Final Report—Suwannee Sound Oyster Reef Mapping

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INTRODUCTION

This report is the second part of an oyster reef mapping project (conducted from 2020-2022) that included Suwannee Sound (**Figure 1**) and Apalachicola Bay. The final report for Apalachicola Bay was submitted earlier (Grizzle et al. 2022). Both mapping efforts were the initial major component of a larger, longer-term effort being conducted by the Florida Fish and Wildlife Conservation Commission (FWC) aimed at restoring degraded oyster reefs in both areas. *The overall aim of the mapping in both areas was to provide current information on the spatial extent of live oyster reefs and bottom types potentially suitable for reef construction/restoration activities.*

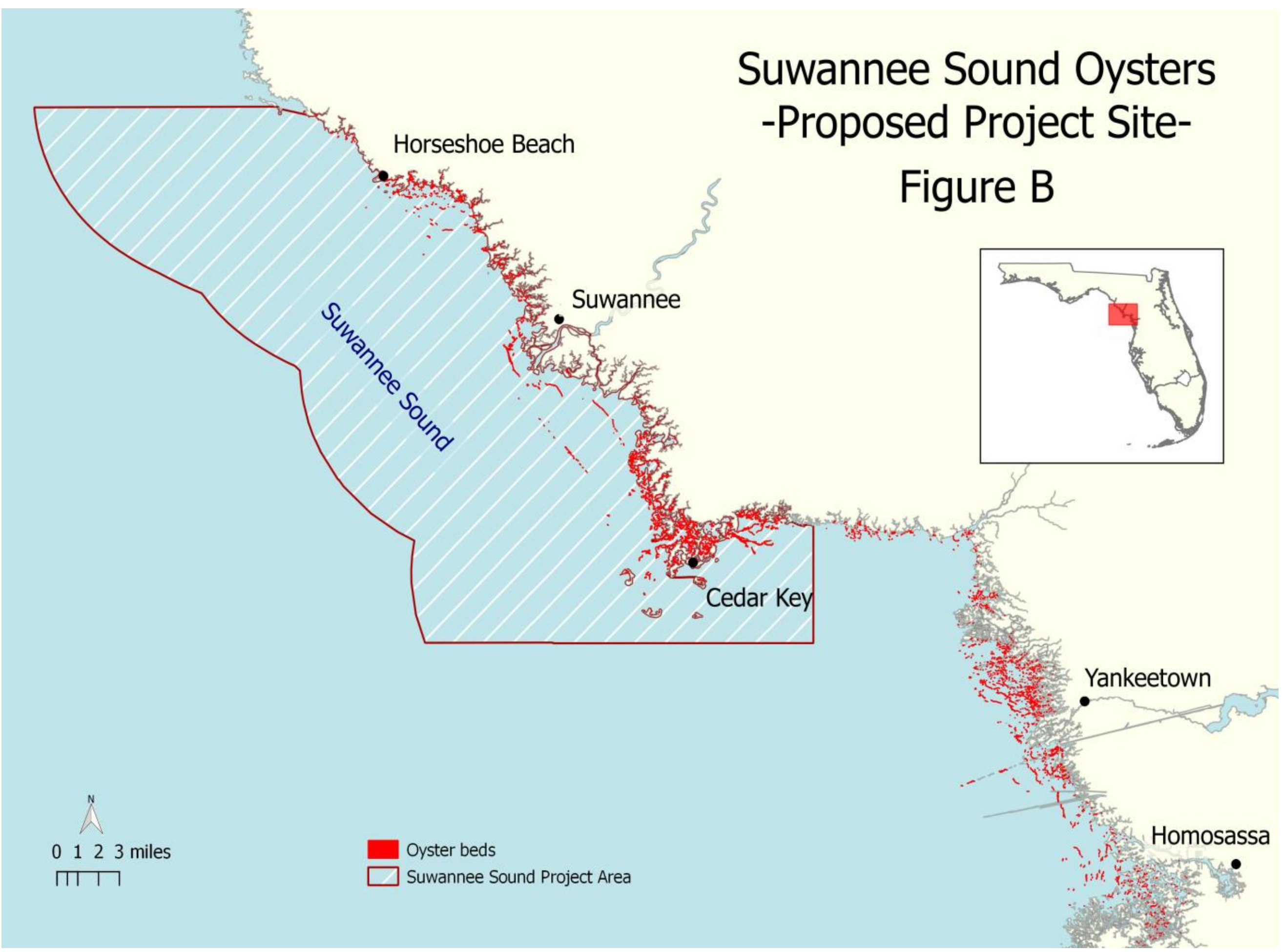

Figure 1. Overview of study area in Suwannee Sound (from FWC NFWF 2019 project proposal).

Mapping efforts in the two areas differed in time required to conduct the mapping and methods used. Apalachicola Bay was the primary focus because it was first-up for restoration, and available maps and other information indicated a much larger oyster resource, at least historically. Mapping in Apalachicola Bay also only included subtidal reefs because the Bay's intertidal reefs recently had been mapped, and areal coverage by subtidal reefs greatly exceeded the intertidal reefs (Grizzle et al. 2018). In contrast, mapping in Suwannee Sound included both intertidal and subtidal reefs, and available maps indicated much less total areal coverage by live oyster reefs compared to Apalachicola Bay.

METHODS

Study Area and Project Initiation

The study area was essentially all areas in Suwannee Sound and areas landward where oysters occurred, from just north of Horseshoe Beach to ~10 km east of Cedar Key (**Figure 1**). The results of other mapping projects in the study area over the past several decades indicated nearly all live oyster reefs were intertidal **(Figure 2**). It was, however, recognized at the start of the project that most (all?) of the historical maps were based on aerial imagery which is usually not capable of effectively detecting oysters in subtidal waters. The major subtidal reefs were thought to have occurred as part of the Great Suwannee Reef, a major offshore reef system which extended from just north of Cedar Key to the mouth of the Suwannee River (blue polygons in **Figure 2**). This reef system had become badly degraded by the 1990s (Patterson 2002; Seavy et al. 2011) and apparently mainly consisted of dead shell and sand when the present survey was initiated. The nearby but closer-to-shore Lone Cabbage reef was mostly intertidal but also included subtidal oysters in some areas (Frederick et al. 2016; Pine et al. 2022). Subtidal reefs were also known to occur in deeper tidal channels near shore, but none had been mapped. In sum, when the present project was started previous mapping efforts had focused on intertidal reefs, and the extent of subtidal reefs was largely unknown. Thus, the overall project included methods capable of sensing/mapping live oysters across a wide range of water depths and extending geographically from tidal creeks well inshore to open-Gulf waters several kilometers offshore.

Figure 2 provided the starting point for the project, for both intertidal and subtidal reefs. It was determined that existing maps of intertidal reefs could be updated effectively using satellite imagery. In contrast, the areal extent of the overall study area, and the shallow waters in many areas at most tide stages, made extensive exploratory mapping in subtidal waters unfeasible within budgetary and other constraints. Thus, subtidal oyster reef mapping was initiated by consulting individuals with local expert knowledge. Subsequent field surveys of subtidal reefs largely were based on expert knowledge provided by individuals in the study area. The report is divided into two sections with each of the two reef types discussed separately.

Intertidal Reefs

Study area and overall design

It was decided early on that the present project would focus on those areas not mapped by Radabaugh and colleagues (Adams et al. 2019), so the two projects combined would cover the entire study area shown in **Figure 1** above. Radabaugh's effort had focused on those reefs about 10 km north of Cedar Key to the Horseshoe Beach area. Thus, the present project included only those areas indicated by the circle surrounding Cedar Key in **Figure 2** and consisted of the four major components described below. Mapping of intertidal reefs followed methods used in Radabaugh's (Adams et al. 2019) and our previous mapping in Apalachicola Bay (Grizzle et al. 2018). Both projects used satellite imagery available online because although it has limitations, it has been demonstrated to be effective for mapping intertidal reefs in other areas and is becoming a standard method for mapping shallow-water coastal habitats in general.

Preliminary field survey (2020)

A preliminary field survey was conducted to determine the most effective methods for ground-truthing the intertidal reefs, as well as to gather information on the potential extent of subtidal oyster reefs (see below). The major concern for intertidal reef ground-truthing was how accessible the reefs would be during various tide stages, and what type(s) of vessel might be required. This site visit also included interviews with local individuals knowledgeable about oyster ecology and commercial oyster harvesting in the Cedar Key area.

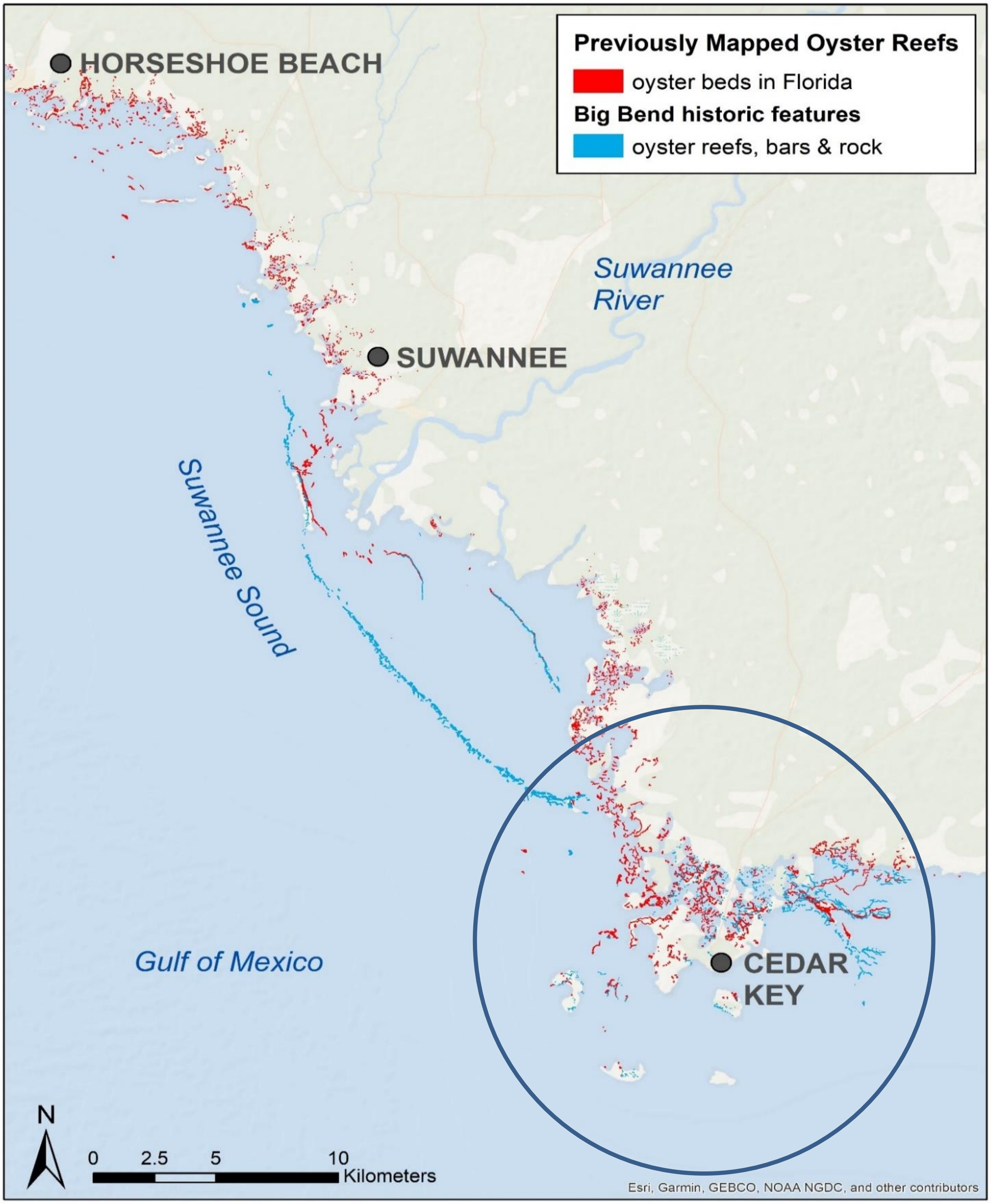

Figure 2. Composite map showing oyster reefs mapped in the study area from various sources before 2000 (blue polygons) and the current (2022) "oyster beds in Florida" online shapefile (red polygons). Blue circle delimits area where intertidal reef mapping was conducted for the present project.

