3 (on following page) Salinity boxplots for each active station in the I.R.L. from the St. Johns River Water Management District (S.J.R.W.M.D.) for January 1996 through October 2019. The relevant water bodies are noted in the upper right corner of each plot: (**A**) N.I.R.L., (**B**) B.R.L., (**C**) C.I.R.L., and (**D**) Creeks. The x-axis labels refer to the station name on the map (**E**). The red line indicates the median value, upper and lower bounds of the boxes are the first and third quartiles, respectively, upper and lower whiskers are the minimum and maximum values, respectively, circles represent outliers greater than 3 times the interquartile, and crosses are outliers between 1.5 and 3 times the interquartile range. The green box on the figures indicate stations with median salinity in the target range of 10 to 28 ppt. The map to the right shows the water quality station locations in the B.R.L. (diamond), C.I.R.L. (square), Creeks (x), and N.I.R.L. (circles), and colors showing interpolated mean salinity with green, blues, and purple representing values in the target range. An additional table of the minimum, maximum, mean, and standard deviations for each station are provided in Appendix C. Raw Data Source: S.J.R.W.M.D.


A
North IRL
Salinity (ppt)
0
10
20
30
40
50
IRLI02 IRLI06 IRLI07 IRLI10 IRLI13 IRLI15 IRLI16 IRLI18 IRLI21 IRLI09E
B
Banana River and Sykes Creek
IRLB02 IRLB04 IRLB05 IRLB06 IRLB09 IRLSCPW IRLNFH01S
C
Central IRL
IRLI23 IRLI24 IRLI26 IRLI27 IRLI28
D
Creeks
IRLEGU IRLUPEGWR IRLCCU IRLTUS IRLTPM IRLBFRR IRLSUS
E
Legend
Water Quality Station Locations
BRL
CIRI
Creeks
NIRL
Mean Salinity (ppt)
0 - 2
2.01-6
6.01-10
10.01-15
15.01-20
20.01-25
25.01-28
28.01-35
IRLBFRR
IRLI02
IRLI06
IRLI07
IRLI09E
IRLI10
IRLI13
IRLI15
IRLI16
IRLI18
IRLB02
IRLSCPW
IRLB04
IRLB05
IRLNFH01S
IRLB06
IRLB09
IRLI21
IRLEGU
IRLUPEGWR
IRLCCU
IRLI23
IRLI24
IRLTUS
IRLTPM
IRLI26
IRLI27
IRLI28
IRLSUS

4.1.2 Water Temperature

Oyster growth rates, pumping rates, and spawning are highly correlated with water temperatures. Growth rates vary with temperature ranging between 6 to 32 °C, peaking around 25 °C (Galtsoff 1964). While growth can also occur at higher temperatures [upper thermal limit of 30 to 32.5 °C (Davis and Calabrese 1964)], larval growth can be negatively affected by water temperatures > 30 °C (Hidu et al. 1974). Optimal temperatures reported for the development of the Caloosahatchee Estuary habitat suitability model were between 20 to 30 °C for both larvae and adults (Barnes et al. 2007). This aligns well with the 20 to 32 °C reported temperature range favorable for oyster pumping rates necessary for oxygenation, feeding, and waste removal (Loosanoff 1958). Generally, spawning occurs around 25 °C after a rapid increase from a period of colder water temperatures and can range from 15 to 34 °C, with mass spawning more likely above 22 to 23 °C (Galstoff 1964). Mass spawning was noted in Apalachicola Bay, FL when temperatures were ≥ 26 °C (Ingle 1951). In a study in Brevard County, Anderson et al. (2019) found that survival of oysters on seeded bar projects was higher for those deployed in the spring rather than later fall, where temperatures dropped soon after deployment.

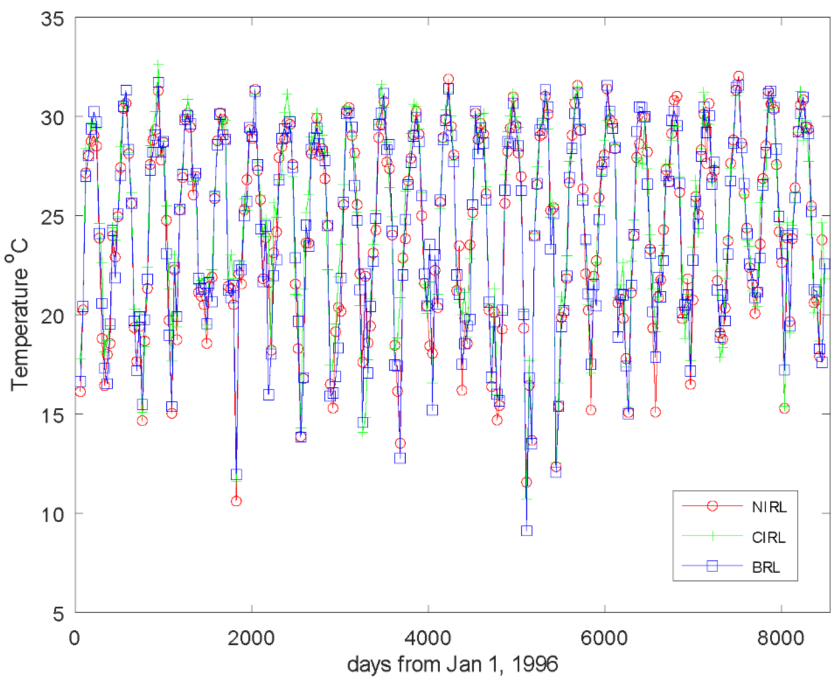


Figure 4 Time series of water column temperature in the Indian River Lagoon by basin, North (red circles), Central (green +), and Banana River Lagoon (blue squares) averaged monthly across multiple stations within each sub-lagoon for January 1996 through October 2019. An additional table of the minimum, maximum, mean, and standard deviations for each station are provided in Appendix C. Raw Data Source: St. Johns River Water Management District

Analyzing data from the S.J.R.W.M.D. sensor array, water column temperatures averaged over the data set spanning from January 1996 through October 2019 for this portion of the

Indian River Lagoon were 24.45 ± 4.87 °C (figure 4). The percentage of recorded temperature below 20 °C were 21.5, 17.0, and 20.5 % for the North I.R.L., Central I.R.L., and Banana River Lagoons, respectively. Above 30 °C, these percentages were 11.0, 12.7, and 11.4 %, respectively. The absolute minimum and maximum temperatures for this data set over the entire Brevard County portion of the I.R.L. were 7.84 and 37 °C. Linear correlation coefficients were calculated on monthly averaged time series between paired stations within each sub-lagoon. For the Banana River Lagoon, station correlation coefficients ranged from 0.95-0.99 ($n=15$, $p<0.05$), the North I.R.L. ranged from 0.92-0.99 ($n=66$, $p<0.05$), and the Central I.R.L. from 0.98-0.99 ($n=183$, $p<0.05$). As 70 to 80 % of temperatures recorded in the I.R.L. between 1996 and 2019 were within the target range, and temperatures trend tightly together between the sub-lagoons (figure 4) we do not expect significant site impacts by temperature.

Target:

- *Average annual temperatures of 20 to 30 °C*
- *Build oyster bar projects during the spring (March) through early fall (mid-October) to avoid cold shock (Anderson et al. 2019).*

4.1.3 Dissolved Oxygen Concentration

While oysters can close their shells to avoid low dissolved oxygen (D.O.) concentrations, or desiccation through air exposure, for some period of time, longer exposure to hypoxic or anoxic environments near the sediment surface can increase mortality rates and decrease reef size and structure (Lenihan and Peterson 1998). Hypoxia is defined as dissolved oxygen concentrations < 2 mg L^{-1} and anoxia as < 0.5 mg L^{-1}. Low D.O. can inhibit metabolism and natural pathways for defense against pathogens (Boyd and Burnett 1999) and reduce settlement, recruitment, growth, and survival (Baker and Mann 1992). Sediment type also influences the near-bottom D.O. concentrations. Preliminary results from work conducted at the Florida Institute of Technology suggested that muck can decrease D.O. concentrations by at least 50% compared to sand (personal communications Dr. Austin Fox and Tyler Provoncha).

During pilot studies in Brevard County, sites were chosen such that average D.O. levels exceeded 4 mg L^{-1} utilizing monthly monitoring data from state/local governments with records covering 1996-2013 (Anderson et al. 2019). Data from S.J.R.W.M.D. and O.R.C.A. Kilroy stations throughout the I.R.L. will be used to determine nearby minimum, maximum, and average D.O. concentrations during site selection. Analysis of historic data from S.J.R.W.M.D. indicates that measured dissolved oxygen concentrations were recorded at < 2 mg L^{-1} for only 3.3% of all data collected at depths between 0.1 m and 0.3 m (n =1812) during monthly water column profile sampling. Available data from S.J.R.W.M.D. continuous water quality stations indicated hourly D.O. concentrations < 2 mg L^{-1} <1% of the time; however, these data were obtained from the water column rather than near-bottom where oysters are present. These depths were chosen as representative for oyster habitat with a vertical relief target of 20 cm above the seafloor.

Target:

- *Near bottom D.O. concentrations > 4 mg L^{-1} on monthly averages over multiple years (figure 5).*
- *Avoid areas where significant sediment and/or muck deposition is expected, which could bury oysters and decrease D.O. concentrations.*

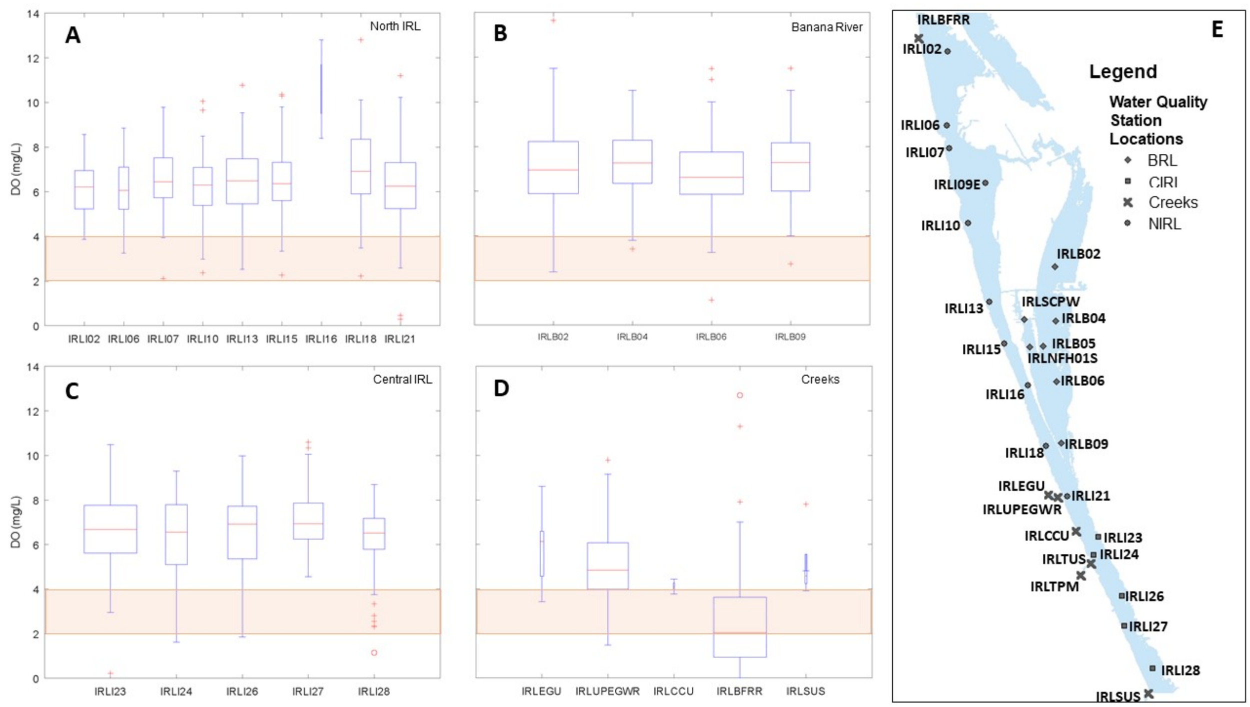


Figure 5 Boxplots of dissolved oxygen concentration from measurements taken between 0.1 and 0.3 m above the seafloor for each active station in the I.R.L. January 1996 through October 2019. The relevant water bodies are noted in the upper right corner of each plot: (**A**) N.I.R.L, (**B**) B.R.L., (**C**) C.I.R.L., and (**D**) Creeks. The x-axis labels refer to the station name on the map (**E**). The red line indicates the median value, upper and lower bounds of the boxes are the first and third quartiles, respectively, upper and lower whiskers are the minimum and maximum values, respectively, circles represent outliers greater than 3 times the interquartile, and crosses are outliers between 1.5 and 3 times the interquartile range. The orange box on the figures indicate potentially unfavorable conditions. Raw Data Source: St. Johns Water Management District.

4.2 Depth

In the Brevard County stretch of the I.R.L., oysters are predominantly subtidal due to the microtidal system, with large seasonal changes in depth that are primarily driven by shifts in the gulf-stream and wind-driven patterns (Smith 1987, 1993; Sheng et al. 1990; Zarillo and Listopad 2017). Tidal period accounts for only 5% of variance in water depth, with monthly amplitudes of a few centimeters, while the amplitude of annual variation is twice that of the semi-annual variation (Smith 1987). Utilizing data available from S.J.R.W.M.D., trends in annual water column depth were determined (figure 6). Monthly depth measurements were averaged for all available years and across all stations within each sub-lagoon to quantify seasonal patterns (figure 6). Large error bars indicate interannual and cross-station variability. Peak to peak amplitude can be defined as the difference between the maximum depth and minimum depth within a year at a single water quality station. In the Banana River, North I.R.L., and Central I.R.L. average (± standard deviation) peak to peak amplitudes across all stations and years were 0.62 ± 0.29, 0.79 ± 0.54, and 0.67 ± 0.21 m, respectively. The average displacement of seasonal minimum depth from annual average depth is approximately half the peak to peak amplitude. Average low water displacements were 0.32 ± 0.23, 0.39 ± 0.32, and 0.30 ± 0.13 m for the Banana River, North I.R.L., and Central I.R.L., respectively. This suggests that in most years, water column depth in the open lagoon can be expected to drop by approximately 0.3 m from the mean (>56% of the time). Nearshore, where oyster bar projects are present, these changes in depths will influence the exposure of projects during low water season to varying degrees controlled by the seasonal water level changes, wind-driven depth variability, and the nearshore bathymetry.

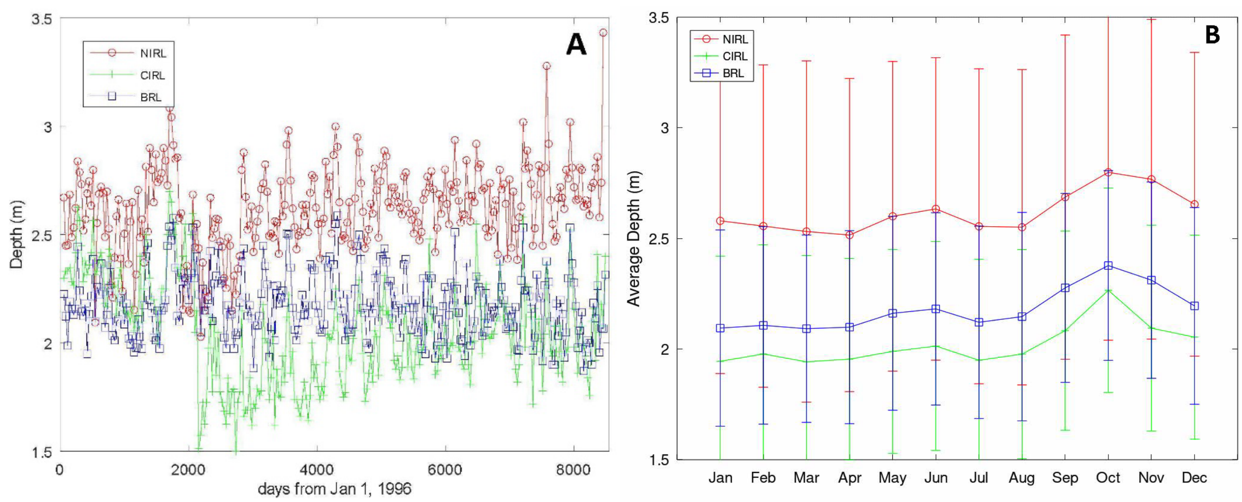


Figure 6 A. Time series of water depth in the Indian River Lagoon by basin, North (red circles), Central (green +), and Banana River Lagoon (blue squares) averaged monthly from multiple stations within each sub-lagoon for January 1996 through October 2019. **B.** Depth data averaged by month and then over all years showing average annual depth cycle, error bars represent the standard deviation in interannual monthly averages. Raw Data Source: St. Johns Water Management District.

In a survey of Sebastian River, oyster reefs were found mostly within shallow water along the shoreline. A few additional reefs were found in the center of the river and none were present in waters deeper than 2 m (Gambordella et al. 2007). Barnes et al. (2007) utilized an optimal depth range of 0.5 to 3 m for their habitat suitability model in the Caloosahatchee Estuary, Florida. Standard restoration criteria for subtidal reefs referenced by Colden et al. (2016) was a depth < 3 m (Wesson et al. 1999). The shoreline in Brevard County typically has a fairly shallow slope with 97% of the shoreline surveyed having an angle ≤ 5° (processed from data presented in Donnelly et al. 2017). When water levels drop in the spring toward the end of the dry season, oyster bars placed within 10 ft of the mean high-water line (M.H.W.L.) can experience extremely low water levels for months, influencing mortality (Anderson et al. 2019). This indicates that oyster bar projects in Brevard generally require placement further than 10 feet from shore to meet depth targets.

Target:

- *Oyster rehabilitation projects will be deployed in waters that are at least 30 cm deep during low water season.*
- *Ideally, oyster bars would be placed further offshore with greater access to higher flows and water depths of at least 0.5 m during low water season.*
- *Through continued investigations of potentially shallow sites within 10 ft of the M.H.W.L., alternative materials and designs will be tested for recruitment and survivability over a minimum of a two-year period.*

4.3 Substrate

4.3.1 Bottom Type

Oysters grow on hard bottom, such as rock, sand, firm mud, clay (Galtsoff 1964; Bahr and Lanier 1981), or semi-hard mud, but not shifting sand or soft mud (Galtsoff 1964). Standard criteria referenced in Colden et al. (2016) for oyster restoration was a “hard bottom substrate” (Wesson et al. 1999), which they applied in Virginia as predominantly sand with some oyster shell hash. In the Caloosahatchee Estuary habitat suitability model, suitable substrate for both larvae and adults comprised of oyster shell, other calcareous mollusk remains, wood material, rocks, gravel, and solid refuse. For their application of this model, the substrate availability was determined by examining existing oyster reef and mangrove roots supporting growth of oyster clusters (Barnes et al. 2007). Oyster larvae prefer to settle on live oyster shell with a high degree of hydrodynamic roughness and interstitial space (Bartol and Mann 1999; Barnes et al. 2010; Whitman and Reidenbach 2012). For restoration and rehabilitation projects, in the absence of existing suitable substrate it has been recommended that additional cultch or other appropriate material is added to the site (Burrows et al. 2005).