Preliminary map production (2021)

Preliminary maps of intertidal reefs in the study area were produced using online imagery accessed on GoogleEarth and processed using ArcGIS software. Oyster reefs were classified (photointerpretation) visually following the 6540 ("Oyster Bars") code from the Florida Land Use, Cover and Forms Classification System (FLUCCS), originally developed by the Florida Department of Transportation (FDOT 1999), using the following characteristics:

1. *Linear and or oval shape with some having branching arms.*
2. *Typically have a bright white signature due to the "hash" (dead oyster shells) that has been bleached due to exposure to the sun. The hash area typically occurs directly adjacent to living oyster bars. During photointerpretation the hash areas are included as part of the oyster bar.*
3. *Parallel ridges formed by remnant oyster shells deposited by waves washing over the bar.*
4. *Oysters typically occur in association with* Spartina *sp. emergent vegetation.* Spartina *is often the only cover type visible on the photography and thus is used to delineate oyster habitat particularly on narrow strand type islands.* Juncus *sp., when visible on the photography, is not included as oyster habitat.*
5. *Code 6541: A cotton-ball like appearance when submerged.*
6. *Presence of bright white signatures indicative of patch oyster reefs in high-flow areas of tidal creeks. These high-flow, deeper areas are typically on the outside bends of the creeks and would scour lighter, less consolidated sediment such as sand or mud deposits.*

The spatial resolution of the imagery used was <1 m, but a minimum mapping unit was set at approximately ~12 m^2 for individual reefs. In cases where multiple small reefs occurred adjacent to one another and likely were connected, a single polygon was drawn that encompassed all the individual reefs.

Ground-truthing and map revision (2021-2022)

Ground-truthing by field visits occurred on two occasions, each followed by revision of the maps. The aim was an iterative mapping process in order to make the final maps as thematically accurate (i.e., level of correct identification) as practical. It should be noted that this is a departure from typical mapping where ground-truthing data are mainly used to calculate thematic accuracy of the final maps in order to provide the user with some level of confidence in the mapped features.

Field surveys were conducted by navigating tidal channels near the mapped reefs in an outboard-powered skiff or an airboat. A laptop running ArcGIS with real-time GPS indicated the vessel position relative to the mapped reefs, and notes were made on mapped reef characteristics. The focus was on whether the mapped reef (polygon) was correctly identified as "intertidal oyster reef" (based on six features above), but also included information on features such as amount of shell hash, mangroves, and salt marsh plants. Map revisions after each ground-truthing visit focused on correcting mis-identified intertidal oyster reefs. It also involved mapping of mangroves that occur on some oyster reefs and "rakes" consisting mainly of shell hash that can be indicative of negative impacts of boat wakes, as found in Apalachicola Bay (Grizzle et al. 2018) and other areas in Florida (Grizzle et al. 2002; Garvis et al. 2020). Note that these areas are typically included in maps of live reefs (see criteria 2 and 6 above).

Final map production (2022)

Final map production involved incorporation of all ground-truthing data into the final revisions of the preliminary maps. The major map product shows the location and size of all mapped intertidal reefs based on the FLUCCS criteria listed above, and are available online as ArcGIS shapefiles with metadata, kml files, and jpeg image files (see Appendices for complete list of all files).

Subtidal Reefs

Study area and overall design

As noted above, subtidal oyster reef mapping was initiated by consulting individuals with local expert knowledge with the major goal being reducing the total survey area (**Figure 1**) to an extent manageable within budgetary and time constraints. Additionally, there was the challenge of generally shallow waters in the study area relative to the draft requirements of the acoustic survey vessel and the need to avoid shoal areas to prevent damage to sensors (**Figure 3**). Thus, field work for subtidal reef mapping was initiated during the preliminary field survey described above for the intertidal mapping effort. This was followed by two acoustic surveys and map production, as described below.

Preliminary field survey, information gathering (2020)

This task consisted of a visit to the study area to interview local fishers, scientists, and others familiar with oysters in the study area coupled with a boat trip to preliminarily survey a portion of the study area. An information gathering event was also hosted by the University of Florida's Nature Coast Laboratory in Cedar Key. A primary take-away from this initial field visit was that subtidal oysters were generally thought to be clustered around known reef structures (e.g., Great Suwannee Reef, Lone Cabbage Reef, Halfmoon Reef, etc.)

Initial acoustics and ground-truthing (2021)

Two acoustic systems and a primary vessel navigation and orientation system mounted on a 24-foot research vessel, *R/V Diversity (***Figure 3A***)*, were used to acquire data along multiple parallel ship tracks navigated across each of the final target reefs. The standard survey equipment on *Diversity* for this project included a bow-mounted Klein 3500 dual-frequency side-scan sonar system, a side-mounted Innomar SES-2000 dual-frequency, parametric sub-bottom profiler, an Applanix POSMV 320 vessel position and motion reference unit, a YSI Castaway conductivity-temperature-depth (CTD) speed of sound profiler, and Hypack hydrographic data acquisition and processing software package.

The Applanix POSMV Global Navigation Satellite System (GNSS), supplemented with real-time differential correctors from both a local base station and the Florida DOT Real-Time network, was used to provide real-time horizontal and vertical error estimates (root mean square) generally less than 5 cm. Raw POSMV observables were recorded during all survey operations and POSPac Mobile Mapping Suite software was used to improve the real-time position and elevation data, especially during periods when there were issues with the real-time differential data link. During the survey, a NAD83 Universal Transverse Mercator (UTM-meters) coordinate system (Zone 17N) and a Mean Lower Low Water (MLLW-meters) vertical datum were used. NGS Geoid Model12B was used to transform the POSMV NAD83 GNSS ellipsoidal heights to NAVD88 orthometric heights, and the published NOAA VDatum offset was used to convert from NAVD88 to MLLW. In addition to the continuous GNSS-derived water-level observations on the survey boat, the data from the NOAA Cedar Key station was also incorporated into the data processing review.

The Klein 3500 is a simultaneous dual-frequency, side-scan sonar operating at 445 and 900 kHz with a nominal horizontal beamwidth of 0.34º and a wideband frequency-modulated chirp pulse width of 1 to 8 msec. For this survey, the sonar towfish was mounted on a rigid bow-mount fairing at a fixed depth below the water surface and with known, fixed offsets to the primary POSMV navigation reference point. The side-scan sonar range-scale was usually set to 50 m, though 25- and 75-m range-scales were also used. The biggest impediment to side-scan sonar data quality was shallow water and water-column refraction which was caused primarily by variations in salinity. Processing the side-scan sonar data included reviewing the raw sensor and navigation data, reviewing and updating the bottom-tracking, clipping data, applying a variety of gain adjustments, and creating imagery mosaics at various resolutions to assess data coverage, to compare overlap areas, and to integrate into the project geodatabase. Though both 455 and 900 kHz side-scan sonar data were acquired, the processing effort focused almost entirely on the 900 kHz data because it provided higher-resolution imagery.

The Innomar SES-2000 dual-frequency parametric sub-bottom profiler was deployed on an over-the-side fairing tightly integrated with the primary POSMV reference point. The SES-2000 high-frequency channel was fixed at 100 kHz and was the primary source for tracking the initial bay bottom reflector and producing the single-beam bathymetry, while the SES-2000 low-frequency channel was user-selectable in the range of 4 - 20 kHz and was the primary source for tracking any sub-surface horizons or objects. The range resolution of the system is dependent on frequency and pulse length, with lower frequencies and longer pulse lengths resulting in lower resolution, but greater potential for imaging deeper below the seabed. For these operations when shallow penetration was the primary focus, the low-frequency channel was set to 12-15 kHz with a pulse length of one, resulting in a range resolution of approximately 10 cm. The range resolution for the high-frequency channel (and single-beam bathymetry) was around 4 cm.

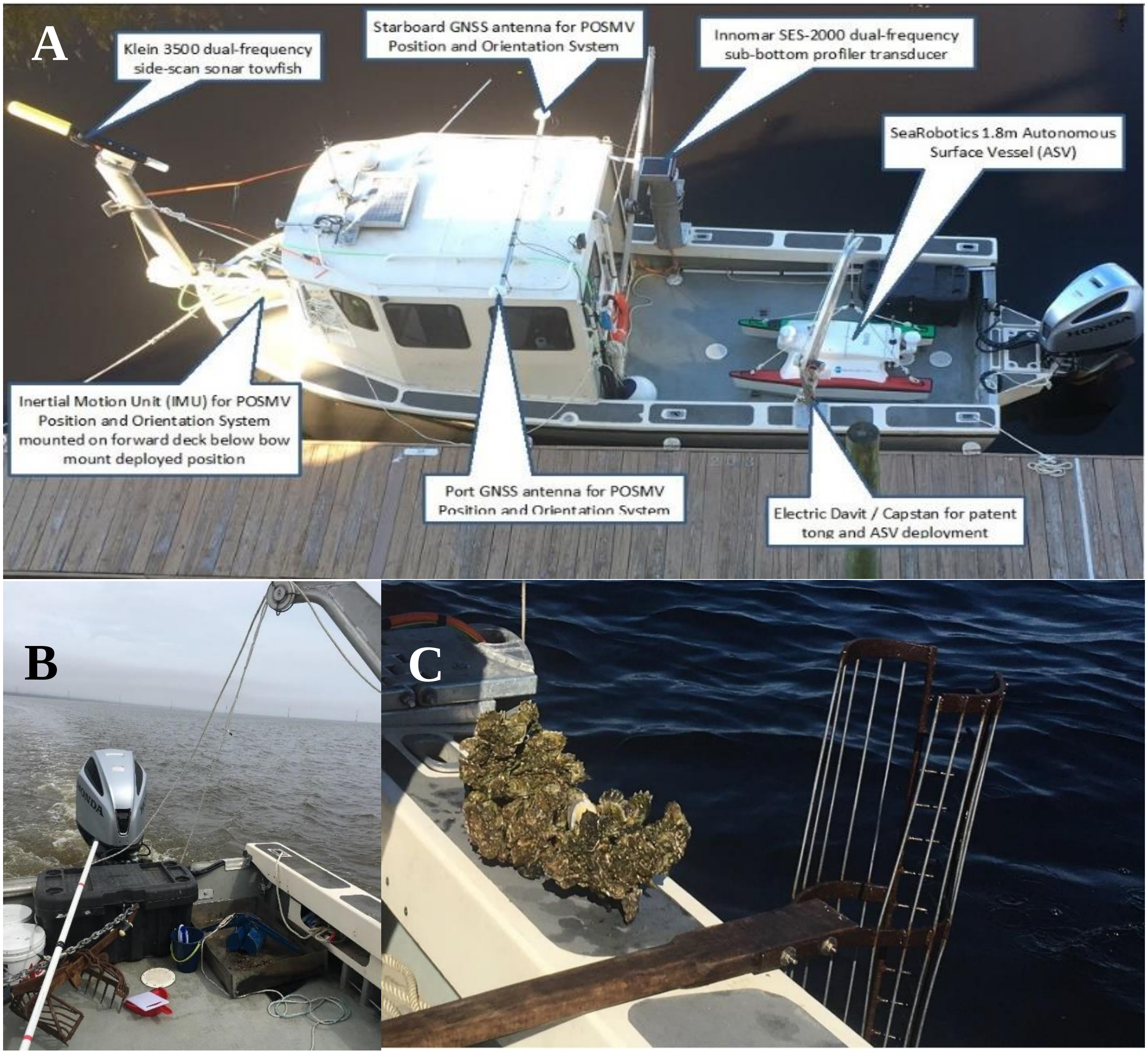

Figure 3. A: R/V *Diversity* (24-foot length, 8-foot beam) with major components used in acoustic surveys labeled: Klein 3500 side-scan sonar deployed from a bow mount; Innomar SES-2000 dual-frequency parametric sub-bottom profiler mounted amidships; Applanix POSMV GNSS antennae mounted on both sides of wheelhouse; SeaRobotics ASV; and davit for deployment of ASV and patent tongs. **B**: gear used for bottom sampling (ground-truthing); **C**: handheld tongs, oyster cluster from Suwannee Sound.

Initial processing of the single-beam data included reviewing the raw sensor and navigation data, reviewing and editing the RTK water-level data, reviewing and applying the speed of sound profile data, cleaning the raw acoustic data, and creating preliminary gridded products. The primary final bathymetric products created from the 100 kHz single-beam data were along-track point files for each of the three survey areas with final gridded MLLW soundings spaced at both 1 and 3 m intervals.

A YSI Castaway CTD profiler was used to acquire water-column profile data before the start of daily survey operations and at routine intervals throughout each survey day. Speed of sound profiles were computed from the CTD data and entered directly into the data acquisition package for application to the single-beam bathymetry data. Despite the overall shallow survey depths (2-3 meters over most areas), there were still significant water-column speed of sound differences (up to 20 m/s) noted in several of CTD profiles that were closely correlated with large salinity differences, primarily associated with freshwater mixing from the Suwannee River

Ground-truthing included probing the bottom with a PVC pipe and sampling with handheld tongs, or patent tongs (**Figure 3**). The surficial sediments at each site were classed as *predominantly*: mud, sand, shell hash, rock, or live oysters. The classification was determined mainly by probing. No samples were extracted for quantitative analysis of textural characteristics, but handheld or patent tong samples were taken at most sites where classification by probing was ambiguous or to confirm the presence of live oysters.

It should be noted that acoustics surveying and ground-truthing were conducted *concurrently*. This was a departure from traditional seafloor mapping protocols where ground-truthing is conducted *after* preliminary maps are produced by acoustics (or other) remote sensing methods in order to determine the “thematic accuracy” of the maps. Our acoustics system provided real-time data for visual inspection, and due to the shallow water depths in most areas, we could quickly probe the bottom or take samples and make notes on our findings, thereby refining the interpretation process of the acoustics imagery as it was collected. The aim was to make the “thematic accuracy” of our final maps ~100%.

Second subtidal reef acoustics survey (2022)

A second (and final) acoustics survey was conducted after acquiring information indicating subtidal reefs likely occurred in most of the tidal channels near their openings (“gaps”) into the Gulf. A total of 44 potential tidal channels to survey were identified ranging geographically from Shired Island north of Suwannee to the Corrigan’s Reef area east of Cedar Key. This survey required mounting the single beam and side scan equipment (see **Figure 3**) onto an FWC vessel suitable for navigating the shallow waters but also providing a stable platform for the gear. Custom mounting brackets were made for the acoustics gear (**Figure 4**). The objective of this effort was to visit as many of the sites as practical obtaining acoustics data and concurrent ground-truthing by probing, handheld tongs, and snorkel surveys in order to determine whether more extensive surveys were warranted.

Figure 4. Custom gear for deploying acoustic sensors from FWC vessel. Left: single-beam sonar and GNSS. Right: bow boom for Klein side-scan tow fish.

Map production (2020-2022)

Map production occurred in all phases of the project and consisted of preliminary maps (2020 and 2021) based on one or two variables, and final maps (2022) based on revisions to earlier maps resulting from ground-truthing or other data. The major preliminary maps were presented in previous progress reports (Grizzle et al. 2020, 2021, 2023), and are only discussed herein when relevant to the final maps. All maps were produced using ArcGIS software, and are available online as shapefiles with metadata, georeferenced image files, and jpeg image files (see Appendices for complete list of all files). In addition, the processed source data files (e.g., side-scan sonar imagery mosaics, bathymetric xyz point data, sampling results spreadsheets, etc.) used to produce the final GIS files have also been provided.

RESULTS AND DISCUSSION

As noted in the Introduction section: *The overall aim of oyster mapping in both areas* (Apalachicola Bay and Suwannee Sound) *was to provide current information on the spatial extent of live oyster reefs and bottom types potentially suitable for reef construction/restoration activities.* The project only included subtidal reefs in Apalachicola because the intertidal reefs had been mapped recently (Grizzle et al. 2018), and the final report for that portion of the project has been submitted (Grizzle et al. 2022). The effort in Suwannee Sound, however, included both intertidal and subtidal reef mapping. Nearly all historical oyster mapping in the Sound focused on intertidal reefs that can be mapped using aerial or satellite imagery. Thus, mapping the intertidal reefs for the present project was planned as a repetition of essentially 'standard methods' using current satellite imagery. Nonetheless, there were unexpected findings during ground-truthing that resulted in expansion of the final map products. All major results for intertidal oyster reefs are described and discussed in the next section, including some discussion of previous mapping of intertidal reefs in the study area.

In contrast, our preliminary investigations turned up very little information on subtidal oyster reefs in Suwannee Sound except for portions of the major offshore reefs (Great Suwannee Reef and Lone Cabbage Reef) that were known to extend well below the intertidal zone in some areas and were likely included to some extent in previous maps that focused on the intertidal portions of these reefs. The overall result with respect to new mapping of subtidal oysters was that our mapping would be breaking new ground because there were *no existing maps* for these reefs. Thus, the subtidal reefs portion of the present project initially focused on expert knowledge provided by scientists, fishers, and others familiar with oysters in the region, followed by design and implementation of field studies based on the new information. The Subtidal Reefs section below describes the overall process, and the major results.

Intertidal Reefs

Preliminary field surveys and maps (2020, 2021)

As noted in Progress Report #2 (Grizzle et al. 2021), intertidal reefs from north of Horseshoe Beach to southern Suwannee Sound were mapped by Adams et al. (2019; **Figure 5, left**). We agreed to combine our efforts and to produce new maps of intertidal oyster reefs from southern Suwannee Sound to a portion of Waccasassa Sound east of Cedar Key (**Figure 5, right**) to complete our contracted study area (**Figure 2**). Field work was conducted over the periods October 23 – 26, 2020 and June 2 – 6, 2021. The initial visit focused on determining how to conduct ground-truthing, and to assess a portion of the first preliminary maps. We concluded from the first visit that an airboat would be required, and the diversity of intertidal reefs in the study area was substantially more than expected. The second visit focused on methods for ground-truthing the preliminary maps. Preliminary maps included a total of ~3,000 individual intertidal reefs ranging in size from 12 m^2 to 5,000 m^2. The June 2021 ground-truthing indicated that 78% of the mapped polygons were oyster reefs, but also revealed substantial diversity in reef characteristics that might be considered for final map production. Three topics are briefly considered here.

Adams et al. (2019; and our effort) mapped areas that included vegetation such as cordgrass and mangroves as well as oysters as "oyster reef" (**Figure 6**). Our ground truthing indicated many more reefs of this complex nature than we have seen in other areas. Long-term successional changes involving oyster reefs becoming mangrove islands is well documented in south Florida (Volety et al. 2009), and recently in east central Florida (McClenachan et al. 2020). The process has not been well studied and it seems likely to be related to climate change as mangroves move further north along both coasts. These areas were included in the overall polygon for each reef in the present project, but future mapping might include separate shapefiles.

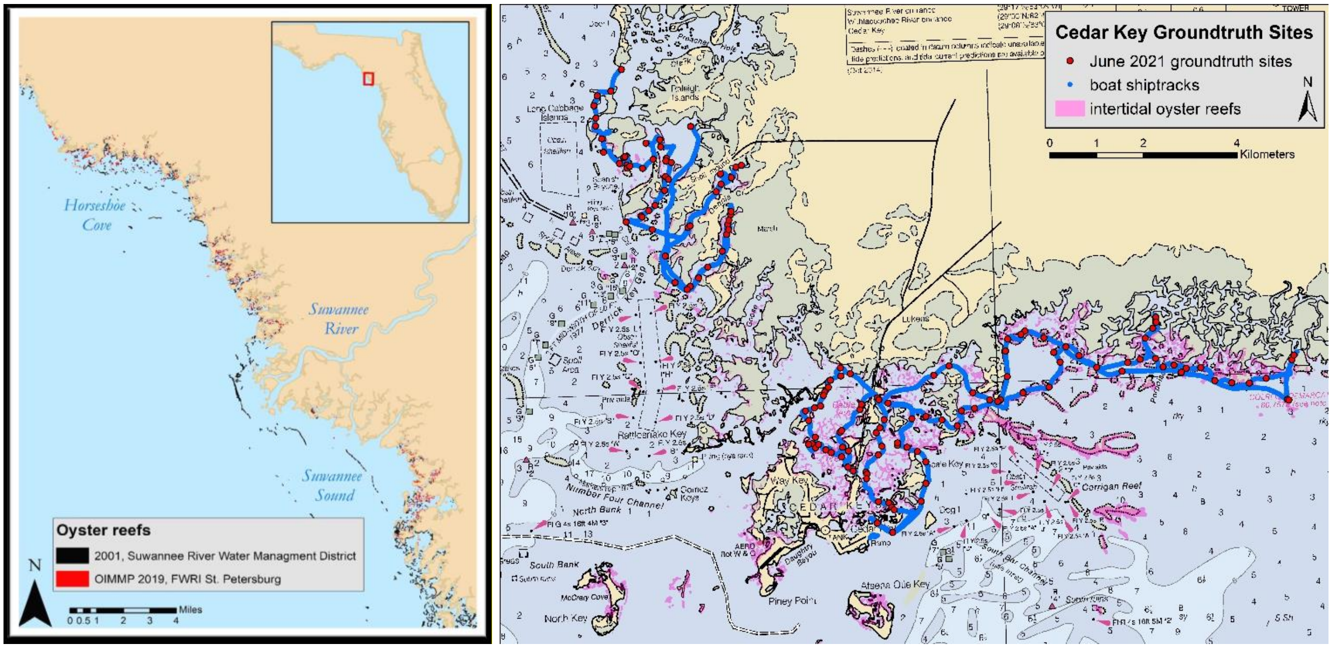

Figure 5. Left: Intertidal oyster reef mapping area conducted by Radabaugh and colleagues in 2019 (Adams et al. 2019). Right: Overview of our intertidal reef mapping area showing ship tracks (blue lines) for ground-truthing, and reefs inspected during site visit in June 2021 (red dots).