Target:

- *Avoid areas that are very soft and/or mucky. U.C.F. completed a shoreline survey for Brevard County which indicated the bottom type and can be used as part of our qualitative site review for the sediment type and confirmed with a site visit.*
- *Qualify sediment type as per field methods described in Reynolds et al. (2021).*
- *Move projects further from shore in areas where large fetch and sandy sediment may generate highly dynamic sediment transport processes near the shoreline.*
- *Begin with the addition of substrate (cultch) to encourage oyster settlement. This may comprise of, but is not limited to:*
    - *Bagged oyster shell*

- *Combination of cement, oyster shell, and natural biodegradable materials (i.e. C.O.R.E. modules or shell bound to biodegradable material)*
- *Galvanized after welding (GAW) steel gabions filled with oyster shells*
- *Corral design with exterior ring of bound oyster shell to contain an interior mound of lose shell*

- *Biodegradable substrates should be deployed so as to stay in place, persist in the environment for approximately 2 - 5 years to capture initial recruitment and establishment of the oyster bar, but eventually degrade as oyster populations bridge and begin forming a cohesive structure.*

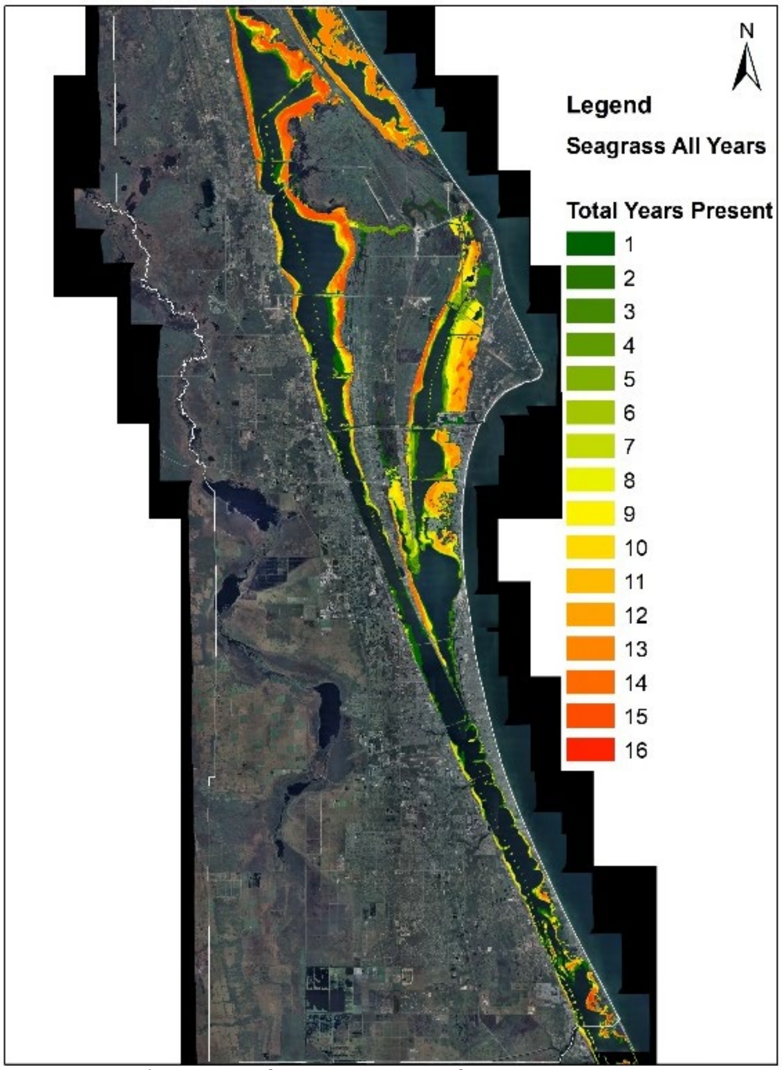


Figure 7 Colormap of persistence of seagrass coverage in Brevard County; warmer colors indicate a greater number of years of seagrass presence and cooler colors represent fewer years. Data was obtained from St. Johns River Water Management District (S.J.R.W.M.D.). Data Source: S.J.R.W.M.D. for 1943, 1986, 1989, 1992, 1994, 1996, 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015, and 2017.

4.3.2 Proximity to Submerged Aquatic Vegetation

In eutrophied systems, drift algae can increase in abundance (Raffaeli et al. 1998), which accumulates, inhibiting oyster recruitment and increasing mortalities of settled spat through feeding interference and flow reduction (Thomsen and McGlathery 2006). However, increasing oyster populations through rehabilitation efforts can benefit turbidity mitigation and water quality improvement (Newell and Koch 2004), with beneficial feedbacks to adjacent seagrass beds (Reidenbach et al. 2013). In the I.R.L., Steward et al. (2005) set seagrass light requirements and target depths after examining unions in seagrass coverage taken in 1943, 1986, 1989, 1992, 1994, 1996, and 1999, light data from 1990-1999, and bathymetry from 1996. Seagrass coverage was considered stable when the coefficient of variation was < 20 – 31 % (Steward et al. 2016).

They determined seagrass median depth targets were 0.8 to 1.8 m and maximum were 1.2 to 2.8 m. Ideal depths utilized in habitat suitability models and restoration of oyster reefs are generally between 0.5 and 3 m (Wesson et al. 1999; Barnes et al. 2007; Colden et al. 2016). The annual light requirements were 33 ± 17 % of subsurface light with a minimum of 20 ± 14 % (Buzzelli et al. 2005). Clearance of sediment through oyster filtration should benefit seagrass by increasing the amount of light that reaches the seafloor, helping to meet these seagrass targets. Further, oyster reefs can serve as wave breaks, which has been found to significantly affect seagrass growth by limiting the resuspension of sediments in modeled systems (Smith et al. 2009). Oyster filtration can generate a plume of clearer water (Smith et al. 2009), and seagrass cover has been found to increase at sites through a "shadow" effect from restored oyster reefs 5 years post-deployment as compared to nearby areas absent oyster restoration (Sharma et al. 2016).

The proposed total rehabilitation of oyster habitat by Brevard County of 14.5 acres is only 0.02% of the seagrass coverage target acreage (if placed entirely within potential seagrass habitat) for the Banana River, North, and Central I.R.L. established by Steward et al. (2005). Added to the remaining reefs mapped in Sebastian River by the Florida Fish and Wildlife Research Institute, rehabilitation plans will bring the total oyster population to less than 1.5% of the oyster bed area mapped in the 1970s.

Target:

- *Avoid covering areas where seagrasses are currently present by conducting seagrass surveys during the growing season (April through October).*
- *Limit oyster rehabilitation area to < 16 % of historical oyster coverage.*
- *Use maps of seagrass persistence (figure 7) to avoid the most important areas for seagrasses. Avoid areas covered by seagrass in at least 14 of 16 survey years (coefficient of variation < 39 %).*

4.4 Hydrodynamic Conditions

As sessile benthic organisms, oysters rely on water flow to deliver food and combat sedimentation (Lenihan 1999). The three-dimensional structure of an oyster reef presents significant drag interacting with local fluid dynamics and altering turbulence structure, wave dynamics, and suspended sediment dynamics (Whitman and Reidenbach 2012; Reidenbach et al. 2013). The reef height quantifies this structural component, which influences flow dynamics, ultimately affecting larval distribution (Southworth and Mann 1998; Hubbard and Reidenbach 2015), recruitment (Whitman and Reidenbach 2012), growth (Coen and Luckenbach 2000), and survival (Burrows et al. 2005).

4.4.1 Access to Food Source

The maximum living biomass that can be supported by an ecosystem, or the carrying capacity, is related to the abundance and access to food (Dame and Prins 1998). For bivalves the carrying capacity is determined by the water turnover time, phytoplankton production time, and oyster clearance rates (Dame and Prins 1998). Turnover times can be quite long in the I.R.L.; 50% renewal occurs on the order of 1 week in the Central I.R.L. near Sebastian Inlet, and up to 230 days in the North (Smith 1993). In a more recent study, Kim (2003) suggested that groundwater seepage may have an important role in the I.R.L. water balance, which could reduce estimated turnover times. Phytoplankton concentrations are controlled by hydraulic flushing and grazing, with abundance related to turnover, such that higher abundances occur in more restricted regions (Phlips et al. 2002). While not directly studied, shallow depths and restricted flow throughout the I.R.L. also increase the probable role of filter feeders in phytoplankton population dynamics (Phlips et al. 2002).

Target:

- *While we do not expect oysters to be food limited, we will avoid still waters and target areas that are open to water flow*.

4.4.2 Flow and Wave Dynamics

Oyster reefs present significant structure which interacts with local hydrodynamics. Reef height and overall roughness influences flow affecting recruitment, growth, and survival (Burrows et al. 2005; Whitman and Reidenbach 2012). Mortality has been observed in areas with flow < 4 cm s^{-1} near the base of subtidal reefs with significantly better survival along the reef crests where flow ranged from 7 to 20 cm s^{-1} (Lenihan 1999, Lenihan et al. 1999). In Mosquito Lagoon within the I.R.L. north of Brevard County, mean main stream flows are 5 cm s^{-1} (Walters et al. 2001). In a study by Reidenbach et al. (2013), oyster reef metabolism and suspended sediment flux across oyster reefs were monitored off the eastern shore of Virginia. Oxygen uptake on intertidal oyster reefs increased linearly with flow speeds. Concurrent measurements of sediment flux across the reef suggested that for flows between 0 and 10 cm s^{-1}, as a result of increased filtration with increasing flow, suspended sediment concentration was reduced. Maximum filtration rates were observed in the range of 10 to 15 cm s^{-1}, and above 25 cm s^{-1} bed shear stresses led to resuspension of sediments from the reef surface.

The hydrodynamic roughness of an oyster reef enhances turbulence and mixing, making more of the water column available to the oysters, which occurs when the ratio of water speed to oyster surface area is greatest (Nelson et al. 2004). This will influence food availability and the efficiency of water filtration as it relates to water clarity ecosystem services. Roughness also increases larval transport to the reef surface from the overlying water column while providing refuge in the interstitial spaces where benthic shear stresses can be reduced by up to 20 times, resulting in greater recruitment that scales with the roughness parameter (Whitman and Reidenbach 2012). Water depth is also a driving variable in oyster settlement probability and interacts with effects of surface roughness (Fuchs and Reidenbach 2013). The required patch length for > 80% of modeled larvae to settle was shorter for shallow water compared to deeper water and for rougher substrates compared to smooth (Fuchs and Reidenbach 2013).

The natural size and spacing of oyster reefs are also controlled by flow and sediment dynamics (Colden et al. 2016). In a study comparing restored reefs positioned perpendicular versus parallel to the shore, Colden et al. (2016) found increased flow over the reef crests, sediment entrainment off the reef crest, and greater area and reef heights in those positioned perpendicular to predominant currents two years post-deployment. They postulated this is likely due to downstream depletion of food and increased sediment deposition limiting growth of the reef in the downstream direction, as has been demonstrated in mussel beds (Colden et al. 2016).

Finally, wave energy can be a limiting factor for oyster reef stability. Wave forcing on the reef can break off individual oysters and lead to unstable substrates and increased sediment loads, reducing spat survival (Wall et al. 2005) and the density of live oysters (Theuerkauf et al. 2017). In a study conducted in North Carolina, oyster reefs containing ≥ 10 oyster m^{-2} were mapped relative to salinity, temperature, wave energy, and sediment grain size. They found that above approximately 500 J m^{-1} relative wave energy, oyster reefs do not occur (Theuerkauf et al. 2017), and below this threshold salinity and sediment grain size were better indicators of oyster presence [with sediment type also correlated to relative wave energy (Theuerkauf et al. 2017)].

Target:

- *We will avoid areas that have significant impediments to flow, such as deep within a cove or canal that have obvious signs of stagnation.*
- *We will target areas where the flow seems relatively high above 4 cm s^{-1} as per Lenihan et al. (1999).*
- *Fetch, wind speed, and bathymetry data have been used to develop a wave model for the Brevard County shoreline of the I.R.L. One modeling effort was undertaken in 2017 and additional modeling is currently underway at the University of Central Florida (Donnelly et al. 2017, Kibler et al. 2020). These efforts will continue to help inform our oyster bar design based on site specific requirements.*

4.4.3 Sedimentation

Oysters filter suspended sediments (Newell 1988) improving water quality; however, high suspended sediment concentrations can negatively affect their filtration (Loosanoff and Tommers 1947) with models utilizing a cessation threshold when suspended sediment loads > 100 mg L^{-1} (Circo and Noel 2005). Both natural and restored reefs can experience habitat loss through siltation and burial that limits their productivity, growth and survival (Lenihan 1999), and reef-building processes (Colden and Lipcius 2015). Reefs impacted by intense boating activity have been found to be correlated with increased sedimentation and the percent silt/clay (Wall et al. 2005). Oyster reefs can also influence local suspended sediment dynamics and sedimentation through interactions with the flow environment. Adjacent to reefs, fine sediments are trapped (Colden et al. 2016) while across the reef crest localized resuspension can occur (Reidenbach et al. 2013; Colden et al. 2016). Sites with higher suspended sediment concentrations have been shown to have correspondingly lower recruitment (Whitman and Reidenbach 2012). When sedimentation occurs on the reef it can also indirectly affect the habitat by decreasing hydrodynamic roughness, thereby reducing turbulence and mixing with the overlying water column (Reidenbach et al. 2010). This alteration of the substrate can also limit settlement and smother spat (Thomsen and McGlathery 2006; Boudreaux et al. 2009; Whitman and Reidenbach 2012). Boudreaux et al. (2009) found that oyster settlement was significantly higher when there was no sediment on shells, whether water was flowing or still, and low when sediment was present regardless of fluid flow.

Target

- *Areas where obvious sediment trapping is occurring will be avoided, such as along accreting shorelines.*
- *Oyster bar projects will be designed to target an approximate 20 cm of vertical relief to help combat sedimentation effects (Powers et al. 2009).*

4.5 Natural Recruitment

Recruitment of oyster spat is influenced by the proximity of a source population, hydrological transport, and the availability of settlement substrate. Evidence of prior recruitment may include the presence of live oysters or oyster scarring. Indications of recruitment versus substrate limitation may be investigated through recruitment tiles or other similar devices, or anecdotal evidence of an historic reef near the location. *C. virginica* larvae tend to settle subtidally (Roegner and Mann 1990, 1995), to the smooth interior of shells (Crisp 1967). Settlement has been noted to increase in the presence of adult oysters (Crisp 1967; Barnes et al. 2010), with reductions when the boring sponge *Cliona* sp. is present (Barnes et al. 2010). Boudreaux et al. (2009) conducted a study to determine the effects of flow, sediment, and barnacle presence on oyster settlement for Mosquito Lagoon, Florida. They found that settlement was greatest when barnacles were absent from shells and flow velocities were 5 cm s^{-1} (representative average mainstream velocity in Mosquito Lagoon), and lowest with still water and the presence of *B. eburneus*, a native barnacle species. In the absence of barnacles, oysters also grew significantly larger and had greater survival (Boudreaux et al. 2009).

The three-dimensional nature of oyster reefs defines their ecosystem engineering, influencing local fluid and sediment dynamics, recruitment, and habitat generation for infauna. This structure is ultimately controlled and maintained by the recruitment and growth of oysters over time, creating a feedback loop (Burrows et al. 2005). Evidence of recruitment can indicate positive site fidelity. However, lack of recruitment does not preclude a site from potential success if the habitat is otherwise suitable. Rather, it could reflect a poor recruitment season or a lack of an established nearby source population [within 1 km of broodstock (Colden et al. 2016)]. Extrapolations made by Anderson et al. (2019) suggested that for a self-sustaining oyster population, oyster bar locations would be necessary every 3 km due to the distance between observed recruitment and a natural source population in a set of pilot studies conducted in Brevard County. This process of re-establishing breeding populations throughout the lagoon will take multiple years.

Target:

- *Oyster rehabilitation will target areas where there is either evidence of prior oyster recruitment and/or a source population within 3 km.*
- *In the absence of natural recruitment, oyster bars will be seeded at approximately 100 oysters m^{-2} within the top layer of the oyster bar.*
- *Oyster bar design will be tailored to each site and the methods of seeding oyster bars will continue to evolve. For example, in the case of oyster C.O.R.E. modules or other similar cement and shell prototypes, materials may be temporarily deployed where there is high natural recruitment or within an aquaculture setting to obtain a spat-set before final placement on an oyster bar. All necessary permits and protocols will be coordinated with the proper regulatory agencies.*
- *As part of the adaptive management strategy (see timeline below), the need for reseeding oyster bars will be determined based on survival of initial populations, investigations of discrete environmental events (i.e. major storms and hurricanes, water quality fluxes, or harmful algal blooms), and evidence of poor recruitment years (lack of recruitment and survival across multiple sites).*

The targets that have been outlined for the habitat suitability indices are included in the formation and application of a decision tree for site selection (Appendix D).

5. *Oyster Bar Performance and Success Criteria*

5.1 Rehabilitation Goals

The functional goal of oyster restoration, defined by the Oyster Metrics Workgroup for Chesapeake Bay, is to have a “sufficiently large spatial scale” with the intent of “dramatically” improving population size and ecosystem function (Allen et al. 2011). To meet functional goals, specific metrics for defining and monitoring success including comparison to natural populations and pre-construction baselines should be implemented (Allen et al. 2011). It is unlikely the effect of restoration activity will be linear, rather the expectation would be for a regime shift to support increased population abundance (Allen et al. 2011), which will take significant time for the oyster reefs to become established, on the order of 3 to 6 years (Coen and Luckenbach 2000; Allen et al. 2011; Baggett et al. 2015).

Interpreting success also requires knowledge of the local natural environment. When success metrics are not met within a year-to-year basis, determining the cause as a site-specific issue or a larger discreet disturbance (such as a major storm event, harmful algal bloom, or poor recruitment year) is imperative to adaptive management procedures. For example, harmful algal blooms (H.A.B.) can greatly impact oysters both directly, through reduced feeding in the presence of certain H.A.B. organisms (Gobler et al. 2013), and indirectly through reductions in sizes of recruits (Gobler et al. 2013) and effects of lowered D.O. on larvae, settlement, and growth (Baker and Mann 1992). From the perspective of adaptive management, an H.A.B. event can plummet recruitment, resulting in losing a full year's recruits (Gobler et al. 2013). However, existing oyster populations may aid in mitigating against H.A.B. events through nitrogen sequestration and denitrification (Kellogg et al. 2014; Smyth et al. 2015).

To ensure success, adaptive management plans allow for continued monitoring and feedback to weigh performance as the system is developing. For example, even if oyster bar projects are below target densities they may be on positive trajectories and providing ecosystem services and substrate for future recruitment (Allen et al. 2011). In the I.R.L. some of these important ecosystem services may include shoreline protection, habitat provisioning, and benefits to adjacent habitats such as seagrasses and salt marshes. The timeline below is meant to help guide check-points. However, response may occur throughout the lifetime of the project, such as making repairs post-hurricane, or early modifications due to heavy sedimentation.