Figure 6. Intertidal oyster reefs colonized by cordgrass (*Spartina*) and mangroves.

Live oyster reefs sometimes have areas of dead shell that are typically included in the overall mapped polygon as oyster reef. Dead shell areas in the middle of intertidal reefs have typically been considered a natural process in some areas, though the mechanisms involved are not well understood (Bahr and Lanier 1981). Dead shell accumulations also occur on reef margins, and when exposed to waves and/or boat wakes can be piled several meters high and are called “shell rakes.” The dead margins we observed in Suwannee Sound ranged from accumulations extending <0.5 m vertically to >2 m (**Figure 7**). Studies in other areas have demonstrated that the dead margins are largely caused by boat wakes which in the long-term result in death of oysters on the reef margins, subsequent degradation of the shells, and eventually movement of the dead shell landward (Grizzle et al. 2002, Wall et al. 2005, Coen & Grizzle 2007, Garvis et al. 2015). Even though boat wakes have been identified as a major factor in some areas, there is a need to better understand the range of factors that can produce shell rakes. Thus, changes over time in the amount of “dead margins” might be a useful reef characteristic to quantify to understand the overall condition of the oyster resource as climate change and sea level rise continue.

Figure 7. Low- (left) and high-relief (right) dead shell margins along two boating channels in Cedar Key area (June 2021).

A final important finding from Adams et al. (2019) and our mapping was that substantial numbers of "new" reefs were found. Adams et al. (2019) found a total of 1,126 oyster reefs that had not been included in the 2001 mapping effort (**Figure 8, Left**), and our findings were of a similar magnitude (**Figure 8, Right**). How should this be interpreted? Perhaps the most likely explanation is that different methods (e.g., imagery used, criteria for defining "oyster reef") were used historically, but this and other explanations need to be explored.

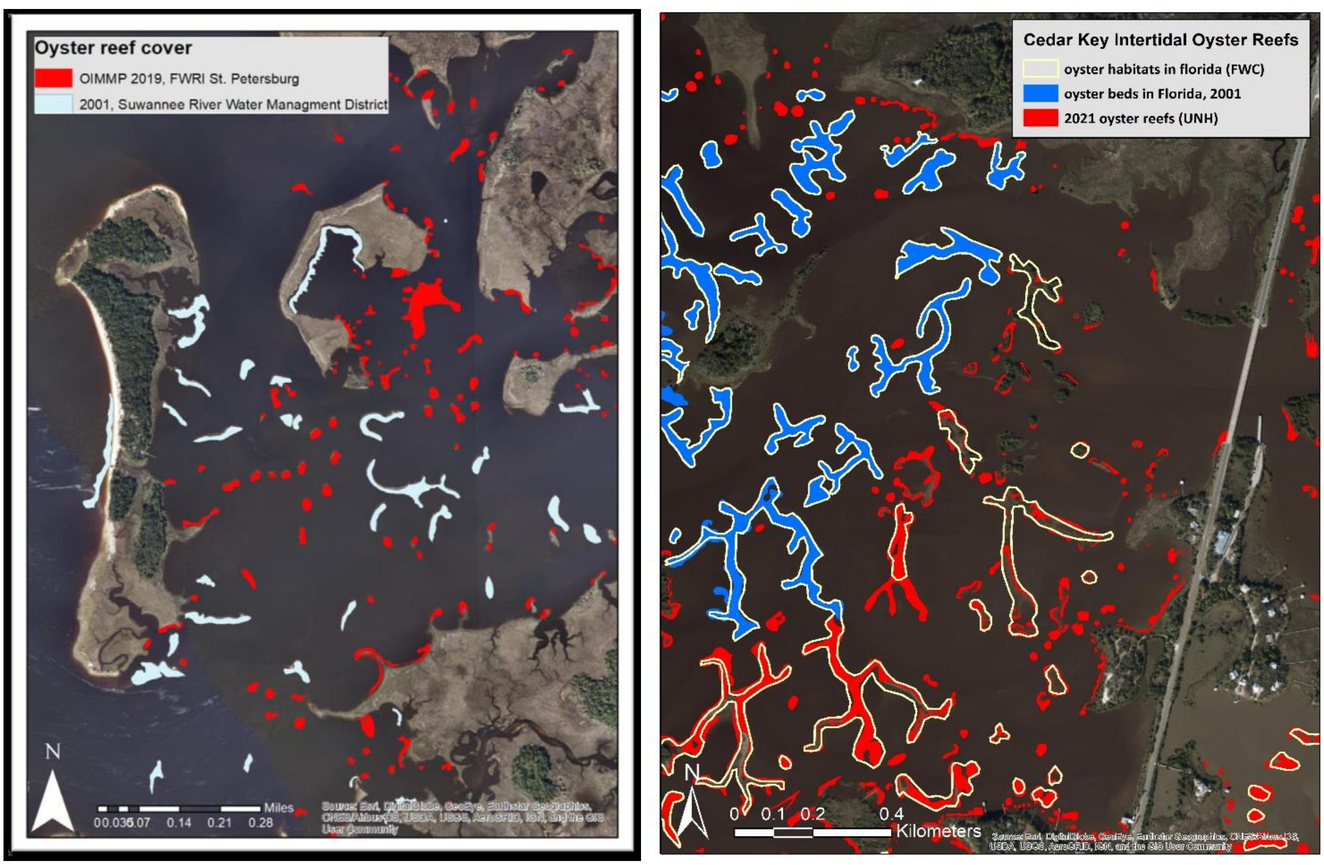

Figure 8. Left: Figure from Adams et al. (2019) illustrating "new" reefs (red polygons) mapped in one area; Right: comparable map from our mapping for one area on Cedar Key expanded to include maps from three sources.

Final ground-truthing and final maps (2022)

As discussed above, the preliminary ground-truthing visit (**Figure 5**) indicated thematic accuracy (correct identification) of the initial mapped intertidal reefs was ~78%. The incorrect identifications were revised, and a second preliminary map was produced. The second and final ground-truthing visit (**Figure 9**) involved visiting 137 questionable reefs (polygons), followed by production of the final map which included a total of 3,817 individual intertidal reefs covering a total of 1,580 acres (640 hectares) (**Figure 10**).

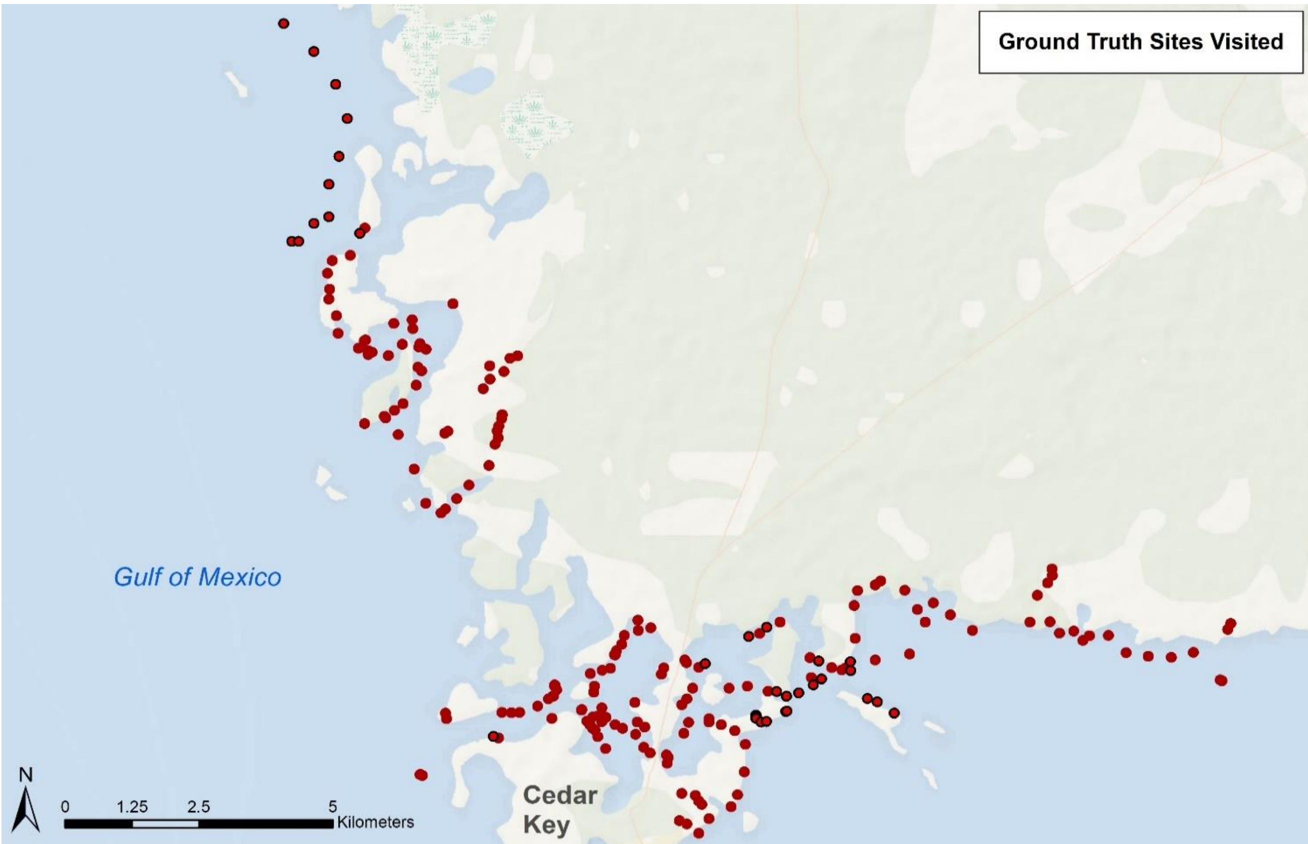

Figure 9. Ground-truthing sites visited on October 23-24, 2020, June 2-4, 2021, and May 24-25, 2022, to inspect intertidal reefs.

Although no attempt was made to compare our current map of intertidal reefs (**Figure 10**) to historical maps, one major change should be noted. The once extensive Corrigan's Reef and the Great Suwannee Reef have suffered major degradations in the past several decades (Berquist et al. 2006; Seavey et al. 2011; Frederick et al. 2016). They currently mainly consist of eroded/transported shell and sand that is easily visible in recent satellite imagery (**Figures 11** and **12**). Thus, a major portion of intertidal reefs in the overall study area have been lost in recent decades. Current mapping (present study and Adams et al. 2019), however, have found perhaps 2,000 individual intertidal reefs that were not mapped in major recent efforts. The implications of these findings remain to be fully assessed in a historical context.

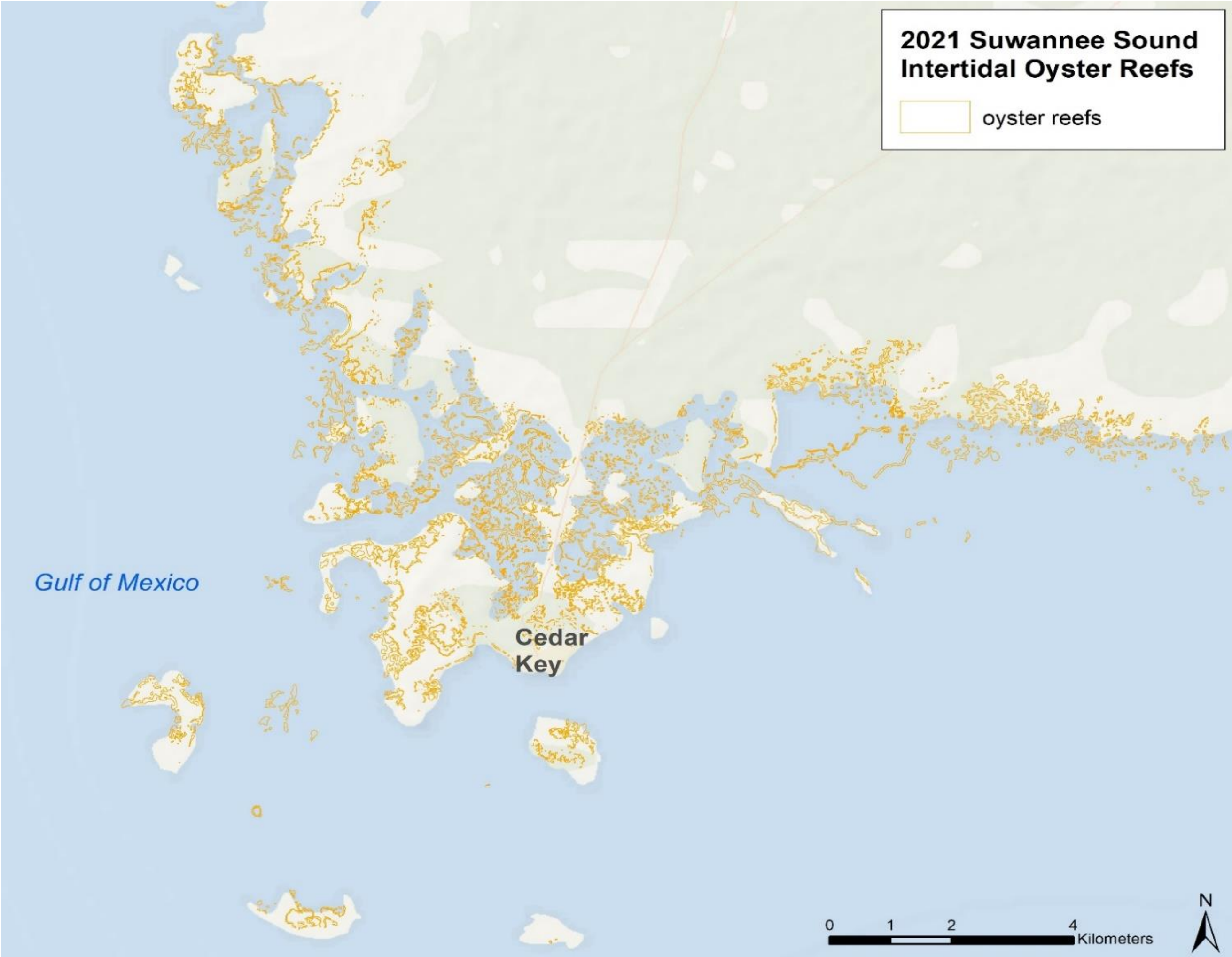

Figure 10. Intertidal oyster reefs in southern portion (see Adams et al. 2019 for northern areas) of study area in Suwannee Sound based on recent (2014 – 2020) satellite imagery and 2021-2022 ground-truthing field inspections.

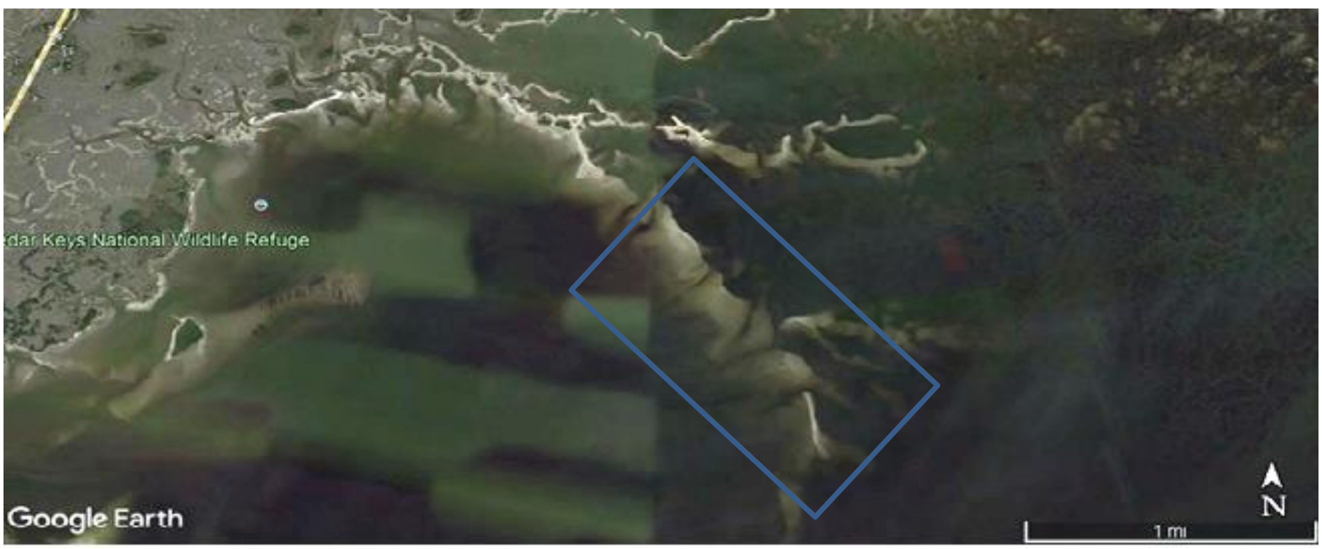

Figure 11. November 2016 Google Earth satellite imagery indicating widespread southwestward erosion of much of Corrigan's Reef in offshore areas (blue rectangle).

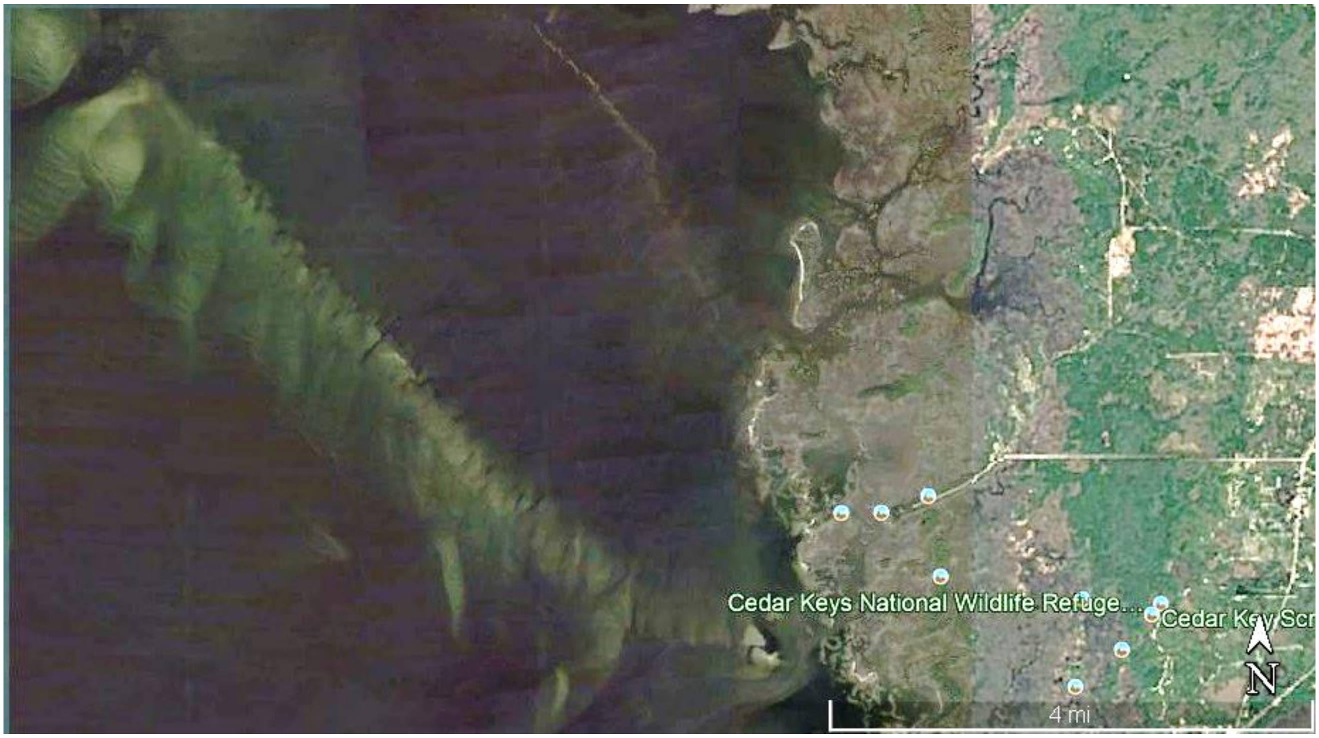

Figure 12. November 2016 Google Earth satellite imagery showing widespread erosion of the Great Suwannee Reef.

Major findings and conclusions for intertidal reefs

The major overall finding for both recent mapping efforts of intertidal reefs in Suwannee Sound ─ Adams et al. (2019) and our mapping ─ was that substantial numbers of "new" reefs were found. Adams et al. (2019) found a total of 1,126 oyster reefs that had not been included in a 2001 mapping effort in their study area (**Figure 8, Left**), and our findings were of a similar magnitude (**Figure 8, Right**). How should this be interpreted? Perhaps the most likely explanation is that different methods (e.g., imagery used, criteria for defining "oyster reef") were used historically. Alternatively, the extent of intertidal reefs in nearshore areas may have increased substantially in the past two decades. Regardless, this and other explanations need to be explored so that future efforts can be more directly compared with historical.

An additional potentially important finding for intertidal reefs was their recent (decadal scale) apparent replacement by mangroves and salt marsh vegetation. Long-term successional replacement of intertidal oysters by mangroves has been well-documented, particularly in south Florida. And in their recent review, Raabe et al. (2021) quantify the decadal scale increase in mangroves but loss of salt marsh habitat in the Big Bend and discuss some management implications. To our knowledge there has been no similar assessment of the management implications of mangroves replacing oyster reefs, nor the relationship of salt marsh vegetation in the process. These assessments would be essential to understanding the effects of climate change and sea level rise on all coastal habitat types.

A final finding of the present study that warrants further assessment was the documentation of shell "rakes" (bleached dead shell) in some areas (**Figure 7**). Research in other geographic areas has implicated boat wakes in rake formation, but other factors are likely involved in some areas. In any case, more research seems warranted for the Sound, perhaps in combination with the effects of climate change and sea level rise.