5.2 Timeline

5.2.1 Time 0 to 1 year:

- Before deployment, any data collection related to the suitability of the site (i.e. those associated with metrics described in Section 4) should be collected to determine the site validity (Allen et al. 2011).
- If projects include the addition of live oysters at deployment, they will be added at an approximate density of 100 oysters m^{-2} to the top layer. The baseline size for these oysters will also be recorded. Specific units will be tagged for monitoring and will be seeded at a minimum size of 40 mm and maximum of 70 mm to differentiate recruitment and capture early survival metrics during future monitoring (occurring between 1 and 6 months). Initial impacts on survival can also be accounted for, such as salinity shock (Anderson et al. 2019), extreme low water, storm events, or sedimentation.
- At the time of deployment, or within the first 6 to 12 months post-deployment, baseline data should be collected on the predetermined success metrics (Allen et al. 2011). Ideally, monitoring would occur at deployment and repeatedly for the first 12 months to capture settlement, recruitment, and growth, particularly for seeded projects to differentiate survival of seeded oysters from rapidly growing recruits. However, at minimum, monitoring at baseline and at least annually after peak recruitment season can suffice (Baggett et al. 2014). Where possible, monitoring control populations can also inform success metrics (Allen et al. 2011). In Brevard County, natural populations of oysters are predominantly located in Sebastian River. These populations may reflect some of the dynamics occurring in the southern C.I.R.L. However, in the N.I.R.L. and B.R.L., where natural reefs have been lost, success will be determined within the context

of the abiotic drivers (water quality, depth, etc.) as well as recruitment and survival across multiple sites and older projects.

5.2.2 Time 2 years post-deployment:

- Experimental data from intertidal oysters in North Carolina suggest that even three years post-construction, oyster abundance and size frequencies were still very different between natural and restored reefs, with as low at 17 % of the density and smaller maximum sizes on the restored versus natural sites, respectively (Coen and Luckenbach 2000). Research in nearby Mosquito Lagoon suggests that convergence of population densities on restored intertidal reefs may occur more quickly in some portions of the I.R.L. Estuary (Walters et al. In Progress).
- In order to allow for adaptive management, after two years the degree of success in meeting interim targets should be determined along with potential causes if targets are not met (Allen et al. 2011). At this time decisions can be made, for example seeding or re-seeding an oyster bar to mitigate against discreet events, such as a poor recruitment year or storm event (Allen et al. 2011), monitoring to determine continued suitability of the substrate and location for possible recovery, or the potential need to remove a project that is not meeting success criteria or providing ecosystem services.
- In accordance with recommendations from the Chesapeake Bay Oyster Metrics Workgroup (Allen et al. 2011), restoration targets published from work in North Carolina (Powers et al. 2009), success targets adopted for the Charlotte Harbor National Estuary Program for oyster restoration (C.H.N.E.P., alignment with success levels noted in brackets) (Boswell et al. 2012), and metrics utilized by the Florida Fish and Wildlife Research Institute in the evaluation of 27 acres of oyster reef installed in the St. Lucie Estuary and Loxahatchee River (Parker and Geiger 2012), success targets include:
    - *Sustaining Success Target:*
        - *Density*: 50 oysters and 50 g dry weight m^{-2} covering at least 30% of the rehabilitated area (Allen et al. 2011) [C.H.N.E.P. Level I]
        - *Recruitment*: Evidence of recruitment in at least 1 of 2 survey years (Powers et al. 2009) with oyster spat defined as settled individuals < 25 mm (Wang et al. 2008) and recruits those that survive to between 10 and 25 mm
        - *Size Class Distribution*: Presence of two distinct size classes (Allen et al. 2011). [C.H.N.E.P. Level II]
    - *Minimum Success Target for Adaptive Management:*
        - *Density:* Previous studies have defined live oyster reefs as those with > 10 live oysters m^{-2} (Theuerkauf et al. 2017). Minimum success included 10 (Powers et al. 2009) to 15 oysters and 15 g dry weight m^{-2}, covering at least 30% of rehabilitated area (Allen et al. 2011) [within C.H.N.E.P. Level I]

- *Size Class Distribution:* At least two oysters > 25 mm shell height per 0.25 m^2 area (Powers et al. 2009).

- If projects are initially seeded with live oysters, their survival will also be examined. Survival for the first six to twelve months will be calculated as the total number of live oysters > 40 mm divided by the initial number of seed oysters deployed, with a target of at least 50 % survival. If the project meets the Minimum Success Targets for density and recruitment, but not the Sustaining Success Targets, then reseeding the oyster bar may be appropriate (Allen et al. 2011). Once new recruits reach the size of the seeded oysters, survival of the seed population can no longer be differentiated; however, the total population can continue to be evaluated based on density and size class targets (Baggett et al. 2014).

5.2.3 Time 3-5 years post-deployment

- The mid-term assessment marks a point at which the oyster bars have had sufficient time to establish (Baggett et al. 2015) and the overall success of the project can be determined (Allen et al. 2014).
- Targets for success include the Minimum and Sustaining Success thresholds of 15 or 50 oysters and 15 or 50 g dry weight m^{-2} described above. Additionally, there should be the presence of two distinct year size classes (Allen et al. 2011).
- By this period, it is also likely that oysters will have formed bridges to generate a more typical reef structure. Therefore, there should be neutral or positive change in the reef spatial extent and reef height as compared to the baseline (Allen et al. 2011). Bridging generally happens between oysters on a reef and, in a rehabilitation project, may be seen between contained units of shell cultch. Emergence of oysters through the mesh when contained should also be considered when assessing reef heights.
- Complete failure of a rehabilitation project can be defined by a lack of recruitment over multiple cycles, high mortality of seed stock with up to two replenishments, and degradation and burial before the population can establish. Even with the failure of oyster bars for rehabilitation goals, important habitat provisioning and resources may continue to be available to adjacent habitats. The C.H.N.E.P. has adopted success targets related to biodiversity defined as the presence of 10 decapod and fish species [Level I], and for adjacent habitat protection equal to pre-restoration baseline for seagrasses, salt marshes, sediment stabilization, and shoreline stabilization [Level I].

6. ***Monitoring for Performance and Adaptive Management***

Adaptive management decisions require a sufficient timeline and appropriate monitoring plan. Literature suggests data be gathered in a B.A.C.I. (Before-After-Control-Impact) design where a natural population is monitored as a control along with the restored site (the impact) before and after construction (Baggett et al. 2014; Baggett et al. 2015). Gathering baseline data pre-construction and monitoring variables over multiple years including, when possible, immediately adjacent to the oyster reef sites allow for the determination of the impact and success of the project. Reference sites should be as pristine as possible, with similar physical conditions, and be monitored for settlement and growth (Coen and Luckenbach 2000; Burrows et al. 2005). To monitor restoration, Baggett et al. (2014) suggests including metrics on reef areal dimensions, height, oyster density, size distribution, and water quality data collected via random sampling and presented with means and standard error. Researchers from the University of Central Florida currently monitoring oyster rehabilitation projects for Brevard County ensure randomization and sample sizes adequate for statistical analysis. Their methodology allows for monitoring across the project footprint, minimizing error due to variable recruitment and habitat within a site (Anderson et al. 2019), and minimizing disruption to oyster bar establishment by only surveying individual monitoring units once within the first 2 years of deployment.

Standardized monitoring and success criteria include three universal environmental variables: (1) water temperature, (2) salinity, and (3) dissolved oxygen and four universal metrics: (1) reef areal dimensions, (2) reef height, (3) oyster density, and (4) oyster size-frequency distribution (Baggett et al. 2015). As part of the monitoring for Brevard County oyster bar projects, data on water temperature, salinity, oyster density, and size-frequency distribution are being collected. At the current ages of our oyster bars and the nature of utilizing bagged oysters, areal dimensions and reef height are not yet applicable metrics. As oyster bars continue to mature and as oysters grow through the bag mesh, it is expected that changes in reef height would become measurable. Data currently collected on bridging of oysters within and between bags can be likened to an early metric of the growth of the areal dimension within the footprint of the project.

The recommended threshold for success should be a pre-determined oyster density target or ecosystem service with a positive shell budget (Allen et al. 2011). The Save Our Indian River Lagoon (S.O.I.R.L.) program has set project goals related to meeting nitrogen loading targets. To that end, Brevard County, in collaboration with the Desert Research Institute and the University of Central Florida, completed a denitrification study on restored oyster bars in Mosquito Lagoon, and are conducting additional denitrification studies in the I.R.L. on S.O.I.R.L. funded oyster bars with faculty at the University of Florida/I.F.A.S. Soil and Water Sciences Department. An additional ecosystem service provided by oyster bars is shoreline projection. This can be quantified via shoreline transects (see proposed methods below) and vegetation monitoring (Baggett et al. 2015) at a subset of oyster bar sites that are paired with shoreline planting projects, which are currently part of Brevard County's planted living shoreline monitoring conducted by the University of Central Florida. However, many of the oyster bar projects in Brevard County occur along hardened shorelines with either rip-rap or seawalls.

In this section we will outline the proposed methodology for key success metrics, for which threshold targets were described in Sections 4 and 5. Not all of the following procedures may be appropriate for every project.

6.1 Water Quality: Salinity, Temperature, Dissolved Oxygen

Research studies have suggested that water quality variations do not necessarily greatly impact reef growth, but deviations from expected growth patterns may derive from fluctuations in salinity (Ridge et al. 2017). The high degree of seasonal freshwater input in the I.R.L. should be considered when weighing salinity targets addressing oyster bar success. In years where there is above average rainfall or direct hurricane impacts, mortality may be tied to more extreme salinity fluctuations and therefore a project should not be deemed a failure. This is particularly true if recruitment coincides with wetter than average conditions.

Instrumentation and Procedure: When possible, water quality parameters should be taken near the seafloor (Baggett et al. 2014). Measure temperature via a thermometer with an accuracy of ± 1 °C (Baggett et al. 2014). If sensors are available to be deployed and left in place, trends in the minimum and maximum temperatures can also be evaluated (Burrows et al. 2005). Salinity sensors can also be deployed with a long-term sensor or via discrete sampling with a refractometer to check samples from the surface and near-bottom (Burrows et al. 2005) at the same frequency as temperature, with an accuracy of ± 1 ppt (Baggett et al. 2014). Dissolved oxygen should also be measured close to the sediment surface, at depths similar to those occupied by oysters (Patterson et al. 2014) on the same frequency as temperature and salinity with an accuracy of 0.1 mg L^{-1}. If possible, continuous measurements of D.O. would be available to capture diurnal lows, especially during peak temperatures (Baggett et al. 2014).

Frequency: Sampling should be conducted year-round as often as possible with additional sampling after storms. Oyster bar rehabilitation projects that are monitored by a third-party expert are currently visited at a high return frequency. During monitoring events, surface salinity is measured with a refractometer and surface temperature with a thermometer. Brevard County will also utilize salinity, temperature, and dissolved oxygen data available through multiple years of monthly sampling and continuous sampling from available water column sensor arrays within the I.R.L. Thirteen continuous water quality stations are currently available and maintained – 5 by the S.J.R.W.M.D. and 8 by O.R.C.A. (4 Kilroy arrays funded by the Legislature and 4 funded by Brevard County).

6.2 Shoreline Protection and Sedimentation

Shoreline protection by oyster reefs can be quantified by shoreline gain or decreasing shoreline loss that is statistically different than that monitored at nearby reference sites (Baggett et al. 2014). Methodology that could be utilized to quantify shoreline change is outlined below, though is not currently part of the Brevard County oyster bar monitoring plan.

Instrumentation and Procedure: Utilizing field survey equipment, elevations along permanent transects spanning from 10 m inland over the oyster reefs to the seaward side of the deployment would be recorded (Baggett et al. 2014). A spatial resolution of 1 m is recommended with additional data points on the high and low side of any present scarps (personal conversation with Dr. Randall Parkinson). A reference transect is also necessary for comparison of the shoreline change, in a location where wave and current conditions are similar (Baggett et al. 2014). Additionally, sediment traps can be deployed at locations along the reef and reference sites to quantify the degree of sediment deposition.

Frequency: Recommended monitoring plans suggest that elevation data transects be collected pre-deployment, within three months post-deployment, on an annual basis thereafter, and additionally after a major storm event (i.e. hurricane) (Baggett et al. 2014).

While shoreline change benefits can be provided by oyster bars, the driving factor for the S.O.I.R.L. funding is through nutrient removal potential. Limited shoreline surveys can be considered when oyster bar rehabilitation occurs in conjunction with vegetated living shoreline projects.

6.3 Nutrient Removal

In 2017, the final report on sequestration and the denitrification potential of restored oyster beds in Mosquito Lagoon was submitted to the County and has been utilized to inform the total nitrogen removal capacity of oyster bar projects throughout the I.R.L. (Schmidt and Gallagher 2017). Brevard County is currently conducting additional testing of some existing oyster bar projects with researchers from the University of Florida I.F.A.S. Soil and Water Sciences Department.

6.4 Population Metrics: Density, Recruitment, and Age Class Distribution

Density and Biomass Procedure: To obtain density, oysters can be counted within quadrats placed on oyster reefs (Burrows et al. 2005). Average and standard error should be calculated, and population size can be estimated as the product of the mean density, including zeros, and the reef area (Allen et al. 2011; Baggett et al. 2014). If oysters are contained, a fixed amount of material can be removed and reviewed (Baggett et al. 2014). While all oysters are counted, oyster recruits should be included in density figures once they have survived to the end of a growing season, generally when they are > 10 mm for *C. virginica* (Baggett et al. 2014). However, to best understand the population dynamics and spat recruitment, all size classes are included in monitoring reports. On Brevard County oyster bar projects, the University of Central Florida opens and empties a set number of bags, calculated to meet statistical requirements based on the linear footage of the project site. Live oysters are counted and at least the first 50 are measured for the size class analysis. Each bag represents approximately 0.25 m^2, and therefore, the mean values represent the density and can be scaled up to the population size.

Based on the project type, stratifying the sampling may also be necessary. For the current design employed in Brevard County, this is not necessary because the live oysters are predominantly in the "crest" proxy (top layer of the bags). As alternative materials and oyster bar module types are tested, sampling methodologies will be reviewed and adapted to meet design specifications.

Large datasets of oyster biomass and shell lengths have been combined to generate calibration curves between shell length and biomass (Cornwell et al. 2016). Data were collected for the Chesapeake Bay region from aquaculture and natural populations. For their B.M.P.

applications, they utilized the 50th quantile curve as it is likely to conservatively estimate biomass since the seeded oysters are grown in the water column, which tends to lead to a higher biomass per unit shell length (Cornwell et al. 2016). Similar relationships have been established for oysters in other locales such as Tampa Bay, Loxahatchee, and the Mosquito Lagoon (summarized in zu Ermgassen et al. 2016). These relationships are similar, with up to a 51 % difference for an oyster of 150 mm, which is on the far upper bound of oyster growth (figure 8). To estimate biomass in Brevard County oyster bar projects, we propose utilizing the curve published for Mosquito lagoon, recognizing additional calibration to the I.R.L. system may be appropriate. Oysters in the Mosquito lagoon are intertidal, versus the subtidal oyster bar projects, however, this allows for a conservative estimate of biomass compared to the 50 % quantile curve from Chesapeake Bay, and is likely more representative of local oyster populations. The goals for meeting density and biomass success are outlined in Section 5.2.

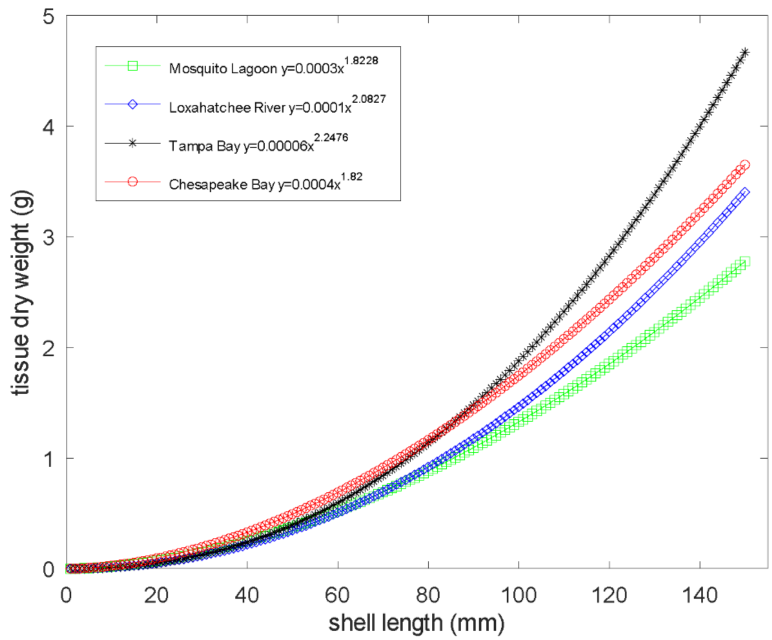


Figure 8 Modeled biomass conversion curves from oyster shell length. Equations for each line were obtained from Cornwell et al. (2016) and zu Ermgassen et al. (2016) and are listed in the figure legend. The red circles represent the 50% quantile curve from wild diploid oysters in the Chesapeake Bay region, green squares, blue diamonds, and black asterisks represent the relationship for oysters in Mosquito Lagoon, Loxahatchee River, and Tampa Bay, respectively.

Recruitment Procedure: Newly settled oysters can first be counted as recruits once they reach > 10 mm (Baggett et al. 2014). Therefore, recruitment can be determined through analysis of oysters in size classes between 10 and 25 mm (the recruitment size defined by Wang et al. 2008). If recruitment is lacking or there is high settlement but low recruitment due to a known cause, adjustments can be made, and addition of seed stock may be necessary (Burrows et al. 2005). Recommended targets include recruitment over more than one season and recruitment which balances mortality rates (self-sustaining), or rapidly covered available substrate to provide additional surfaces for recruitment over time (Burrows et al. 2005).

Age Class Distribution Procedure: Oyster sizes are measured with rulers or calipers during field surveys for at least 50 oysters per sample and 250 per reef to the nearest 1 mm (Baggett et al. 2014). Size classes are defined as: < 25 mm for spat, > 40 mm as survivors of gardened oysters, and > 76 mm for adults to meet the success metric suggested in Allen et al. (2011) (50 g dry weight estimate for a 76 mm oyster). This aligns with the current methodology utilized by the University of Central Florida to monitor Brevard County oyster projects. The goal for success is to have multiple size classes present on the oyster bar (Burrows et al. 2005; Allen et al. 2011).

Frequency: At a minimum, density and age class distribution should be sampled annually (Baggett et al. 2014). Density sampling should occur at the end of the growing season when settled oysters are > 10 mm. The sampling dates should also remain consistent throughout the years and multiple sites (Baggett et al. 2014). Natural variability in the system will influence recruitment (Baggett et al. 2014); therefore, monitoring for population metrics should occur at 1, 3, and 6 years post deployment (Burrows et al. 2005; Allen et al. 2011; Baggett et al. 2014). Currently, as a start-up measure, oyster bar projects in Brevard County will be monitored at least once within the first 6 months, and annually thereafter for the first three years, or until adaptive management targets are met.

6.5 Reef Areal Dimension

Instrumentation and Procedure: Monitoring the areal dimensions helps to frame the overall reef performance (Baggett et al. 2014) with a goal of neutral or positive change (Allen et al. 2011). Surveying can include utilizing a surveyor's wheel around the outer edge of the reef, G.P.S., laser rangefinder, or transect tape to gather the perimeter, maximum length, and width to the nearest 0.5 m (Baggett et al. 2014; Colden et al. 2016). The continuous line where the percent coverage of live oyster to substrate is greater than 25% defines the edge of the reef (Baggett et al. 2014).

Frequency: Measurements of the reef dimensions should be gathered pre-construction and within 3 months, 1 year, 3 year, and 6 years post-construction (Allen et al. 2011; Baggett et al. 2014). Additionally, the dimensions should be checked following storm events that may impact the structure (Baggett et al. 2014). For the current oyster bar deployment configuration, the footprint does not change until oysters bridge between the bags; therefore, the aerial dimension effectively is not changing within the first few years. Also, as oyster bar projects are not restoring existing dead reefs, there is no pre-construction dimension.

6.6 Reef Height

Instrumentation and Procedure: The literature suggests taking cross sectional profiles of reef height at 1 m resolution along the long axis of an oyster reef (Colden et al. 2016). This can be done in addition to shoreline survey transects so that reef height data along both axes of the oyster reef are collected. By coupling with the shoreline survey and utilizing survey equipment, the height of the crest and rugosity of the vertical relief can both be quantified. Understanding how the reef height evolves is important for adaptive management, with a goal of neutral or positive change in reef height. The reef crest height should be 20 cm above the seafloor (Powers et al. 2009), which is currently incorporated into oyster bar designs in Brevard County. However, reef height performance should not be deemed as “poor” if oyster density success metrics are being met (Baggett et al. 2014). Further, the design of the oyster bars often includes a base layer to provide hard substrate and a top layer where live oysters are expected through seeding and recruitment. As sediment accretion occurs on the base layer, the footprint and relative height of the oyster bar may decrease though oyster populations remain stable.

Frequency: The sampling regime should follow the same schedule as that set for the reef areal dimensions (Allen et al. 2011).

6.7 Shell Budget

Procedure: Shell budgets should reflect net accretion over shell loss (Allen et al. 2011; Baggett et al. 2014). To fully assess the shell budget, information on shell volume, recruitment, mortality, and shell loss are included (Allen et al. 2011; Baggett et al. 2014). In order to obtain the shell volume, oysters must be sacrificed to compare the volume of displacement by live (with meat removed) and dead shell (Baggett et al. 2014). Allen et al. (2011) suggest that short of determining a full shell budget, a subjective estimate of the degree of anoxic (black) versus oxic shells can be determined to reflect the bioavailable shells. With the proposed monitoring of recruitment, mortality, and potentially sedimentation, the important components reflecting the shell budget are included in this plan. Further, as oyster bar rehabilitation includes the addition of cultch, measurements of blank shell will be disproportionately high, negatively biasing the shell budget.

Though there is no comprehensive metric for mortality, counting the “boxed” oyster shells, where both shells are still connected at the hinge, can serve as a proxy. Once a box is counted, shells are broken so as to not be included in future monitoring. Further, when initial seeding occurs, individuals in pre-selected monitoring units are between 40 and 70 mm. These oysters are monitored upon deployment, so the size and number of seeded oysters is known. Post-deployment counts can thereby clearly determine recruitment and survival of seeded oysters by size class analysis (Baggett et al. 2014) for at least the first six months to 1 year following deployment. With the survival metric, mortality can also be extrapolated until new recruits grow to the size of the seeded oysters. The proportion of live oysters can also be calculated with this data as the percent of live and boxed oysters (Gambordella et al. 2007). With this method, monitoring of seed stock is only reasonable within the first season, as new recruits will catch up to the seed stock (Baggett et al. 2014).

Frequency: If applicable, analysis of a shell budget would be at 1, 3, and 6 years post-deployment to help inform the persistence of a restored oyster reef (Allen et al. 2011). Monitoring seed stock and assessing mortality should occur for 1 - 2 years at the end of each growing season (Baggett et al. 2014).

7. ***Literature Cited***

Allen, R.L. and R.E. Turner. 1989. Environmental influences on the oyster industry along the west coast of Florida. Journal of Shellfish Research 8(1): 95-104.

Allen, S., A.C. Carpenter, M. Luckenbach, K. Paynter, A. Sowers, E. Weissberger, J. Wesson, and S. Westby. 2011. Restoration goals, quantitative metrics and assessment protocols for evaluating success on restored oyster reef sanctuaries. Report of the Oyster Metrics Workgroup.

Anderson, L., P. Sacks, M. Donnelly, V. Barker, S. Anderson, and L. Walters. 2019. Oyster reef enhancement utilizing gardened oysters in a subtropical estuary. Restoration Ecology. doi: 10.1111/rec.12927.

Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock. 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA, 96pp.

Baggett, L.P., S.P. Powers, R.D. Brumbaugh, L.D. Coen, B.M. DeAngelis, J.K. Greene, B.T. Hancock, B.L. Allen, D.L. Breitburg, D. Bushek, J. H. Grabowski, R.E. Grizzle, E.D. Grosholz, M.K. La Peyre, M.W. Luckenbach, K.A. McGraw, M.F. Piehler, S.R. Westby, and P.S.E. zu Ermgassen. 2015. Guidelines for evaluating performance of oyster habitat restoration. Restoration Ecology. doi: 10.1111/rec.12262.

Bahr, L.N. and W.P. Lanier. 1981. The ecology of intertidal oyster reefs of the south Atlantic coast: A community profile. U.S. Fish and Wildlife FWS/OBS/81.15. Washington, DC. 105pp.

Baker, S.M. and R. Mann. 1992. Effects of hypoxia and anoxia on larval settlement, juvenile growth, and juvenile survival of the oyster *Crassostrea virginica*. Biological Bulletin 182: 265-269.

Barnes, T.K., A.K. Volety, K. Chartier, F.J. Mazzotti, and L. Pearlstine. 2007. A Habitat suitability index model for the eastern oyster (*Crassostrea virginica*), a tool for restoration of the Caloosahatchee Estuary, Florida. Journal of Shellfish Research 26(4): 949-959.

Barnes, B.B., M.L. Luckenbach, and P.R. Kingsley-Smith. 2010. Oyster reef community interactions: The effect of resident fauna on oyster (*Crassostrea* spp.) larval recruitment. Journal of Experimental Marine Biology and Ecology 391: 169-177.

Bartol, I.K. and R. Mann. 1999. Chapter 10: Small-scale patterns of recruitment on a constructed intertidal reef: The role of spatial refugia. M.W. Luckenbach, R. Mann, and J.A. Wesson (Eds.) Oyster Reef Habitat Restoration: A Synopsis and Synthesis of approaches; Proceedings from the Symposium, Williamsburg, Virginia, April 1995. 373pp.

Beck, M.W., R.D. Brumbaugh, L. Airoldi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G.J. Edgar, B. Hancock, M.C. Kay, H.S. Lenihan, M.W. Luckenbach, C.L. Toropova, G. Zhang, and X.

Guo. 2011. Oyster Reefs at risk and recommendations for conservation, restoration, and management. BioScience 61(2): 107-116.

Boswell, J.G., J.A. Ott, and A. Birch. 2012. Charlotte Harbor National Estuary Program Oyster Habitat Restoration Plan. Charlotte Harbor National Estuary Program Technical Report.

Boudreaux, M.L., L.J. Walters, and D. Rittschof. 2009. Interactions between native barnacles, non-native barnacles, and the eastern oyster *Crassostrea virginica*. Bulletin of Marine Science 84(1): 43-57.

Boyd, J.N. and L.E. Burnett. 1999. Reactive oxygen intermediate production by oyster hemocytes exposed to hypoxia. The Journal of Experimental Biology 202: 3135-3143.

Brice, J.J. 1897. Report on the Fisheries of Indian River, Florida. Senate 54th Congress, 2nd Session Document No. 46.

Burrows, F. J.M. Harding, R. Mann, R. Dame, and L. Coen. 2005. Chapter 4: Restoration monitoring of oyster reefs. In G.W. Thayer, T.A. McTigue, R.J. Salz, D.H. Merkey, F.M. Burrows, and P.F. Gayaldo (Eds.) Science-Based Restoration Monitoring of Coastal Habitats Volume II: Tools for Monitoring Coastal Habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA National Centers for Coastal Ocean Science, Silver Springs, MD. 628 pp. plus appendices.

Buzzelli, C., P. Gorman, P.H. Doering, Z. Chen, and Y. Wan. 2015. The application of oyster and seagrass models to evaluate alternative inflow scenarios related to Everglades restoration. Ecological Modelling 297: 154-170.

Cerco, C.F. and M.R. Noel. 2005. Assessing a ten-fold increase in the Chesapeake Bay native oyster population. Report to the EPA Chesapeake Bay Program, July 2005.

Chambers, L.G., S.A. Gaspar, C.J. Pilato, H.E. Steinmuller, K.J. McCarthy, P.E. Sacks, L.J. Walters. 2018. How well do restored intertidal oyster reefs support key biogeochemical properties in a coastal lagoon. Estuaries and Coasts 41:784-799.

Coen, L.D. and M.W. Luckenbach. 2000. Developing success criteria and goals for evaluating oyster reef restoration: Ecological function or resource exploitation? Ecological Engineering 15: 323-343.

Colden, A.M. and R.N. Lipcius. 2015. Lethal and sublethal effects of sediment burial on the eastern oyster *Crassostrea virginica*. Marine Ecology Progress Series. 527: 105-117.

Colden, A. M., K. A. Fall, G.M. Cartwright, and C.T. Friedrichs. 2016. Sediment suspension and deposition across restored oyster reefs of varying orientation to flow: Implications for restoration. Estuaries and Coasts 39: 1435-1448.

Cornwell, J., J. Rose, L. Kellogg, M. Luckenbach, S. Bricker, K. Paynter, C. Moore, M. Parker, L. Sanford, B. Wolinski, A. Lacatell, L. Fegley, and K. Hudson. 2016. Panel recommendations on the oyster BMP nutrient and suspended sediment reduction effectiveness determination decision framework and nitrogen and phosphorus assimilation in oyster tissue reduction effectiveness for oyster aquaculture practices. Oyster BMP Expert Panel First Incremental Report.

Crisp, D.J. 1967. Chemical factors inducing settlement in *Crassostrea virginica* (Gmelin). Ecology 36(2): 329-335.

Dame, R.F. and T.C. Prins. 1998. Bivalve carrying capacity in coastal ecosystems. *Aquatic Ecology* 31: 409-421.

Davis, H.C. and A. Calabrese. 1964. Combined effects of temperature and salinity on development of eggs and growth of larvae of *M. mercenaria* and *C. virginica*. Fisheries Bulletin 63(3): 643-655.

Donnelly, M., K. Kibler, and L. Walters. 2017. Developing a shoreline habitat restoration and management plan for Brevard County – Phase I. Final Report to Brevard County Department of Natural Resources Management.

Down, C. 1978. Vegetation and other parameters in the Brevard County bar-built estuaries. Project Report 06-73 Brevard County Health Department Environmental Engineering.

Estevez, E.D. and M.J. Marshall. 1992. Sebastian River salinity regime Report of a Study. St. John River Water Management District Special Publication SJ94-SP1. 319pp.

Florida Fish and Wildlife Conservation Commission. 2012. Florida's Wildlife Legacy Initiative: Florida's State Wildlife Action Plan. Tallahassee, Florida, U.S.A.

Fuchs, H.L. and M.A. Reidenbach. 2013. Biophysical constraints on optimal patch lengths for settlement of a reef-building bivalve. PLoS ONE 8(8): e71506. doi: 10.1371/journal.pone.0071506.

Futch, C.R. 1967. A survey of the oyster resources of Brevard County, Florida. Florida Board of Conservation, Special Scientific Report No. 18, St. Petersburg. 6pp.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* Gmelin. United States Fish and Wildlife Service Fishery Bulletin 64: 1-480.

Gambordella, M. L. McEachron, C. Beals, and W.S. Arnold. 2007. Report: Establishing baselines for monitoring the response of oysters in southeast Florida to changes in freshwater input.

Gobler, C.J., F. Koch, Y. Kang, D.L. Berry, Y.Z. Tang, M. Lasi, L. Walters, L. Hall, and J.D. Miller. 2013. Expansion of harmful brown tides caused by the pelagophyte, *Aureoumbra lagunensis* DeYoe et Stockwell, to the US east coast. Harmful Algae. doi: 10.1016/j.hal.2013.04.004.

Grizzle, R.E., J.K. Greene, and L.D. Coen. 2008. Seston removal by natural constructed intertidal eastern oyster (*Crassostrea virginica*) reefs: A comparison with previous laboratory studies, and the value of in situ methods. Estuaries and Coasts 31: 1208-1220.

Hernandez, A.B., R.D. Brumbaugh, P. Frederick, F. Grizzle, M.W. Luckenbach, C.H. Peterson, and C. Angelini. 2018. Restoring the eastern oyster: How much progress has been made in 53 years? *Frontiers in Ecology and the Environment: Reviews* 16(8): 463-471. doi: 10.1002/fee.1935.

Hidu, H., W.H. Roosenburg, K.G. Drobeck, A.J. McErlean, and J.A. Mihursky. 1974. Thermal tolerance of oyster larvae, *Crassostrea virginica* Gmelin, as related to power plant operation. Proceedings of the National Shellfisheries Association 64: 102-110.

Hubbard, A.B. and M.A. Reidenbach. 2015. The effects of larval swimming behavior on the dispersal and settlement of the eastern oyster *Crassostrea virginica*. Marine Ecology Progress Series 535: 161-176.

Indian River Lagoon National Estuary Program. 2019. Looking Ahead to 2030: A 10-Year Comprehensive Conservation and Management Plan for the Indian River Lagoon, Florida.

Ingle, R.M. 1951. Spawning and setting of oysters in relation to seasonal environmental changes. Bulletin of Marine Science 1(2): 111-135.

Kellogg, M.L., M.W. Luckenbach, B.L. Brown, R.H Carmichael, J.C. Cornwell, M.R. Piehler, and M.S. Owens. 2013. Quantifying nitrogen removal by oysters workshop report. Submitted to: NOAA Chesapeake Bay Office.

Kellogg, M.L., J.C. Cornwell, M.S. Owens, and K.T. Paynter. 2013. Denitrification and nutrient assimilation on a restored oyster reef. Marine Ecology Progress Series 480:1-19.

Kellogg, M.L., A.R. Smyth, M.W. Luckenbach, R.H. Carmichael, B.L. Brown, J.C. Cornwell, M.F. Piehler, M.S. Owens, D.J. Dalrymple, and C.B. Higgins. 2014. Use of oysters to mitigate eutrophication in coastal waters. Estuarine, Coastal and Shelf Science 151: 156-168.

Kibler, K.M, M. Donnelly, D. Cannon, J. Phagan, L. Walters, G. McClenachan, and A. Roddenberry. 2020. Developing a shoreline restoration suitability model for North Indian River and Mosquito Lagoon, Phase II. Indian River Lagoon National Estuary Program Report IRL2018-017.

Kim, Y.T. 2003. Water balance and flushing time in the restricted Indian River Lagoon (IRL), Florida, USA. Ocean and Polar Research 25(1): 75-87.

Kimbro, D.L., J.W. White, H. Tillotson, N. Cox, M. Christopher, O. Stokes-Cawley, S. Yuan, T.J. Pusack, and C.D. Stallings. 2017. Local and regional stressors interact to drive a salinization-induced outbreak of predators on oyster reefs. Ecosphere 8(11): e01992.10.1002/ecs2.1992.

La Peyre, M.K., A.T. Humphries, S.M. Casas, and J.F. La Peyre. 2014. Temporal variation in development of ecosystem services from oyster reef restoration. Ecological Engineering 63:34-44.

Lapointe, B.E., L.W. Herren, D.D. Debortoli, and M.A. Vogel. 2015. Evidence of sewage-driven eutrophication and harmful algal blooms in Florida's Indian River Lagoon. Harmful Algae 43: 82-102.

Lenihan, H.S. and C.H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8(1): 128-140.

Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: How habitat structure influences individual performance. Ecological Monographs 69(3): 251-275.

Lenihan, H.S., F. Micheli, S.W. Shelton, and C.H. Peterson. 1999. The influence of multiple environmental stressors on susceptibility to parasites: An experimental determination with oysters. Limnology and Oceanography 44(3): 910-924.

Locher, B., N.R. Hurst, L.J. Walters, and L.G. Chambers. 2020. Juvenile Oyster (*Crassostrea virginica*) biodeposits contribute to a rapid rise in sediment nutrients on restored intertidal oyster reefs (Mosquito Lagoon, FL, USA). Estuaries and Coasts. doi: 10.1007/s12237-020-00874-2.

Loosanoff, F.L. and F.D. Tommers. 1947. Effect of suspended silt and other substances on rate of feeding of oysters. Science 107(2768): 69-70.

Loosanoff, V.L. 1958. Some aspects of behavior of oysters at different temperatures. Biological Bulletin 114(1): 57-70.

Luckenbach, M.W., R. Mann, and J.A. Wesson. 1999. Oyster reef habitat restoration: A synopsis and synthesis of approaches; proceedings from the symposium, Williamsburg, Virginia, April 1995. Virginia Institute of Marine Science, College of William and Mary. doi: 10.21220/V5NK51.

Mikkelsen, P.M., P.S. Mikkelsen, and D.J. Karlen. 1995. Molluscan biodiversity in the Indian River Lagoon, Florida. Bulletin of Marine Science 57(1): 94-127.

Morris, R., D.M. Bilkovic, M.K. Boswell, D. Bushek, J. Cebrian, J. Goff, K.M. Kibler, M.K. La Peyre, G. McClenachan, J. Moody, P. Sacks, J.P. Shinn, E.L. Sparks, N.A. Temple, L.J. Walters, B.M. Webb, S.E. Swearer. 2019. The application of oyster reefs in shoreline protection: Are we over-engineering for an ecosystem engineer? *Journal of Applied Ecology: Commentary* 2019: 1-9. doi: 10.1111/1365-2664.13390.

Nelson, K.A., L.A. Leonard, M.H. Posey, T.D. Alphin, and M.A. Mallin. 2004. Using transplanted oyster (*Crassostrea virginica*) beds to improve water quality in small tidal creeks: A pilot study. Journal of Experimental Marine Biology and Ecology 298(2): 347-368.

Newell, R.I.E. 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the American oyster, *Crassostrea virginica*? P. 536-546. *In* M.P. Lynch and E.C. Crome (eds.), Understanding the Estuary, Advances in Chesapeake Bay Research (Proceedings of a Conference, 29-31 March 1988, Baltimore, Maryland). CRC Publication 129. Chesapeake Bay Consortium.

Newell, R.I.E., J.C. Cornwell, and M.S. Owens. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: A laboratory study. Limnology and Oceanography 47(5): 1367-1379.

Newell, R.I.E., and E.W. Koch. 2004. Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries 27(5): 793-806.

Parker, M.L. and S.P. Geiger. 2012. Martin County oyster reef restoration project: A compilation and summary of four short-term biological monitoring studies.

Parker, M., V. Encomio, J. Beal, P.A. Klarmann, E. Dark, J. Breithaupt, and K.R. Radabaugh. 2019. Chapter 8: Central Eastern Florida. *In* K.R. Radabaugh, S.P. Geiger, and R.P. Moyer (Eds.) Oyster Integrated Mapping and Monitoring Program Report for the State of Florida. 163 pp plus Appendices.