Subtidal Reefs

Preliminary investigations (2020, 2021)

Field work for this task was conducted over the period October 22–26, 2020. A total of ~50 sites in Suwannee Sound were visited and the bottom probed or sampled with handheld tongs. We assessed a diversity of available information, including interviews with individuals familiar with the oyster resources in the study area, in order to define potential acoustic survey areas. After the preliminary survey, a workshop was hosted by Mike Allen at the Nature Coast Biological Station on June 3, 2021, to discuss our mapping project for subtidal oysters in the context of ongoing or anticipated programs by others. The overall conclusion was that our subtidal mapping should be focused in three areas: near the mouth of Suwannee River, landward of Lone Cabbage Reef, and on both sides of the Great Suwannee Reef (**Figure 13**).

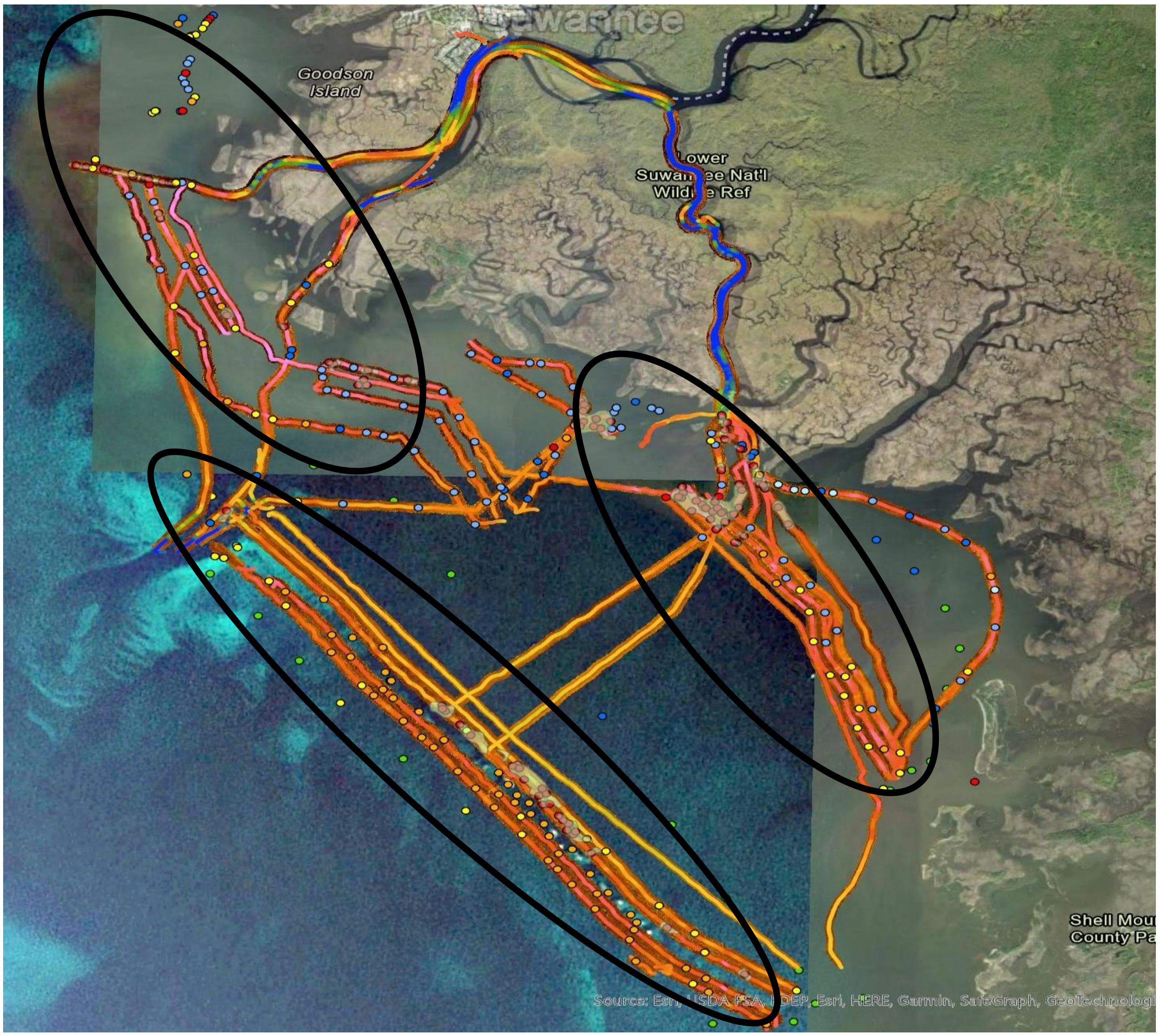

Figure 13. Ship tracks for acoustic surveys of three major areas (black ellipses) in Suwannee Sound during March 5–16, 2021 displayed as color-coded bathymetric data shading from blue (deepest) to red (most shallow) on narrow lines, side-scan imagery (yellow to brown) along wide lines, and ground-truthing data as color-coded circles: red (oysters), blue (mud), yellow (sand), green (shell hash). Green-shaded polygons encompassing oysters (red circles) delimit approximate spatial extent of subtidal oysters based on side-scan sonar imagery and ground-truth samples. See **Figure 14** for larger scale view of major subtidal oyster reef areas.

Initial acoustics and ground-truthing (2021)

Figure 13 above is an overview of the three major areas listed above that were the focus of mapping subtidal reefs, which was conducted on March 5–16, 2021. Surveying in most areas proved to be challenging due to shallow water depths. In addition, persistent easterly winds in early March led to lower-than-normal water levels. Water depths in most areas surveyed ranged from intertidal to >4 m, as indicated by the color-coded bathymetric data along the ship tracks. Together, these factors represented hazardous conditions for the acoustics gear and limited the extent of the subtidal mapping. Nonetheless, acoustic data and a total of 288 ground-truthing datapoints were acquired in the three areas shown in **Figure 13** and subtidal oysters were mapped in many areas (**Figure 14**).

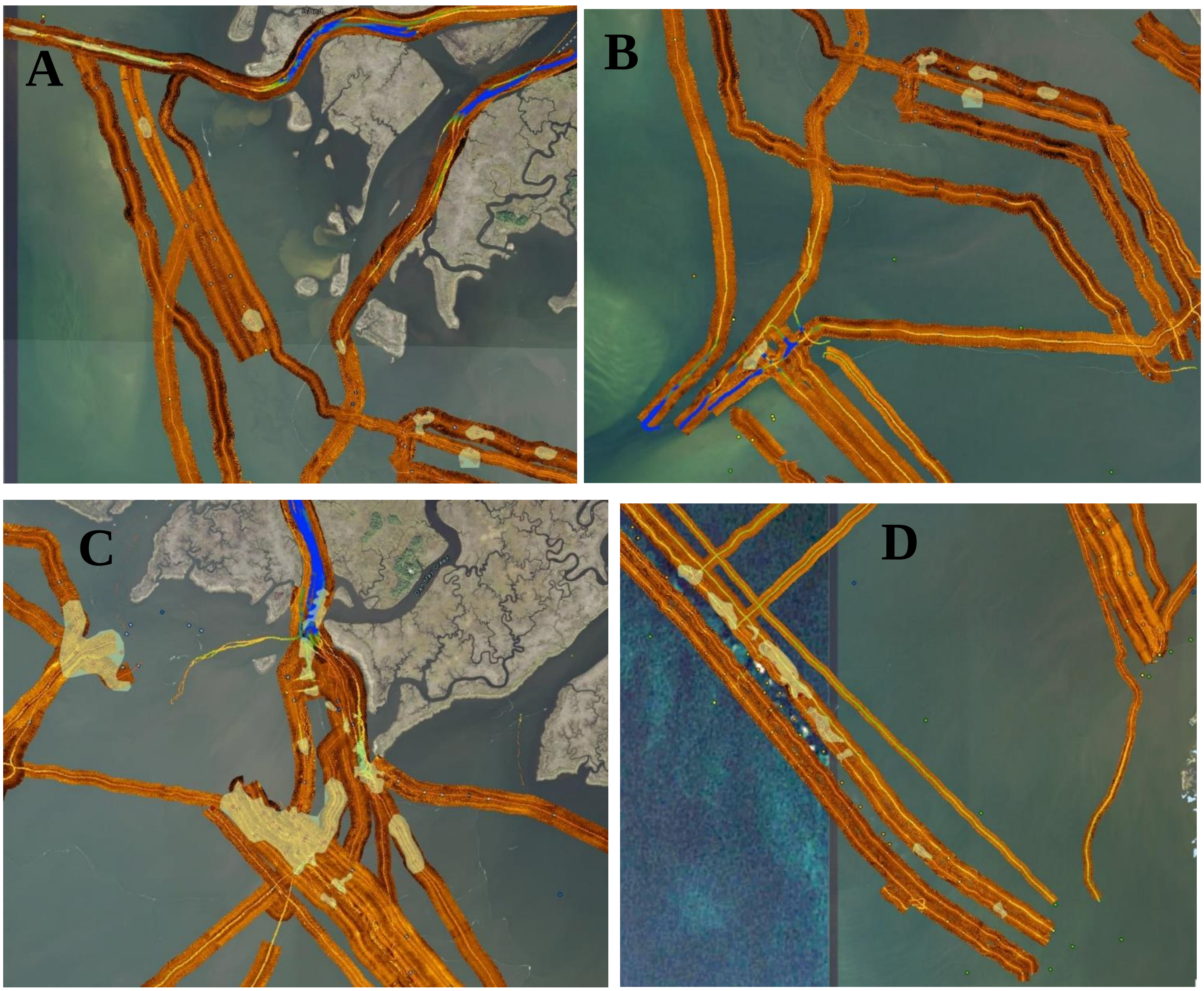

Figure 14. Close-ups of four major areas where live oysters were detected. (A) Suwannee River North and Center Channels, and Halfmoon Reef. (B) Halfmoon Reef and northern section of Great Suwannee Reef. (C) East Pass Suwannee River and Lone Cabbage Reef. (D) Southern section of Great Suwannee Reef.

A total of 32 subtidal reefs ranging in size from 0.2 acre (0.08 hectare) to 69.7 acres (28.2 hectares) were mapped. The total bottom area covered by these reefs was 294 acres (119 hectares). Subtidal oysters were found in all four areas illustrated, but their distribution can be divided into two general areas: at the mouths of major tidal channels (images A, B and C) and on the landward side of the historic Great Suwannee Reef (D). The largest spatial concentration of live subtidal oysters was found around the outlet of the East Pass of the Suwannee River and near the northern sections of Lone Cabbage Reef (image C). Oysters were dense in several of these areas and included clusters that extended ~20 cm above the bottom consisting of multiple size/age classes of live oysters (**Figures 15** and **17**). This area is in a "Prohibited" to harvest zone, and the clusters of oysters collected may represent the vertical extent and other characteristics of unharvested subtidal reefs generally. There was no attempt to rigorously compare the characteristics of subtidal reefs relative to shellfish harvesting area classification, but the tonged oysters in some areas in "Conditionally Approved" waters did not have the structure and vertical extent of those in **Figures 15** and **17** (see more discussion in "Gaps" section below).