Patterson, H.K., A. Boettcher, and R.H. Carmichael. 2014. Biomarkers of dissolved oxygen stress in oysters: A tool for restoration management efforts. PLoS One 9(8): e104440. doi: 10.1371/journal.pone.0104440.

Peterson, C.H., J.H. Grabowski, and S.P. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: Quantitative valuation. Marine Ecology Progress Series 264: 249-264.

Phlips, E.J., S. Badylak, and T. Grosskopf. 2002. Factors affecting the abundance of phytoplankton in a restricted subtropical lagoon, the Indian River Lagoon, Florida, USA. Estuarine, Coastal and Shelf Science. doi: 10.1006/ecss.2001.0912.

Powers, S.P., C.H. Peterson, J.H. Grabowski, and H.S. Lenihan. 2009. Success of constructed oyster reefs in no-harvest sanctuaries: Implications for restoration. Marine Ecology Progress Series 389: 159-170.

Raffaelli, D.G., J.A. Raven, and L.J. Poole. 1998. Ecological impacts of green macroalgal blooms. Oceanography and Marine Biology: An Annual Review 36: 97-125.

Reidenbach, M.A., M. Limm, M. Hondzo, and M.T. Stacey. 2010. Effects of bed roughness on boundary layer mixing and mass flux across the sediment-water interface. Water Resources Research 46(W07530). doi: 10.1029/2009/WR008248.

Reidenbach, M.A., P. Berg, A. Hume, J.C.R. Hansen, and E.R. Whitman. 2013. Hydrodynamics of intertidal oyster reefs: The influence of boundary layer flow processes on sediment and oxygen exchange. Limnology and Oceanography Fluids and Environments 3: 225-239.

Reynolds, L.K., N.C. Stephens, S.C. Barry, and A.R. Smyth. 2021. Living shoreline monitoring – How do I evaluation the environmental benefits of my living shoreline? Department of Soil and Water Sciences, U.F./I.F.A.S. Extension SL481.

Ridge, J.T., A.B. Rodriguez, and F.J. Fodrie. 2017. Evidence of exceptional oyster-reef resilience to fluctuations in sea level. Ecology and Evolution 7:10409-10420.

Roegner, G.C. and R. Mann. 1990. Settlement patterns of *Crassostrea virginica* (Gmelin, 1791) larvae in relation to tidal zonation. Journal of Shellfish Research 9(2): 341-346.

Roegner, G.C. and R. Mann. 1995. Early recruitment and growth of the American oyster *Crassostrea virginica* (Bivalvia: Ostreidae) with respect to tidal zonation and season. Marine Ecology Progress Series 117: 91-101.

Schmidt, C. and S. Gallagher. 2017. Final Report: The denitrification potential and ecosystem services from ten years of oyster bed restoration in the Indian River Lagoon.

Sharma, S., J. Goff, R.M. Moody, D. Byron, K.L. Heck Jr., S.P. Powers, C. Ferraro, and J. Cebrian. 2016. Do oyster reefs benefit seagrasses? An experimental study in the Northern Gulf of Mexico. Restoration Ecology. doi: 10.1111/rec.12329.

Sheng, Y.P, S. Peene, and Y.M. Liu. 1990. Numerical modeling of tidal hydrodynamics and salinity transport in the Indian River Lagoon. Oceanographic Sciences. 53: 147-168

Smith, N.P. 1987. An introduction to the tides of Florida's Indian River Lagoon. I. Water levels. Oceanographic Sciences. 50: 49-61.

Smith, N.P. 1993. Tidal and nontidal flushing of Florida's Indian River Lagoon. Estuaries 16(4): 739-746.

Smith, K.A., E.W. North, F. Shi, S. Chen, R.R. Hood, E.W. Koch, and R.I.E. Newell. 2009. Modeling the effects of oyster reefs and breakwaters on seagrass growth. Estuaries and Coasts 32: 748-757.

Smyth, A.R., M.F. Piehler, and J.H. Grabowski. 2015. Habitat context influences nitrogen removal by restored oyster reefs. Journal of Applied Ecology 52: 716-725.

Southworth, M. and R. Mann. 1998. Oyster reef broodstock enhancement in the Great Wicomico River, Virginia. Journal of Shellfish Research 17(4): 1101-1114.

Steward, J.S., R.W. Virnstein, L.J. Morris, and E.F. Lowe. 2005. Setting seagrass depth, coverage, and light targets for the Indian River Lagoon System, Florida. Estuaries 28(5): 923-935.

Theuerkauf, S.J., D.B. Eggleston, B.J. Puckett, and K.W. Theuerkauf. 2017. Wave exposure structures oyster distribution on natural intertidal reefs, but not on hardened shorelines. Estuaries and Coasts 40: 376-386.

Thomsen, M.S. and K. McGlathery. 2006. Effects of accumulations of sediments and drift algae on recruitment of sessile organisms associated with oyster reefs. Journal of Experimental Marine Biology and Ecology 328: 22-34.

Wall, L.M., L.J. Walters, R.E. Grizzle, and P.E. Sacks. 2005. Recreational boating activity and its impact on the recruitment and survival of the oyster *Crassostrea virginica* on intertidal reefs in Mosquito Lagoon, Florida. Journal of Shellfish Research 24(4): 965-973.

Walters, L.J., A. Roman, J. Stiner, and D. Weeks. 2001. Water resource management plan, Canaveral National Seashore. Titusville, Fl: National Park Service, Canaveral National Seashore. 224 pp.

Wang, H., W. Huang, M.A. Harwell, L. Edmiston, E. Johnson, P. Hsieh, K. Milla, J. Christensen, J. Stewart, and X. Liu. 2007. Modeling oyster growth rate by coupling oyster population and hydrodynamic models for Apalachicola Bay, Florida, USA. Ecological Modeling 211: 77-89.

Weaver, R.J., A. Stehno, N. Bonanno, A. Sager, A. Kenny, J.A. Zehnder, C. Glasser, and A. Allen. 2017. Scale Model design of oyster reef structures as part of a showcase living shoreline project. Shore and Beach 85(4): 41-54.

Wesson, J., R. Mann, and M. Luckenbach. 1999. Chapter 8: Oyster Restoration Efforts in Virginia. *In* M.W. Luckenbach, R. Mann, and J.A. Wesson (eds.) Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches; Proceedings from the Symposium, Williamsburg, Virginia, April 1995.

Whitman, E.R. and M.A. Reidenbach. 2012. Benthic flow environments affect recruitment of *Crassostrea virginica* larvae to an intertidal oyster reef. Marine Ecology Progress Series 463: 177-191.

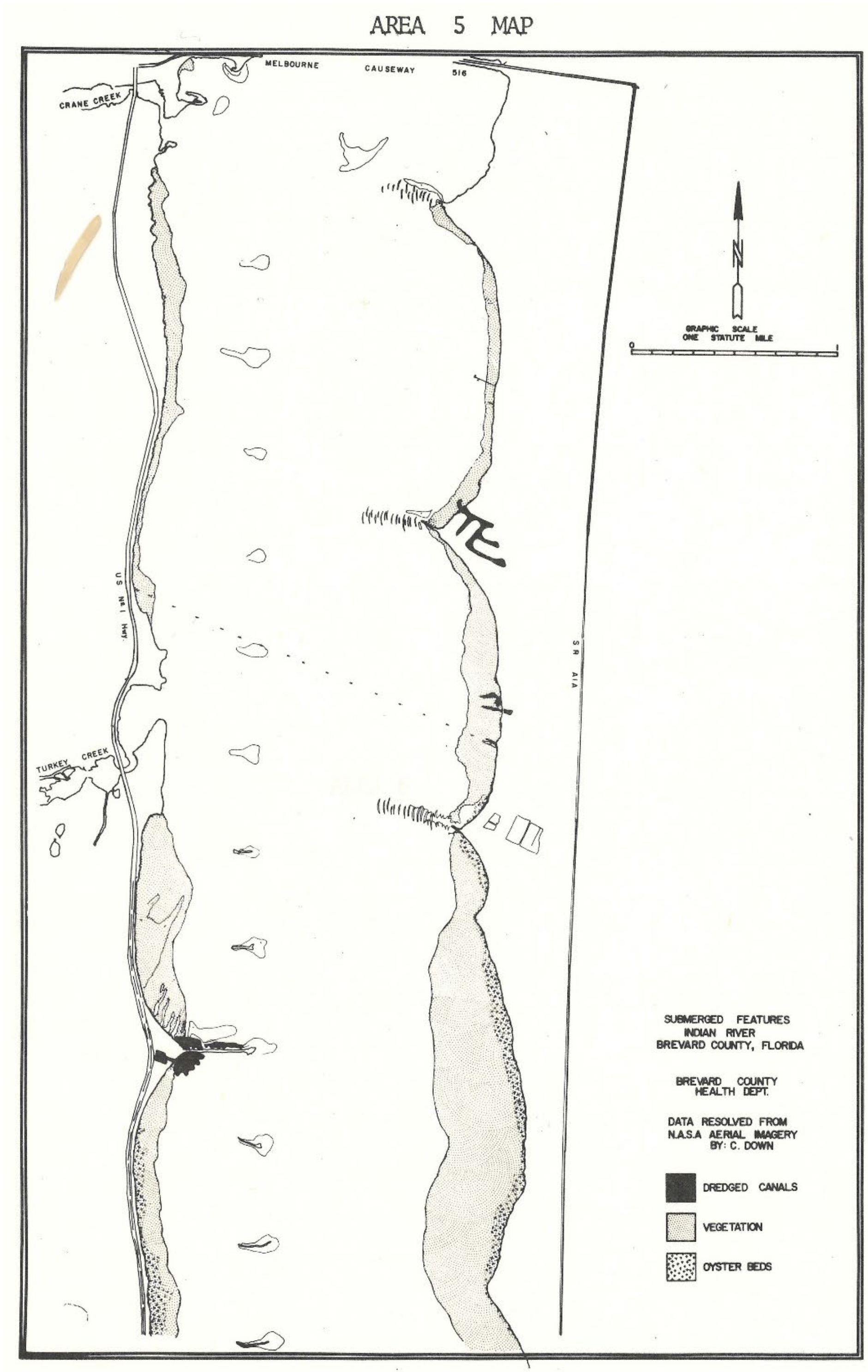
Wilcox, W.A. 1896. Commercial Fisheries of Indian River, Florida. Report of the United States Commissioner of Fish and Fisheries. 22: 249-262.

Zarillo, G.A. and C. Listopad. 2017. Indian River Lagoon Hydrodynamic and Water Quality Model Quality Assurance Plan. Prepared for Brevard County and the Florida Department of Environmental Protection and Brevard County Natural Resources Management Dept., D.E.P. Grant Agreement No. S0714.

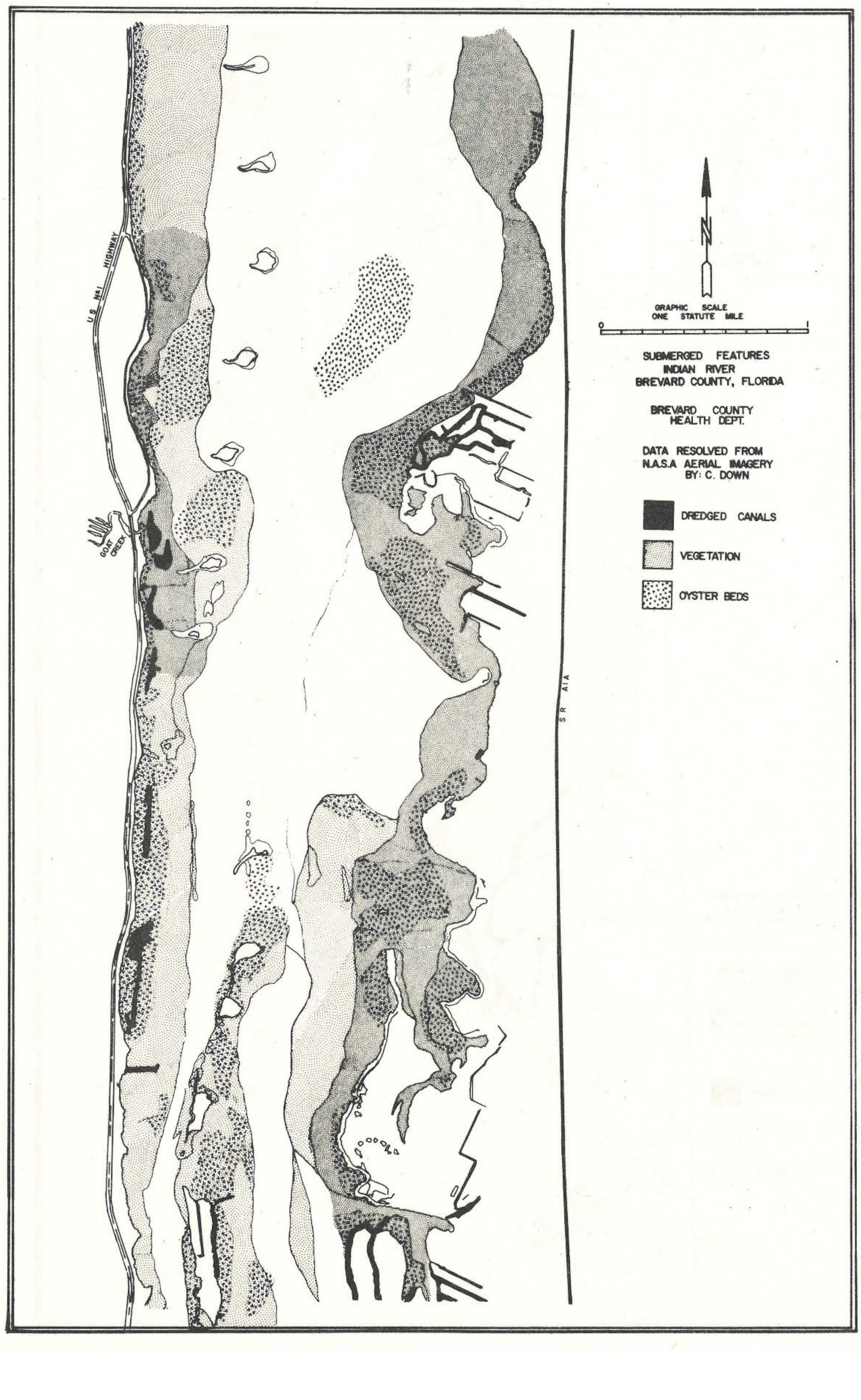
zu Ermgassen, P., B. Hancock, B. DeAngelis, J. Greene, E. Schuster, M. Spalding, and R. Brumbaugh. 2016. Setting objectives for oyster habitat restoration using ecosystem services: A manager’s guide. The Nature Conservancy, Arlington VA. 76 pp.

8. ***Appendices***

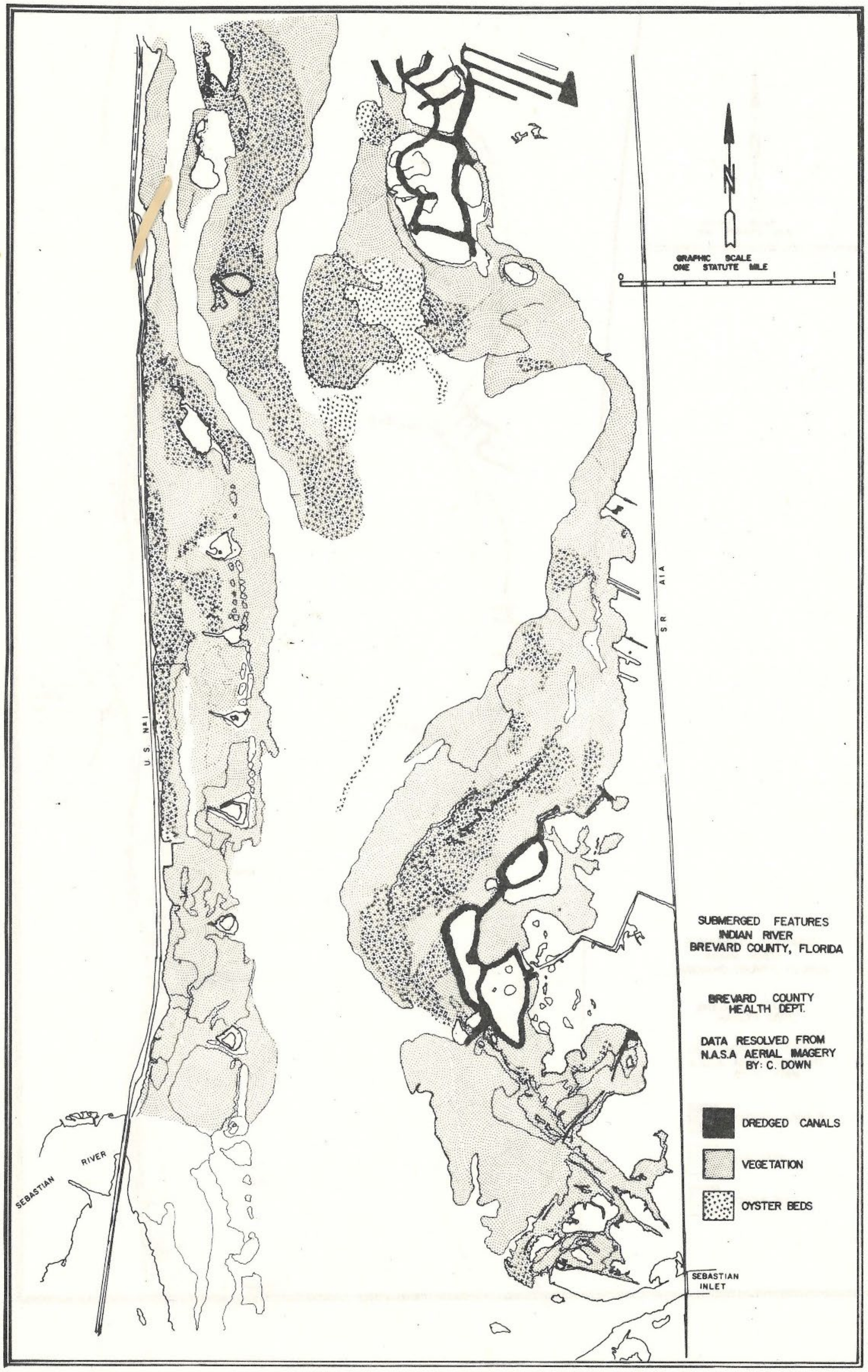
Appendix A: Historic Oyster Habitat Maps for Brevard County



AREA 5 MAP


N
GRAPHIC SCALE
ONE STATUTE MILE
0
1
SUBMERGED FEATURES
INDIAN RIVER
BREVARD COUNTY, FLORIDA
BREVARD COUNTY
HEALTH DEPT.
DATA RESOLVED FROM
N.A.S.A AERIAL IMAGERY
BY: C. DOWN
DREDGED CANALS
VEGETATION
OYSTER BEDS
U.S. No1 HIGHWAY
GOAT CREEK
S R A1A

AREA 5 MAP



Return to Introduction

Appendix B: Brevard County Save Our Indian River Lagoon (S.O.I.R.L.) Living Shoreline Monitoring – Monthly Report for January 2020 (Abridged)

Principal Investigators: Dr. Linda Walters, Dr. Melinda Donnelly, Dr. Paul Sacks

Department of Biology, University of Central Florida, 4000 Central Florida Blvd., Orlando,

Florida, 32816

Date Submitted: 30 January 2020

U.C.F. Contract Number: 24-03-8396, 24-03-8424

Executive Summary: Four Brevard County restoration/stabilization sites have been monitored since their deployment by U.C.F. to help the county evaluate S.O.I.R.L. success. **No field monitoring was required in January 2020**; therefore, in this update, we compare the site locations and the results of all the prior monitoring to date to look for trends over time.

A comparison of the site characteristics documents that two of the sites face into open lagoon waters (Bomalaski and Marina Isles), while the other two sites are situated along narrow canals (Bettinger and Gitlin). The sites that face open lagoon waters have more consistent salinities, whereas those sites located in narrow canals show large fluctuations. The two open lagoon sites have had distinct pulses of oyster recruitment and increases in total oyster numbers since deployment. In comparison, the two canal sites show little evidence of oyster recruitment and overall decreasing oyster numbers. The two open lagoon sites also have the higher numbers of potential oyster predators compared to the canal sites; however, recruitment and growth of gardened oysters suggest predator densities are not limiting success of these oyster breakwaters.

I. INTRODUCTION

Situated along the east coast of Florida, the Indian River Lagoon (I.R.L.) is a diverse ecosystem consisting of three major bodies of water: Mosquito Lagoon, Banana River, and Indian River. The I.R.L. spans five east coast counties from northern Volusia County, south to Martin County. Amongst these counties, approximately 70% of the I.R.L. falls within Brevard County's boundaries. Thus, the I.R.L. functions as a natural asset for Brevard County, providing both economic and ecological benefits such as tourism, commercial fisheries, and increased waterfront property values.

However, an increasing human population has resulted in 64% of Brevard County's shorelines being converted to hard armoring such as bulkhead or riprap (Donnelly et al., 2017). Vast urbanization in Brevard County has led to unintended degradation of the I.R.L. waterways due to stormwater runoff, septic sewer systems, excess fertilizer application, and nutrient-rich reclaimed water (Tetra Tech, Inc. and CloseWaters, LLC, 2016). To address these multifaceted problems, local governments are implementing projects devoted to improving the I.R.L. Brevard County, recognizing the importance of this natural asset, passed a referendum on 23 August

2016 to increase the county's sales tax by half a cent, which now provides funding for projects aimed at improving the I.R.L. (Board of County Commissioners, 2016).

Brevard County's Save Our Indian River Lagoon Project Plan (S.O.I.R.L.) includes a portfolio of projects with four main goals: 1) **Reduce** primary sources of pollution, 2) **Remove** historical pollution now accumulated in muck deposits, 3) **Restore** natural stabilization and filtration systems (including oysters bars and living shorelines) including project monitoring, and 4) **Respond** to monitoring data, new technology, changing conditions, alternative project proposals, and recommend plan revisions to the County Commission annually.

With these goals in mind, the University of Central Florida is conducting third-party monitoring of Brevard County S.O.I.R.L. shoreline restoration/stabilization projects after deployment by county agencies and non-profit groups. S.O.I.R.L. "living shorelines" utilize a single component or combination of oyster breakwaters and native vegetation to prevent further erosion of shorelines and improve water quality through nutrient absorption. Project monitoring is essential to complete the final step of the S.O.I.R.L. project plan, of responding to new data and changing conditions.

II. OBJECTIVES

The following long-term objectives will be completed by the University of Central Florida for this project:

(1) Conduct long-term monitoring of the Bomalaski oyster reef breakwater in Brevard County at 1 month, 3 months, 4 months, 5 months, 6 months, 9 months, 12 months, 18 months, and 24 months; and remaining oyster reef breakwaters at 1 month, 3 months, 6 months, 12 months, 18 months and 24 months post-deployment.
(2) Conduct long-term monitoring of deployed vegetation in Brevard County at 1 month, 3 months, 4 months, 5 months, 6 months, 9 months, and 12 months post-deployment.
(3) Provide and analyze plant survival and oyster survival/recruitment data for oyster reef breakwaters and vegetation in Brevard County in the form of a deliverable at the end of each month.

III. SCOPE:

All locations in Brevard County included in this monitoring project are shown in figure B-1. The following methods were applied to all sites where deployment of oyster shell bags has occurred as of September 2019.

3.1 Oyster Breakwater - General Layout and Formation

The oyster shell bags used in oyster breakwaters are made of mesh tubing filled with either blank (clean) shell, or blank shell plus live gardened oysters, sealed on both ends with nylon heavy-duty cable ties. The base layer of Brevard Zoo breakwaters consists of two rows of blank shell bags placed on the bottom while oyster shell bags containing live oysters are placed on top centered in the middle of the base layer, like a pyramid. Each of these oyster shell bags with live oysters contains approximately 25 measured live oysters, ranging in size from 30 to 60 mm. Each shell bag containing live oysters is approximately 36 in. by 10 in. by 6 in. in dimensions. The oyster breakwaters are constructed so that each section of the reef has a base layer of 65 bags in length and 2 bags in width (130 bags total), with 65 bags containing live oysters placed on top.

3.2 Oyster Breakwater Emptied Bag Monitoring Methods

One shell bag was emptied and quantified for every 25 ft of shoreline. For breakwaters that are 100 ft or less, we surveyed five bags rather than four to meet requirements for statistical analysis. Using numbers produced by a random number generator, we randomly selected shell bags to be pulled from each reef unit. These bags were emptied, analyzed, re-bagged, and replaced in the same spot from which the bag was removed. Emptied shell bags were marked with green tags to ensure that these specific shell bags are not re-visited later in the year.

For each shell bag, data was collected by temporarily removing and emptying bag to sort contents and included the following measures: 1) total number live oysters, 2) shell length of first 50 haphazardly selected live oysters, including all living gardened oysters (larger than 30 mm after 1 month), 3) numbers of live competitors (e.g. native and invasive mussels), 4) numbers of live predators (e.g. crown conch, oyster drills, stone crabs, blue crabs, etc.) along with the first 10 crab carapace lengths for each species, and 5) numbers of oysters impacted by live boring sponge. All shell and live oysters were placed in a new shell bag, returned to the oyster breakwater, and reattached to the original breakwater with cable ties.

Abiotic variables (salinity, wind, air and water temperature) were collected using a thermometer, wind gauge, and refractometer at all sites on all monitoring dates. Measurements of seaward water depth at the base of the shell bags were collected every 25 ft to determine the depth of water relative to the height of shell bags.

3.3 Oyster Breakwater Visual Inspection Monitoring Methods: Year 2

Beginning in September 2019, the oyster breakwater will be visually inspected for the following data. First, all bags will be evaluated to determine if any have been damaged or displaced. For those bags that have been damaged or displaced, up to one hour of time will be spent making repairs. In addition, the presence or absence of live oyster shell bridge formation within and between bags, the presence or absence of algal overgrowth, and the number and identification of any macroinvertebrates on shell bags will be recorded.

3.4 Site Descriptions of Deployed Wave Break Locations

A summary of site characteristics for all locations can be found in Table 1. The locations of the sites are shown in figure B-1, B-2, B-3 and B-4.

Bomalaski Residence: Brevard Zoo deployed 100 ft of oyster breakwater at the Bomalaski residence on 23 August 2018. A total of 390 shell bags were deployed in two sections. Of these, 130 were shell bags that contained 25 live gardened oysters, for a total of 3250 live oysters. U.C.F. did not pre-measure oysters prior to deployment at this location.

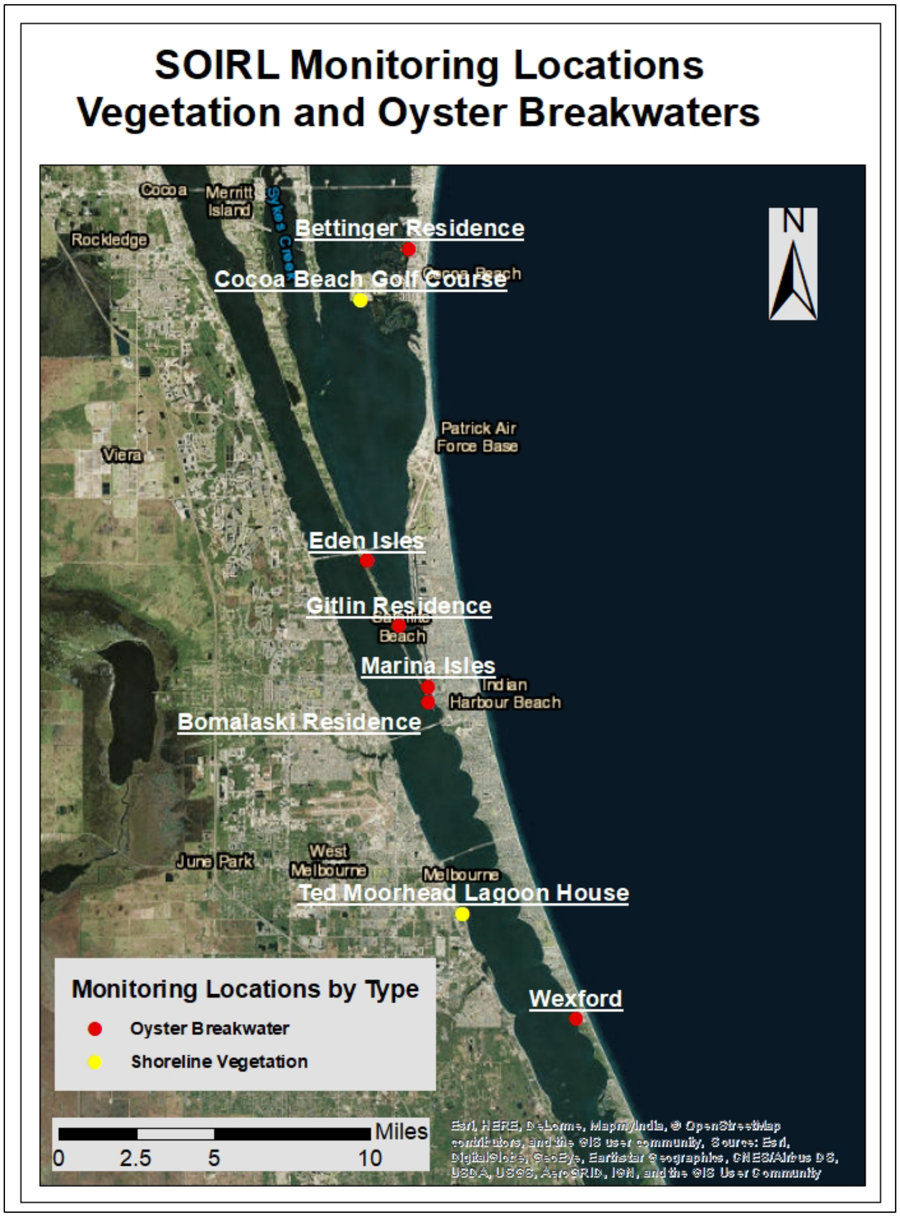


Figure B-1 Site map.

Bettinger Residence: Brevard Zoo deployed 120 ft of oyster breakwater at the Bettinger residence on 2 February 2019. A total of 468 shell bags were deployed in three sections. Of these, 156 shell bags each contained 25 live gardened oysters, for a total of 3900 live oysters. Twenty shell bags containing measured live oysters were tagged for monitoring. Shell lengths of gardened oysters prior to deployment ranged from a minimum of 40 mm to a maximum of 100 mm. An additional 19 individuals < 40 mm were recorded that were attached to gardened clusters.

Gitlin Residence: On 15 May 2019, one day prior to community deployment event, we counted and measured gardened oysters and placed 25 per bag, in prepared, tagged oyster shell bags. Bags were included with the next day's deployment, spaced evenly across the oyster breakwater, and their locations marked on a map. Salinity measurements found this location to be 8 ppt; this value is much lower than all other sites. The Gitlin oyster breakwater extends a total of 180 feet and includes two 75-ft breakwaters and one 30-foot breakwater along the seawall. The oyster breakwaters were constructed so that each of the two 75 ft sections of reef had a base layer of 97 bags in length and 2 bags in width (195 bags total), with 98 bags containing live oysters placed on top. The 30 ft section was constructed with a base layer of 39 bags in length and 2 bags in width (78 bags total), with 39 bags containing live oysters placed on top. Each of the oyster shell bags with live oysters contained 25 measured live oysters, ranging in size from 40 to 100 mm.

<u>Marina Isles Community:</u> The oyster breakwater was deployed in June 2019 and is 300 linear feet in length and located in Indian Harbor Beach. This property includes single homes in front with condominiums in the back. The area is fringed by stands of mangroves, including white (*Laguncularia racemosa)*, black (*Avicennia germinans*), and red (*Rhizophora mangle*), as well as Brazilian pepper (*Schinus terebinthifolius*). The oyster breakwater extends along a seawall, with a footprint of 1505 sq. ft. The number of bags and placement varied from prior layouts. The four defined sections are: Section C: 35 ft. long, bottom layer consisting of 137 bags, placed 3 bags wide with 91 shell bags placed on top, 2 bags wide. Section D, at 20 ft. in length, has 64 bags placed as the bottom layer, with 26 oyster shell bags placed on top. Section E, at 35 ft. in length, contains 91 bags on the bottom layer, 2 bags wide, with 46 oyster shell bags placed at the top layer. Section F consists of 2 sections 60 ft. each, with 192 oyster shells bag for the bottom layer and 78 shell bags placed on the top layer. A total of 484 shell bags were deployed and 241 shell bags each contained approximately 25 live gardened oysters, for a total of ~6025 live oysters. On 24 June 2019, one day prior to community deployment event, we counted and measured gardened oysters and placed 25 per bag, in 48 prepared, tagged oyster shell bags. The tagged bags were spaced evenly across the oyster breakwater, and locations marked on a map. Shell lengths ranged from 40 mm to 116 mm. To avoid damaging gardened clusters, additional individuals, mostly < 40 mm, were recorded that were attached to gardened clusters.

IV. RESULTS FOR OYSTER BREAKWATER MONITORING:

January 2020 Update

This month's report compares the location and settings of the four oyster breakwater sites: Bomalaski, Bettinger, Gitlin and Marina Isles (figure B-1, B-2, B-3 and B-4). The report also provides analysis of the previous monitoring results for each of the four sites. Salinity (measured during site visits), abundances of oyster predators, and size-frequency oyster data are summarized for all monitoring periods by location and discussed here.

Locations

The Bomalaski residence is the southernmost oyster breakwater, and it is the only one located in the Indian River part of the Indian River Lagoon system (figure B-1 and B-2). It is along the west facing shoreline of the narrow peninsula that separates the Indian River from the Banana River. The Bomalaski residence oyster breakwater is exposed to the water currents, waves and wind of the whole 1.5-mile width of the Indian River at this location.

The Bettinger residence oyster breakwater is almost 13 miles north of the Bomalaski site and is located in a canal along the east side of the Banana River near the Thousand Islands (figure B-1 and B-3). The oyster breakwater is about 1000 feet along the canal from the main part of the Banana River. The canal is 100 to 200 feet in width and branches at this location. Both branches terminate about 600 feet further to the east and south of the breakwater site. As a result of this location, water flow in the canal is likely to be restricted.

The Gitlin residence oyster breakwater, also along the east side of the southern Banana River, is located at the junction of a canal that branches off the large canal, locally known as the Grand Canal, that separates Lansing Island from the rest of Satellite Beach (figure B-1 and B-4). The branching canal terminates about 700 feet to the east. At the terminus of the canal, there is a stormwater outfall adjacent to the Satellite Beach fire station. The branching canal is 75 feet wide, and the Grand Canal is about 200 feet wide at this location. The Grand Canal is connected to the Banana River at both the north and south ends.

The Marina Isles Community oyster breakwater is located near the south end of the Banana River part of the Indian River Lagoon system (figure B-1 and B-2). It is along the west facing shoreline. The Banana River is about 800 feet wide at this point. The Marina Isles Community oyster breakwater is exposed to the water currents as water moves between the Banana and Indian rivers.

Figure B-2 Map showing location of the Bomalaski and Marina Isles residences in the Indian River and Banana River.

Figure B-3 Map showing location of the Bettinger Residence oyster breakwater in a canal off the Banana River.

Figure B-4 Map showing location of the Gitlin Residence oyster breakwater in a canal in between Lansing Island and Satellite Beach.

Analysis of Monitoring Results Over Time

Bomalaski Residence: The oyster breakwater at the Bomalaski residence was deployed in August 2018. Here, we summarize some of the results of monitoring at 1, 3, 6, 9, and 12 months post-deployment. The next monitoring is scheduled for February 2020. Our salinity measurements have been fairly consistent and ranged between 20 and 25 ppt since deployment, with a slight decrease below 20 ppt during the Summer of 2019 (figure B-5).

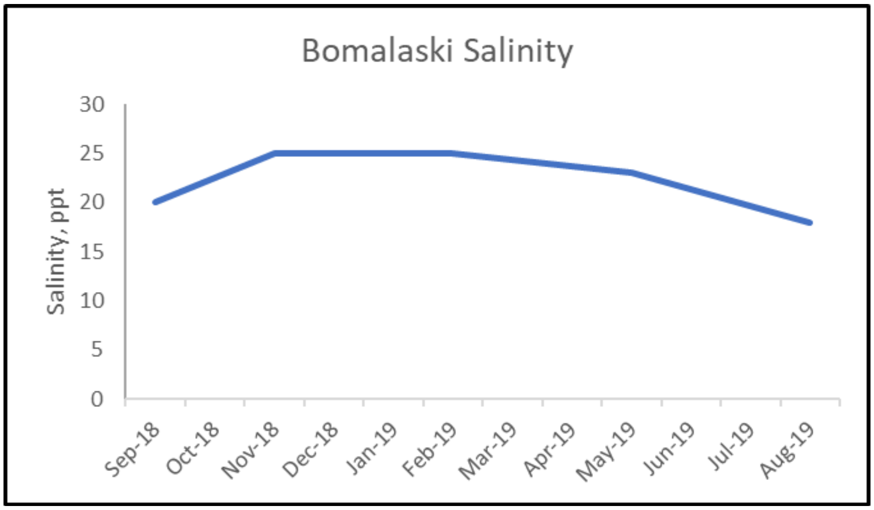


Figure B-5 Salinity trends at the Bomalaski residence oyster breakwater at 1, 3, 6, 9 and 12 months since deployment.

Figure B-6 shows the changes in frequency distribution of shell lengths of measured oysters at the Bomalaski residence. This provides evidence of both recruitment and growth of oysters since deployment. Recruitment is indicated in two ways. First the overall height of the curves increases from September 2018 through to August 2019; this indicates more oysters counted during each monitoring session. Second, the trendlines show additional peaks at the smaller oyster size ranges. The 1-month (September 2018) trendline has a single peak at 41-50 mm, consistent with the size of the deployed oysters. The November 2018 trendline shows both a peak at 41-50 mm, and a second, smaller peak at 21-30 mm. This indicates a pulse of oyster recruitment occurred since the September 2018 monitoring. By February and May 2019, the recruitment peak has become higher, and has shifted to larger sizes. The August 2019 trendline is higher, especially at the smaller shell length sizes, indicating another pulse of oyster recruitment after May 2019. In the larger size classes, we have seen increases over time in the number of oysters greater than 50 mm, suggesting growth of surviving oysters; however, few oysters have grown larger than 81 mm (2.6 % of total oysters ≥81mm after 12 months).