Although the subtidal surveys focused on three areas indicated in **Figure 13**, the large area between the two major reefs (Lone Cabbage and Great Suwannee) were partially surveyed during transits between the main study areas. The assumption was that if a subtidal reef did occur in the area, it would likely be oriented parallel to the other two reefs. No oysters were evident in the acoustic imagery along the transit tracks and probing indicated primarily mud or fine sand along these tracks. A final topic to note is that probing detected oysters in a few areas where no acoustic data were acquired (e.g., northwest of the mouth of the North Channel of the Suwannee River) primarily because of wind-driven low-water conditions during the sampling period. . These findings and other information provided the rationale for conducting a second acoustic survey in other areas, as described below.

Figure 15. Clumps of live oysters collected in channel area near north end of Lone Cabbage Reef on March 11, 2021 (ruler scale in inches). Note dense live oysters of multiple size/age classes and vertical relief ~20 cm.

Second subtidal reef survey of "gaps" (2022)

A second and final subtidal acoustic survey was designed based on information provided by Kenny McCain's (UFL, Nature Coast Laboratory) knowledge of oysters and harvest practices in the Cedar Key area. In brief, Kenny suggested that subtidal oysters (which are *not* usually detectable by remote sensing methods used in all historic oyster mapping assessments of the Suwannee Sound area) occurred in many major tidal channels ("gaps") north and east of Cedar Key. Additionally, Kenny provided information on a total of 44 tidal channels where oysters likely occurred or had occurred historically and may have been harvested to depletion (**Figure 16**). <u>The "gaps" survey was aimed at providing data sufficient to estimate the potential spatial extent of nearshore subtidal oysters in the Suwannee Sound/Cedar Key area, and to design future studies to better characterize their extent and condition throughout the region.</u>

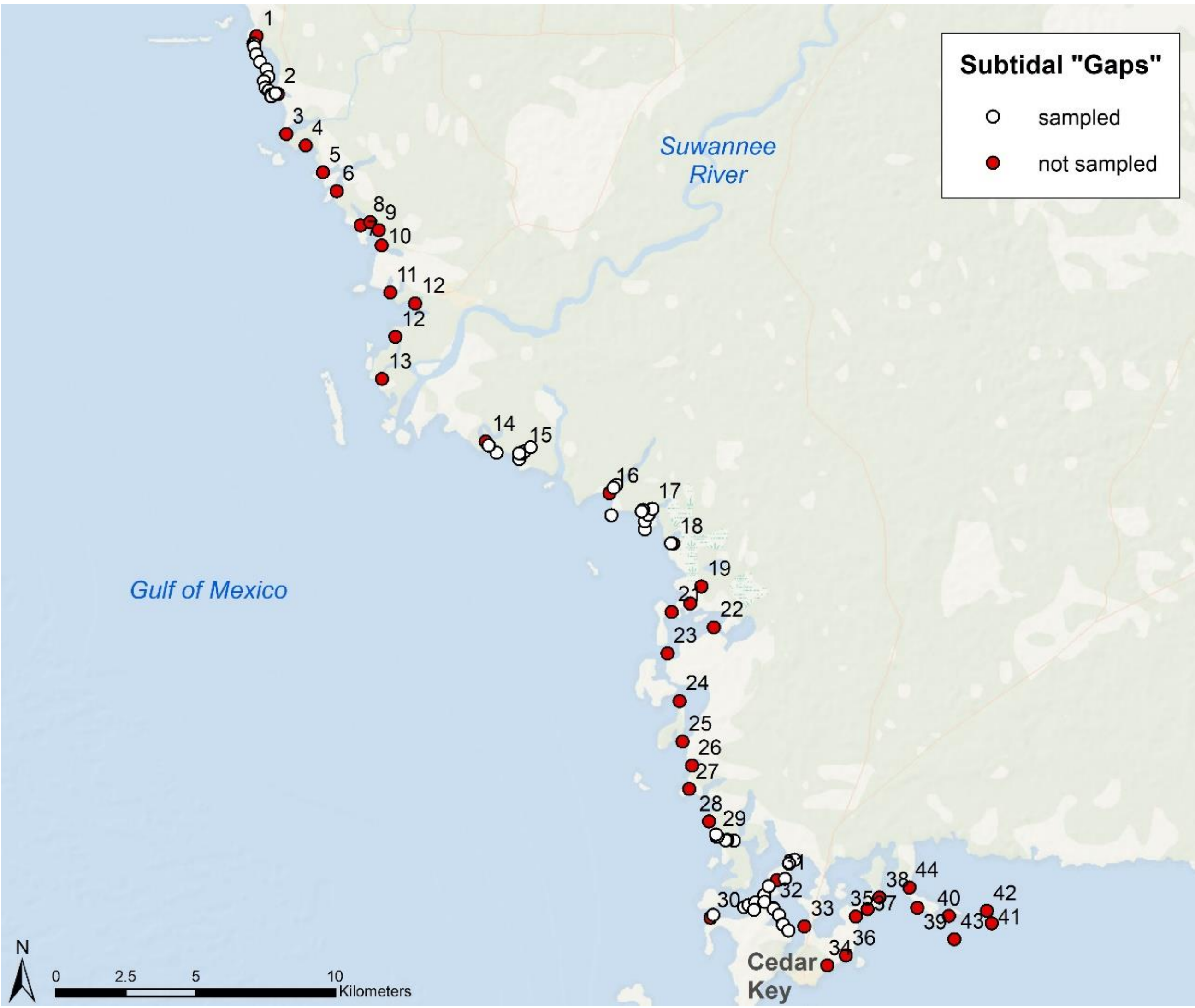

Figure 16. Locations of forty-four "gaps" identified as areas where oysters likely occur subtidally. Red dots were target sites not surveyed, white dots indicate those that were surveyed and are listed in **Table 1**.

A total of 18 of the 44 target gaps were surveyed over the period May 2 – 6, 2022. Based on ground-truthing (probing, tonging, or diver survey), all but two of the 18 sites had live oysters or dead oyster shell present (**Table 1**). These data alone confirm that most, if not all, of the tidal channels in the Cedar Key area probably provide potential habitat for subtidal oyster reefs. There is very little understanding of the relationship between intertidal and subtidal oyster reefs in the entire region, including what factors are involved in determining why one reef type tends to dominate in a particular area. Oyster reefs in the Cedar Key area clearly include both intertidal and subtidal reefs, with both types in close proximity in many areas, but the controlling mechanisms involved are poorly understood. Moreover, the extent of the subtidal reefs has only preliminarily been assessed.

Table 1. Data for gap sites (white dots in **Figure 16**) acoustically surveyed and ground-truthed during May 2 – 6, 2022.

Gap #	Date	Sampling Method	Field Notes
1	5/4/2022	snorkel	sand, rock?, small oyster clumps, mostly dead, some spat
2	5/4/2022	snorkel	4 photos, large clumps, mostly dead, some live spat
3	5/4/2022	probe	oysters in deeper areas
4	5/4/2022	probe	small clumps live oysters
5	5/4/2022	probe	scattered live oyster clumps along ~300 m path into the gap mouth
6	5/4/2022	snorkel	4 photos of live clumps, some started on rocks, multiple size classes
16	5/5/2022	snorkel	~3m deep water, 2 photos, 1 large clump retreived, ate one (not briny, sweet, frim)
17	5/5/2022	snorkel	2 photos, 2 reefs oriented perpendicular to channel, multiple size/year classes, mussels abundant
18	5/5/2022	snorkel	3 photos of large live clumps, multiple size classes
28	5/6/2022	probe	soft sediments
29	5/6/2022	probe	soft sediments, shell, live oysters?
30	5/6/2022	probe	major channel, sand bottom, sand waves in single-beam, some shell
31	5/6/2022	probe	firm bottom, shell, live oysters?
32	5/6/2022	probe	live oyster clumps, major channel
34	5/2/2022	tongs	hard bottom, no live adults, some live spat
35	5/3/2022	tongs	one live oyster, spat, mostly dead shell for 100+ m transect
37	5/3/2022	probe	oysters
44	5/3/2022	tongs	mud, some live oysters, west side

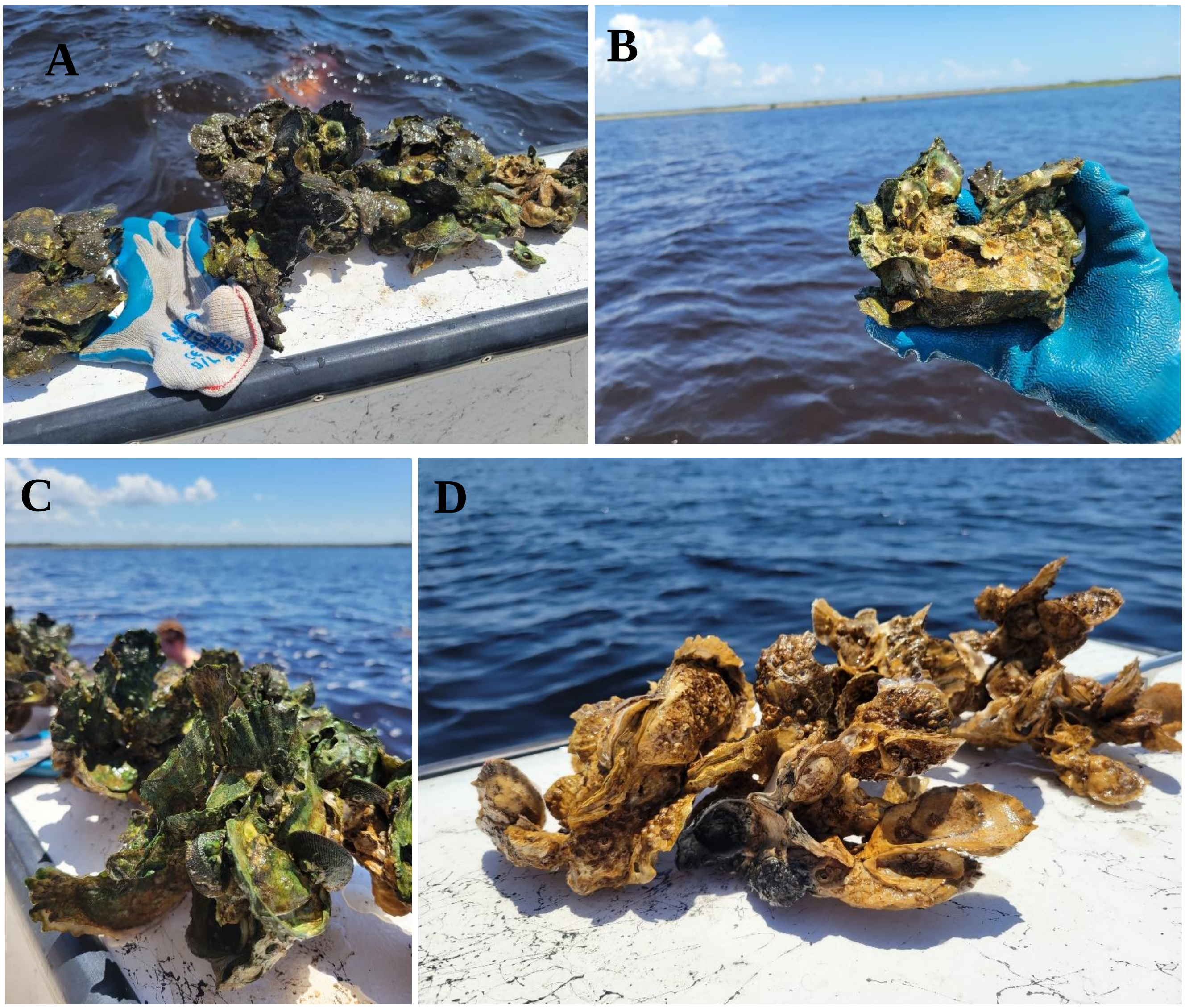

Figure 17. Subtidal oysters from gap site 6 (A and B), gap site 17 (C), and gap site 16 (D).