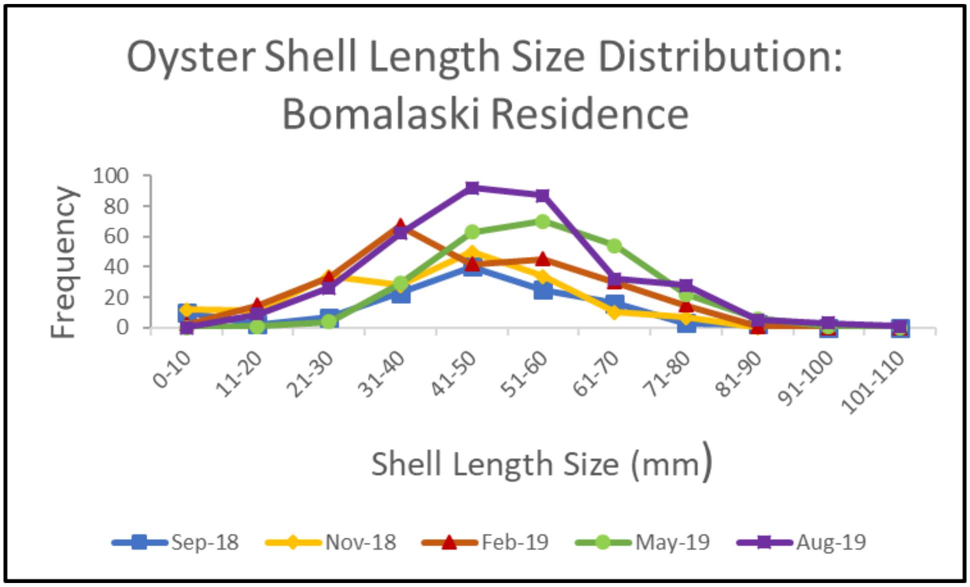


Figure B-6 Shell length size distribution of measured oysters within emptied bags at Bomalaski residence from 1 to 12 months post-deployment (September 2018 – August 2019).

Potential oyster predators include oyster drills and stone, blue and mud crabs; these were counted during monitoring (figure B-7). The number of crabs found in the monitored shell bags initially increased, but the numbers have shown relatively small changes since then. The number of recorded oyster drills has been consistently low.

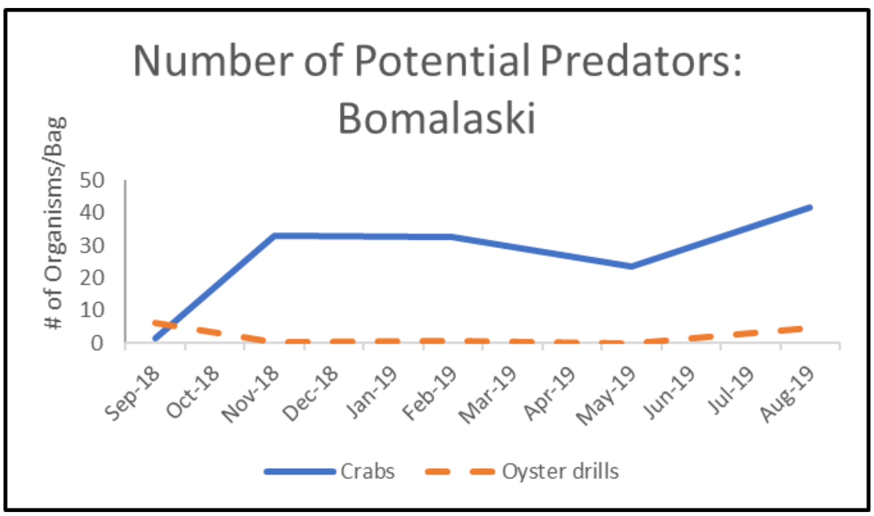


Figure B-7 Number of potential predators per emptied shell bag at the Bomalaski residence oyster breakwater.

Bettinger Residence: The oyster breakwater at the Bettinger residence was deployed in February 2019. It has been monitored at 1, 3, 6, and 9 months post-deployment. The next scheduled monitoring is in February 2020. Salinity measured on monitoring visits has varied by 13 ppt and decreased to 10 ppt during August 2019 (figure B-8).

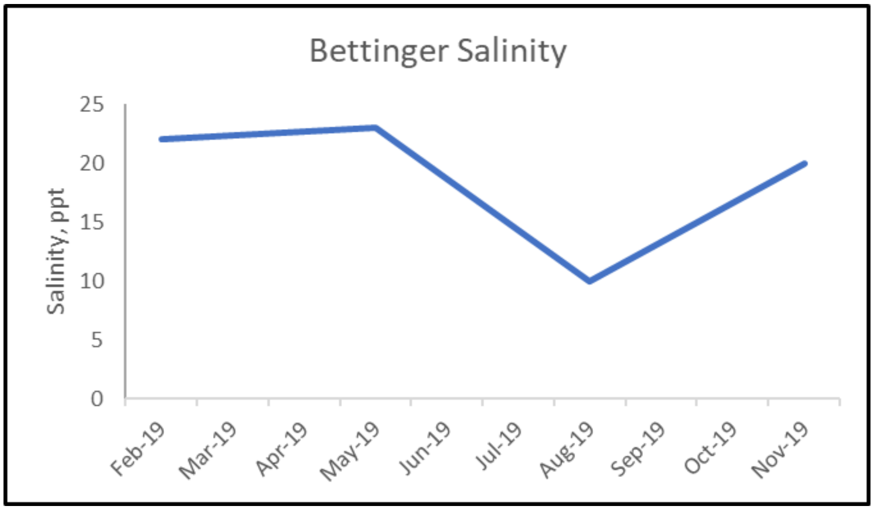


Figure B-8 Salinity trends at the Bettinger residence oyster breakwater at 1, 3, 6, and 9 months since deployment.

Figure B-9 shows the changes in frequency distribution of shell lengths of measured oysters at the Bettinger residence. It shows little evidence of recruitment or growth of oysters since deployment (figure B-9). Minimal numbers of oysters in the smallest size classes have been observed at Bettinger and there has been no oysters larger than 81 mm after 9 months. The overall height of the trendlines from deployment in January to November 2019, shows a decrease. This is consistent with a decrease in the number of gardened live oysters counted during each monitoring session.

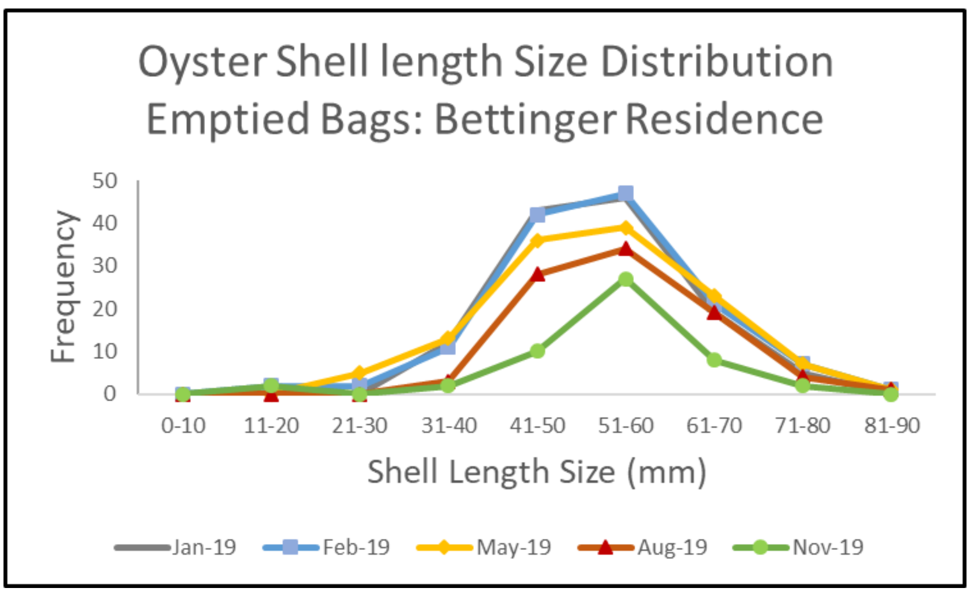


Figure B-9 Shell length size distribution of measured oysters within emptied bags at the Bettinger residence from 0 to 9 months post-deployment (January -November 2019).

Potential oyster predators include oyster drills and stone, blue and mud crabs; these were counted during monitoring (figure B-10). The number of crabs found in the monitored shell bags initially increased, but the numbers have shown a decrease since May 2019. This decrease coincides with the drop in salinity during the August 2019 monitoring. The numbers of oyster drills that have been counted has been consistently low.

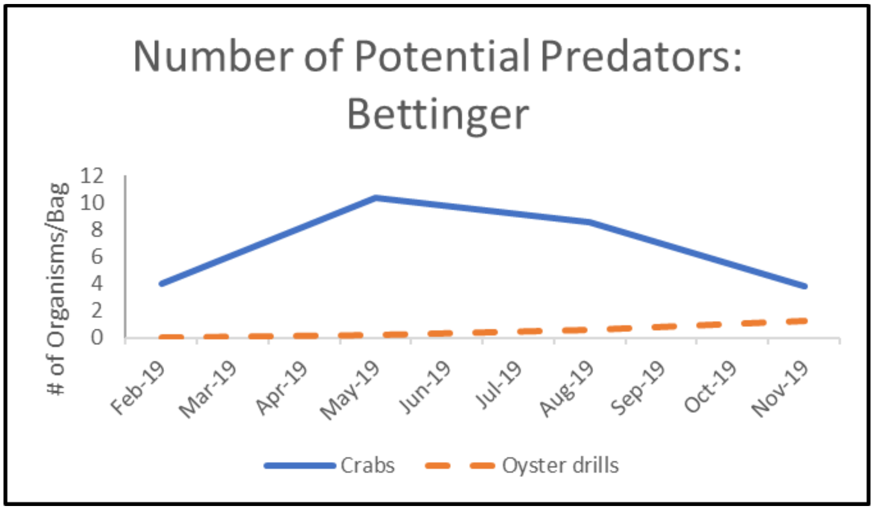


Figure B-10 Number of potential predators per emptied shell bag at the Bettinger residence oyster breakwater.

Gitlin Residence: The oyster breakwater at the Gitlin residence was deployed in May 2019. It has been monitored at 1, 3, and 6 months post-deployment. The next scheduled monitoring is in February 2020. Salinity started at a low of 8 ppt at deployment and increased by 12 ppt during the first month. Salinity has fluctuated between 12 ppt and 20 ppt since that time based on our monitoring during site visits (figure B-11).

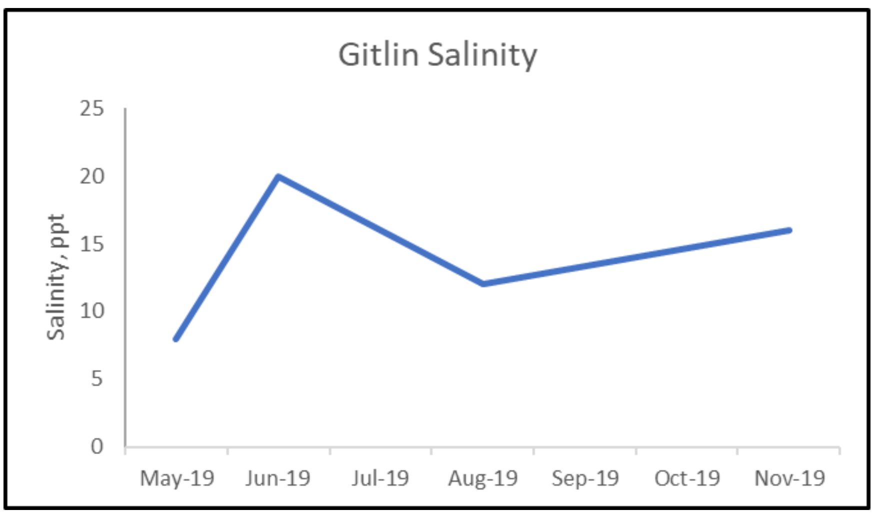


Figure B-11 Salinity trends at the Gitlin residence oyster breakwater at 1, 3, and 6 months since deployment.

Figure B-12 shows the changes in frequency distribution of shell lengths of measured oysters at the Gitlin residence. There is little evidence of recruitment of oysters since deployment, with few oysters observed in the smallest size classes. The peak of each sequential trendline is shifted toward larger shell lengths with each monitoring session; this indicates the surviving oysters have been growing. However, few oysters grow larger than 81 mm; only 8.2 % are 81mm or larger after 6 months. The overall height of the trendlines from deployment in May to November 2019, shows a decrease. This is consistent with a decrease in the number of live oysters counted during each monitoring session.

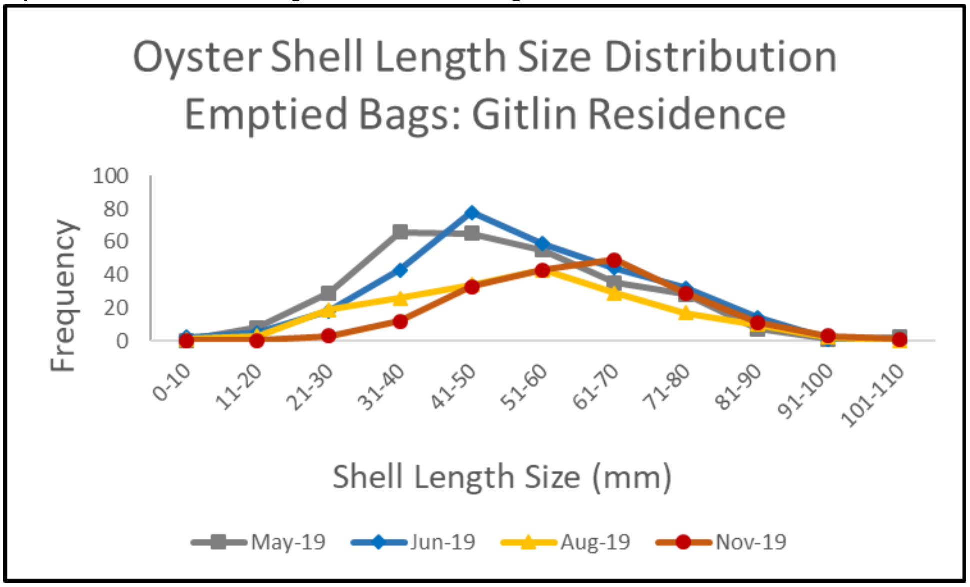


Figure B-12 Shell length size distribution of measured oysters within emptied bags at the Gitlin residence from 0 to 6 months post-deployment (May -November 2019).

Potential oyster predators include oyster drills and stone, blue and mud crabs; these were counted during monitoring (figure B-13). The number of crabs found in the monitored shell bags decreased markedly from June to August 2019. This decrease coincides with the drop in salinity during the August 2019 monitoring. Both crab and oyster drill numbers have increased since August coinciding with an increase in salinity.

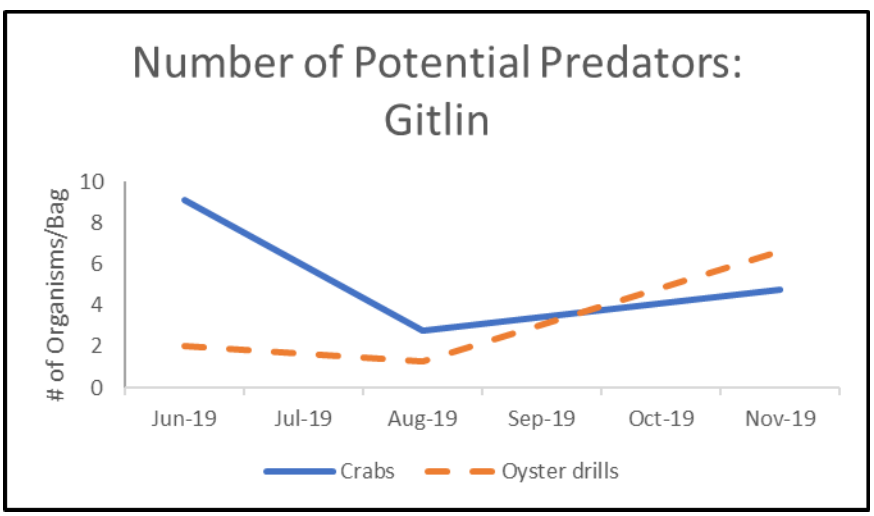


Figure B-13 Number of potential predators per emptied shell bag at the Gitlin residence oyster breakwater.

Marina Isles Community: The oyster breakwater at the Marina Isles Community was deployed in June 2019. It has been monitored at 1, 3, and 6 months post-deployment. The next scheduled monitoring is in March 2020. Salinity has changed little since deployment, ranging between 20 and 22 ppt (figure B-14).

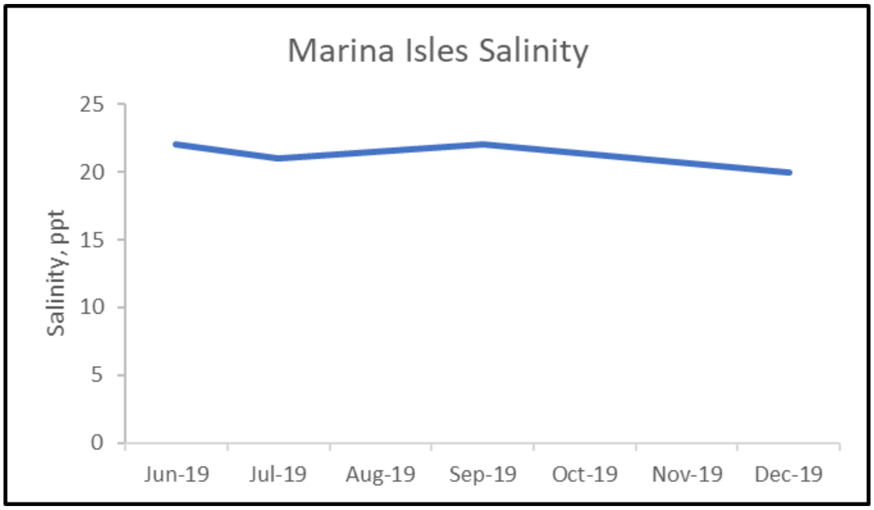


Figure B-14 Salinity trends at the Marina Isles Community oyster breakwater at 0, 1, 3, and 6 months since deployment.

Figure B-15 shows the changes in frequency distribution of shell lengths of measured oysters at the Marina Isles Community. It shows evidence of recruitment and growth of oysters since deployment (figure B-15). There was little change during the first month after deployment in June 2019. However, the trendlines for September and December 2019 both show a peak at shell lengths smaller than the shell-length peak at deployment. The peak at 11-20 mm in the September data indicates a pulse of recruitment. The taller peak at 21-30 mm shell-lengths in the December data indicates additional recruitment and growth of the earlier recruits. Few oysters have grown larger than 81 mm; only 1.2 % are 81mm or larger after 6 months.

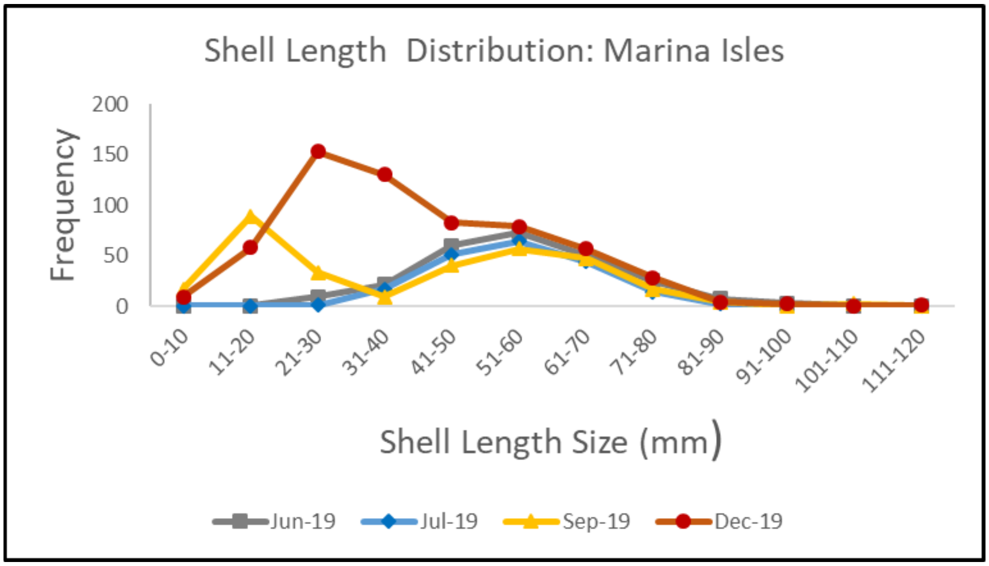


Figure B-15 Shell length size distribution of measured oysters within emptied bags at the Marina Isles Community from 0 to 6 months post-deployment (June -December 2019).

Potential oyster predators include oyster drills and stone, blue and mud crabs; these were counted during monitoring (figure B-16). The number of crabs found in the monitored shell bags increased from July to September, and then decreased to December 2019. The numbers of oyster drills also decreased since the initial monitoring.

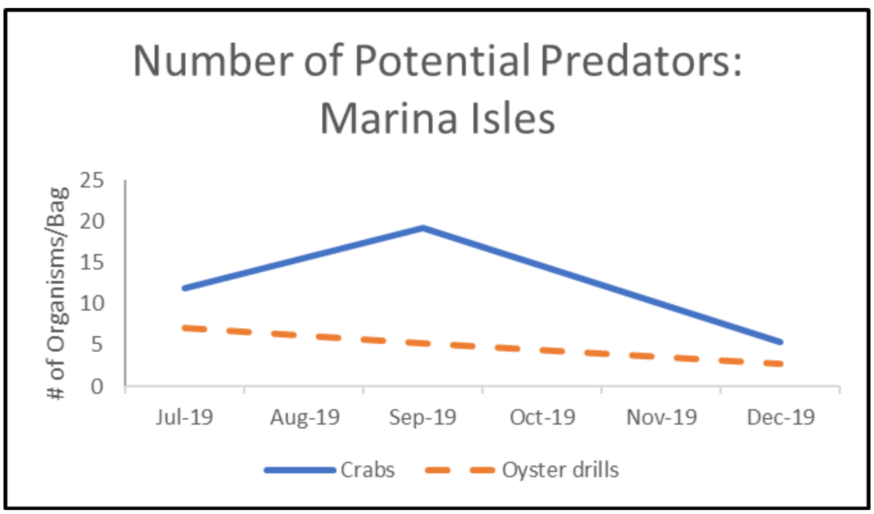


Figure B-16 Number of potential predators per emptied shell bag at the Marina Isles Community oyster breakwater.

Summary:

Two of the Brevard County oyster breakwater projects are located along the open shorelines of the Indian River Lagoon - Bomalaski and Marina Isles. The other two sites are along narrow canals - Bettinger and Gitlin. Differences in site characteristics, particularly in reference to salinity and location within the water body (and predicted water flow), may affect the survival of gardened oysters and recruitment to the breakwaters. The two open lagoon sites show the smallest changes in salinity over time since deployment in comparison to the canal sites. The two open lagoon sites likewise show distinct pulses of recruitment followed by increases in oyster numbers and shell sizes of the recruits. In comparison, the two canal sites show little evidence of recruitment and a decrease in numbers of live oysters over time. At present, all sites consistently have few oysters larger than 81 mm in shell length. In general, the number of potential oyster predators was highest at the two open lagoon sites, and lowest at the canal sites. The sites with the highest predator numbers coincides with the highest oyster recruitment and increases in oyster numbers; the sites with the lowest predator numbers coincides with the lowest recruitment and declines in oyster numbers. Since the crabs and oyster drills are marine species, the variable salinities in the canals may limit abundances of these species at Bettinger and Gitlin. Higher abundances of predators at Bomalaski and Marina Isles could be an effect of the increased number of oysters and other organisms in the breakwaters because of greater food availability for the predatory species. However, the number of predators at Bomalaski and Marina Isles did not limit oyster recruitment or survival of oysters during year 1.

REFERENCES:

Board of County Commissioners (2016). Ordinance 2016 – 15 of the Board of County Commissioners of Brevard County, Florida. Brevard County.

Tetra Tech, Inc., and CloseWaters, LLC (2016). Save Our Lagoon Project Plan for Brevard County. Brevard County Natural Resources Management Department.

Donnelly, M., Kibler, K., and Walters, L. (2017). Developing a Shoreline Habitat Restoration and Management Plan for Brevard County – Phase 1. University of Central Florida.

Return to 4.1.1 Salinity Target

Appendix C: Salinity and Temperature Tables

(**A**) Salinity and (**B**) Temperature minimum, maximum, mean, and standard deviation (Stdev) for S.J.R.W.M.D. stations within the I.R.L., including creeks, over years spanning from 1996 to 2019 taken at approximately 0.5 m below the water surface. Highlighted rows represent overall means within the target 10 – 28 ppt or 10-25 °C. Data Source: St. Johns River Water Management District.

A. Salinity

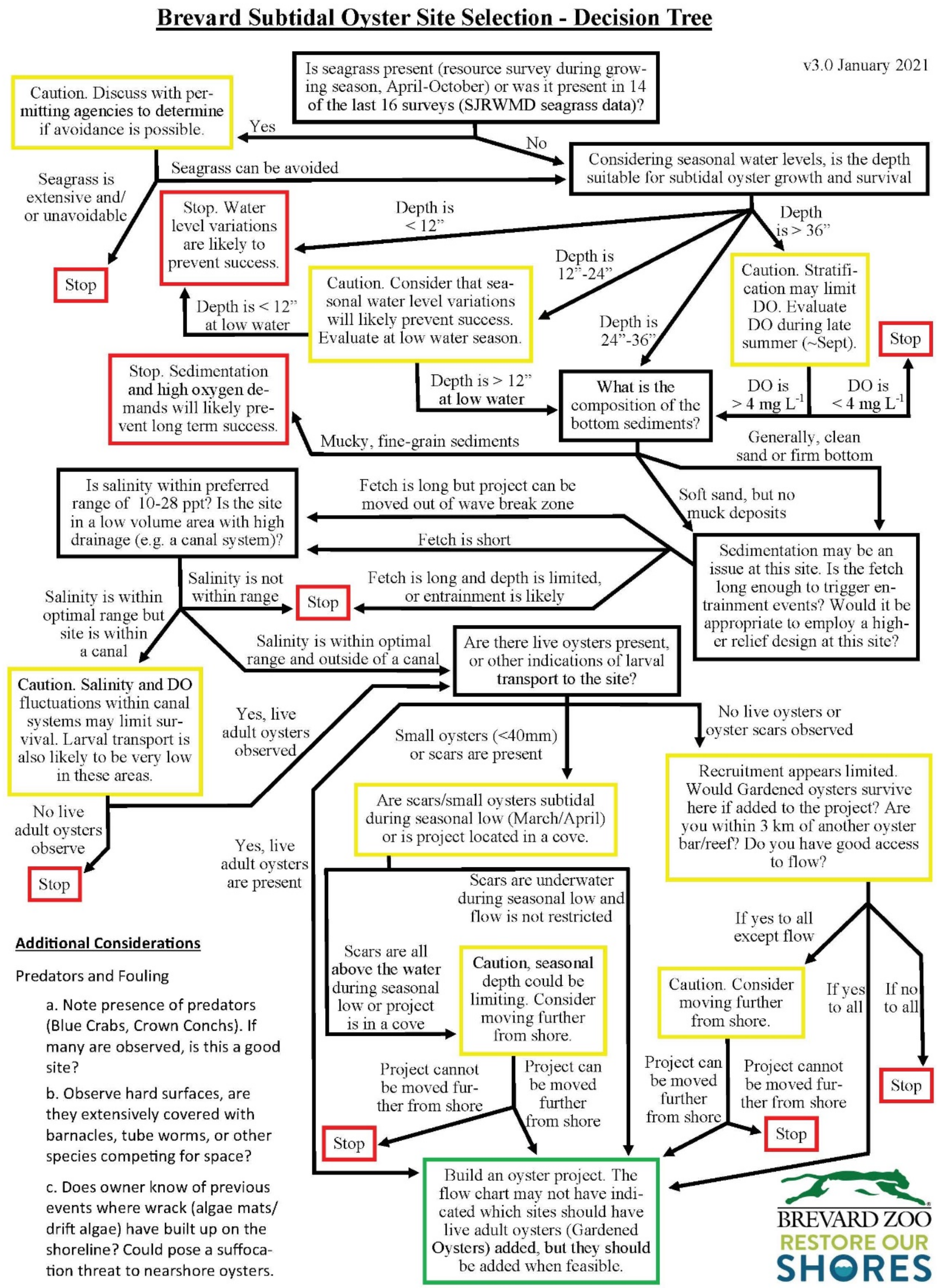
StationID	Min	Max	Mean	Stdev
IRLI02	15.10	44.33	30.60	6.46
IRLI06	15.70	40.46	29.98	5.65
IRLI07	14.90	39.84	27.46	5.91
IRLI10	14.20	39.24	25.62	5.80
IRLI13	13.80	38.70	23.76	5.69
IRLI15	13.60	37.97	23.16	5.56
IRLI16	11.00	37.12	24.77	5.61
IRLI18	7.50	38.30	21.74	5.74
IRLI21	7.00	36.97	21.21	5.81
IRLI09E	19.49	39.47	29.31	5.18
IRLI23	9.90	37.93	21.35	6.21
IRLI24	9.49	37.81	23.70	6.07
IRLI26	11.44	38.71	25.25	6.39
IRLI27	8.00	37.90	25.03	7.16
IRLI28	10.44	37.51	29.01	5.58
IRLB02	9.00	40.80	23.24	7.24
IRLB04	10.00	38.91	22.78	6.54
IRLB05	18.23	35.42	26.29	4.72
IRLB06	10.50	35.15	21.71	5.88
IRLB09	12.00	38.88	21.42	5.76
IRLSCPW	14.15	35.81	26.12	5.62
IRLNFH01S	17.13	23.06	19.75	1.52
IRLEGU	0.20	32.06	15.76	6.34
IRLUPEGWR	0.20	1.12	0.64	0.11
IRLCCU	0.00	35.32	14.49	8.62
IRLTUS	0.00	36.60	11.29	9.81
IRLTPM	0.17	23.82	1.44	2.41
IRLBFRR	1.32	53.19	28.37	10.05
IRLSUS	0.33	37.50	23.46	9.65

B. Temperature

StationID	Min	Max	Mean	Stdev
IRLI02	8.94	31.64	23.55	5.12
IRLI06	10.28	32.62	24.06	5.10
IRLI07	10.23	34.12	24.13	4.99
IRLI10	10.88	32.65	24.44	5.11
IRLI13	10.97	32.17	24.28	4.94
IRLI15	11.02	32.26	24.68	4.86
IRLI16	14.72	37.00	25.01	4.79
IRLI18	10.93	32.93	24.71	4.72
IRLI21	11.34	32.49	24.75	4.76
IRLI09E	12.83	30.90	24.43	4.60
IRLI23	11.31	32.73	24.52	4.74
IRLI24	13.05	32.04	24.74	4.71
IRLI26	9.65	31.89	24.60	4.86
IRLI27	10.25	33.19	24.98	4.68
IRLI28	9.30	31.40	24.81	4.52
IRLB02	10.20	34.00	24.14	4.97
IRLB04	7.84	31.96	24.14	4.93
IRLB05	17.18	32.38	25.32	4.16
IRLB06	9.18	32.32	24.28	4.88
IRLB09	8.29	32.89	24.46	4.95
IRLSCPW	15.53	32.84	25.24	4.39
IRLNFH01S	17.09	31.63	24.35	4.56
IRLEGU	12.01	34.55	25.49	4.82
IRLUPEGWR	12.27	31.55	24.84	4.13
IRLCCU	11.98	34.34	25.45	4.62
IRLTUS	12.83	33.71	25.18	4.50
IRLTPM	11.71	31.63	24.86	4.35
IRLBFRR	7.24	31.85	23.69	4.96
IRLSUS	12.76	31.64	24.60	4.31

Return to Figure 3

Appendix D. Site Selection Decision Tree



Site Selection Decision Tree Long Description

I. Top of chart begins: “Is seagrass present (resource survey during growing season, April-October) or was it present in 14 of the last 16 surveys (SJRWMD seagrass data)?” (2 options)
   a. If “Yes” to seagrass being present, then “Caution. Discuss with permitting agencies to determine if avoidance is possible.” (2 options)
      i. If Seagrass is extensive and / or unavoidable then Stop.
      ii. If Seagrass can be avoided then ask: “Considering seasonal water levels, is the depth suitable for subtidal oyster growth and survival” – refer to list item II to continue.
   b. If “No” to seagrass being present, then ask: “Considering seasonal water levels, is the depth suitable for subtidal oyster growth and survival” – refer to list item II to continue.

II. After addressing Seagrass presence, if able to continue through the decision tree the next question is: “Considering seasonal water levels, is the depth suitable for subtidal oyster growth and survival?” (4 options)
   a. If the Depth is less than 12 inches then “Stop. Water level variations are likely to prevent success.”
   b. If the Depth is in between 12 inches and 24 inches then “Caution. Consider that seasonal water level variations will likely prevent success. Evaluate at low water season.” (2 options)
      i. If Depth is less than 12 inches at low water then “Stop. Water level variations are likely to prevent success.”
      ii. If Depth is greater than 12 inches at low water then ask: “What is the composition of the bottom sediments?” – refer to list item III to continue.
   c. If the Depth is between 24 inches and 36 inches then ask: “What is the composition of the bottom sediments?” – refer to list item III to continue.
   d. If the Depth is greater than 36 inches then “Caution. Stratification may limit D.O. Evaluate D.O. during late summer (around September)” (2 options)
      i. If D.O. is less than 4 milligrams per liter then Stop.
      ii. If D.O. is greater than 4 milligrams per liter then ask: “What is the composition of the bottom sediments” – refer to list item III to continue.

III. After addressing Depth, if able to continue through the decision tree the next question is: “What is the composition of the bottom sediments” (2 options)
   a. If the Bottom has mucky, fine-grain sediments, then “Stop. Sedimentation and high oxygen demands will likely prevent long term success.”
   b. If the Bottom has generally, clean sand or firm bottom, or soft sand, but no muck deposits, then “Sedimentation may be an issue at this site. Is the fetch long enough to trigger entrainment events? Would it be appropriate to employ a higher relief design at this site?” – refer to list item IV to continue.

IV. After considering Bottom composition, if able to continue through the decision tree the next question is: "Is the fetch long enough to trigger entrainment events? Would it be appropriate to employ a higher relief design at this site?" (2 options)
    a. If Fetch is long and depth is limited, or entrainment is likely, then Stop.
    b. If Fetch is short or fetch is long but project can be moved out from wave break zone, then ask: "Is salinity within preferred range of 10-28 ppt? Is the site in a low volume area with high drainage (e.g. a canal system?" – refer to list item V to continue.

V. After considering Fetch, if able to continue through the decision tree the next question is: "Is salinity within preferred range of 10-28 ppt? Is the site in a low volume area with high drainage (e.g. a canal system?" (3 options)
    a. If Salinity is not within range, then Stop.
    b. If Salinity is within optimal range but site is within a canal, then "Caution. Salinity and D.O. fluctuations within canal systems may limit survival. Larval transport is also likely to be very low in these areas." (2 options)
        i. If no Live Adult Oysters are observed, then Stop.
        ii. If Live Adult Oysters are observed, then ask: "Are there live oysters present or other indications of larval transport to the site?" – refer to list item VI to continue.
    c. If Salinity is within optimal range and outside of a canal, then ask "Are there live oysters present, or other indications of larval transport to the site?" – refer to list item VI to continue.

VI. After considering Salinity, if able to continue through the decision tree the next question is: "Are there live oysters present, or other indications of larval transport to the site?" (3 options)
    a. If yes, Live Adult Oysters are present, then "Build an oyster project. The flow chart may not have indicated which sites should have live adult oysters (Gardened Oysters) added, but they should be added when feasible."
    b. If no Live Oysters or oyster scars observed, then "Recruitment appears limited. Would Gardened oysters survive here is added to the project? Are you within 3 km of another oyster bar/reef? Do you have good access to flow?" (3 options)
        i. If "no to all", then Stop.
        ii. If "yes to all", then "Build an oyster project. The flow chart may not have indicated which sites should have live adult oysters (Gardened Oysters) added, but they should be added when feasible."
        iii. If "yes to all except flow", then "Caution. Consider moving further from shore." (2 options)
            1. If project cannot be moved further from shore, then Stop.
            2. If project can be moved further from shore, then "Build an oyster project. The flow chart may not have indicated which sites should

have live adult oysters (Gardened Oysters) added, but they should be added when feasible."

c. If small oysters (less than 40 millimeters) or scars are present, then ask: "Are scars/small oysters subtidal during seasonal low (March/April) or is project located in a cove." (2 options)
    i. If scars are underwater during seasonal low and flow is not restricted then, "Build an oyster project. The flow chart may not have indicated which sites should have live adult oysters (Gardened Oysters) added, but they should be added when feasible."
    ii. If scars are all above the water during seasonal low or project is in a cove, then "Caution, seasonal depth could be limiting. Consider moving further from shore." (2 options)
        1. If project cannot be moved further from shore, then Stop.
        2. If project can be moved further from shore, then "Build an oyster project. The flow chart may not have indicated which sites should have live adult oysters (Gardened Oysters) added, but they should be added when feasible."

VII. Additional considerations for oyster site selection regarding Predators and Fouling:
    a. Note presence of predators (Blue Crabs, Crown Conchs). If many are observed, is this a good site?
    b. Observe hard surfaces, are they extensively covered with barnacles, tube worms, or other species competing for space?
    c. Does owner know of previous events where wrack (algae mats/drift algae) have built up on the shoreline? Could pose a suffocation threat to nearshore oysters.

Return to Section 5