Live oysters collected from the gaps varied widely in several respects. Some had formed clusters with substantial vertical relief and consisted of multiple age/size classes ranging from small spat to large adults (**Figure 17**), while at other sites only live juvenile spat and dead shell occurred. Some of the more developed subtidal reefs with substantial vertical relief were found in areas where harvesting is prohibited. The complex physical structure of these reefs indicate they had not been harvested in at least the past several years. In contrast, subtidal oysters in some areas (e.g., gaps 2 and 34, **Table 1**) consisted mainly of loose dead shell with the live oysters consisting only of juvenile oysters. Harvesting essentially destroys the complex vertical structure of the reef because it removes or breaks up clusters which typically consist of multiple year/size classes of oysters cemented together. We emphasize, however, that surveys of the gaps in the present study were only preliminary in design. Most of the 44 target gaps were not visited, and sufficient spatial coverage to estimate size was not acquired from any of those surveyed. **Figure 18** below illustrates the wide range of bottom types in some gaps, and the utility of side-scan imagery for mapping small-scale spatial patterns.

Figure 18. Example side-scan imagery from Gaps 29 and 31 (just west of Cedar Key) showing high-reflectance (lighter colors) "textured" pattern typical of hard oyster bottom. See Table 1 for notes.

Major findings and conclusions for subtidal reefs

The major overall finding for subtidal reefs was that they cover a substantial amount of bottom area in Suwannee Sound, but their extent and condition have not been determined. Detailed maps were acquired in a few areas (**Figures 13** and **14**), but none of the subtidal oysters found in the gaps survey were adequately mapped. Even so, subtidal reefs that were mapped covered a total of 294 acres of bottom area in our study area compared to 1,580 acres of intertidal reefs. Essentially all previous mapping in the Sound had focused on intertidal reefs because of the methods used: aerial, drone, or satellite-deployed sensors that are only capable of detecting intertidal or shallow subtidal reefs. The present project demonstrated that acoustic methods coupled with ground-truthing can be effective in mapping the shallow subtidal areas likely to provide habitat for oysters.

Data from the present study also suggested that some subtidal areas had not been harvested in recent years, and thus might serve as "source" reefs to provide recruits for new restoration efforts involving cultching. And some gaps reportedly had been cultched in previous restoration efforts, though only on small spatial scales. In any case, the wide range of bottom sediment types observed in the 18 gaps surveyed indicate that ambient bottom type would need to be determined in future surveys aimed at designing restoration efforts.

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The project benefited greatly from the help of others. Some shared their knowledge of the area, some their expertise and help in the field, and some assisted in other ways. The following list, beginning with their home institutions, identifies many but not all.

- University of Florida: Bill Pine, Leslie Sturmer, Peter Frederick, Mike Allen, Kenny McCain, Ed Camp, Vince Lecours, Bradley Ennis
- Florida Fish and Wildlife Conservation Commission: Tomena Scholtz, Trevor Kirkland, Tracey Vlasak, Jonathan Brown, Gabe Hopkins, and Caleb Purtlebaugh
- Local fishers: Laura Adams, Jerry Beckham Sr, Rob Hill, Brian Akins
- SeaRobotics, Inc.: Jack Herbert
- Substructure, Inc: Rolf Bremer, Carol Riley

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APPENDIX A – Map Products for Intertidal Reefs

Sound files (UNH_Substructure) – Parent Folder
Files available for Suwannee Sound <u>intertidal</u> oyster reef mapping (folder shared on Dropbox)

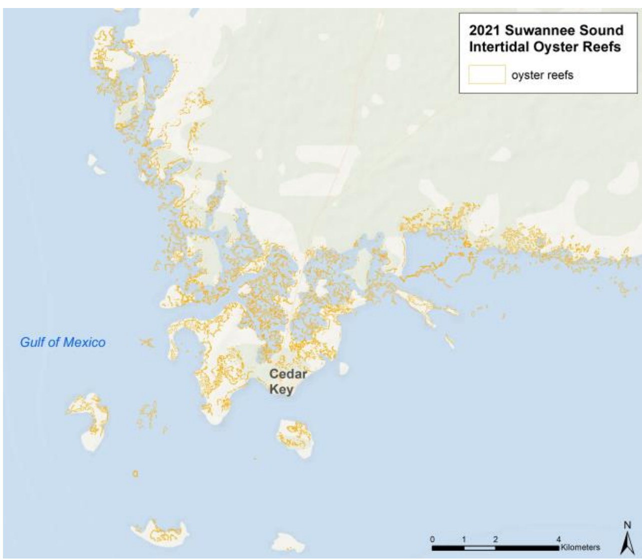
2020-2022 Suwannee Sound Files (UNH_Substructure)
Final Report – Suwannee Sound Oyster Reef Mapping, FWC Contract #19286
UNHSubstructure Progress Rep #4 2023 01 21

Processed data files_utm17n_m (folder):
2020_2022 Suwannee Sound ground truth summary_final (.xlsx)

Report map jpegs (folder):
This folder contains all map jpegs found in this 2022 Suwannee Sound final report

2020-2022 Suwannee Sound files (folder):
GIS shapefiles & Google Earth kml files (folder):

- Suwannee Sound ground truthing intertidal and subtidal oyster reefs_2020_2022_wgs84
- 2022 Suwannee Sound intertidal reefs_UNH (.shp) with associated metadata
- 2022 Suwannee Sound intertidal reefs_UNH (.kml)
- Intertidal oyster reefs metadata (Word document, see below)



Suwannee Sound Intertidal Reefs (2020-2022)

Tags:
Florida, Big Bend, Suwannee Sound, Cedar Key, intertidal oyster reefs, ground truthing, satellite imagery, Google Earth imagery, Florida Fish and Wildlife Conservation Commission (FWC), oyster reef mapping

Summary:

Maps of intertidal reefs in the study area were produced using online imagery accessed on Google Earth (2014 & 2022) and processed using ArcGIS software. Oyster reefs were classified (photointerpretation) visually following the 6540 ("Oyster Bars") code from the Florida Land Use, Cover and Forms Classification System (FLUCCS), originally developed by the Florida Department of Transportation (FDOT 1999), using the following characteristics:

1. *Linear and or oval shape with some having branching arms.*
2. *Typically have a bright white signature due to the "hash" (dead oyster shells) that has been bleached due to exposure to the sun. The hash area typically occurs directly adjacent to living oyster bars. During photointerpretation the hash areas are included as part of the oyster bar.*
3. *Parallel ridges formed by remnant oyster shells deposited by waves washing over the bar.*
4. *Oysters typically occur in association with* Spartina *sp. emergent vegetation.* Spartina *is often the only cover type visible on the photography and thus is used to delineate oyster habitat particularly on narrow strand type islands.* Juncus *sp., when visible on the photography, is not included as oyster habitat.*
5. *Code 6541: A cotton-ball like appearance when submerged.*
6. *Presence of bright white signatures indicative of patch oyster reefs in high-flow areas of tidal creeks. These high-flow, deeper areas are typically on the outside bends of the creeks and would scour lighter, less consolidated sediment such as sand or mud deposits.*

Description:

Field surveys were conducted by navigating tidal channels near the mapped reefs in an outboard-powered skiff or an airboat. A laptop running ArcGIS with real-time GPS indicated the vessel position relative to the mapped reefs, and notes were made on mapped reef characteristics. The focus was on whether the mapped reef (polygon) was correctly identified as "intertidal oyster reef" (based on six features above), but also included information on features such as amount of shell hash, mangroves, and salt marsh plants. Map revisions after each ground-truthing visit focused on correcting mis-identified intertidal oyster reefs.

Side-scan, bathymetric, and ground-truthing data were used in combination to manually draw polygons and indicate size and location of "live oyster/oyster shell" bottom. This mapping effort was the initial major component of a larger, longer-term effort being conducted by Florida Fish and Wildlife Conservation Commission (FWC) aimed at restoring degraded oyster reefs in the Suwannee Sound area. The overall aim of the mapping in this area was to provide current information on the spatial extent of live oyster reefs and bottom types potentially suitable for reef construction/restoration activities. This file was created for FWC under contract #19286.

Each live oyster ground-truthing point was outlined. There were 3817 polygons totaling ~1580 (~640 ha) acres of live oysters/dead shell identified. Some of the polygons include areas of sparse spartina.

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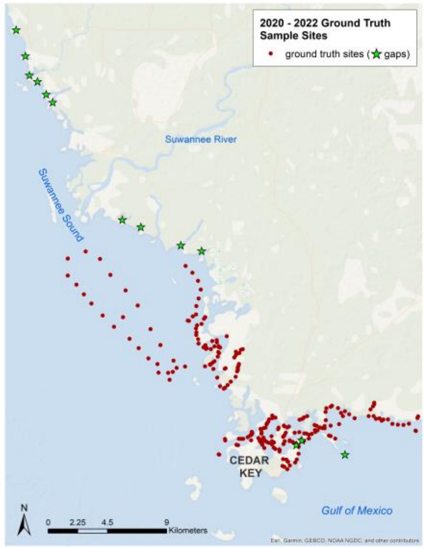
Use limitations:

There are no access and use limitations for this item.



Suwannee Sound ground truthing intertidal and subtidal oyster reefs (2020-2022)

Tags:

Florida, Big Bend, Suwannee Sound, Cedar Key, intertidal oyster reefs, ground truthing, satellite imagery, Google Earth imagery, Florida Fish and Wildlife Conservation Commission (FWC), oyster reef mapping

Summary:

The study area was essentially all areas in Suwannee Sound and areas landward where oysters occurred, from just north of Horseshoe Beach to ~10 km east of Cedar Key We agreed to combine our efforts with Adams (Adams et al.2019) and to produce new maps of intertidal oyster reefs from southern Suwannee Sound to a portion of Waccasassa Sound east of Cedar Key to complete our contracted study area.

The overall aim of ground truthing in this area was to provide current information on the spatial extent of live oyster reefs and bottom types potentially suitable for reef construction/restoration activities. This file was created for FWC under contract #19286.

Our ground truthing efforts resulted in the production of our final map of intertidal oyster reefs which included a total of 3.817 individual intertidal reefs covering a total of 1,580 acres (640 hectares).

Description

The initial visit focused on determining how to conduct ground-truthing, and to assess a portion of the first preliminary intertidal oyster reef maps we created using Google Earth satellite imagery. We concluded from the first visit that an airboat would be required, and the diversity of intertidal reefs in the study area was substantially more than expected. The second visit focused on methods for ground-truthing the preliminary maps which included hand drawn polygons in ArcGIS 10.2 around intertidal oyster reefs. Preliminary maps included a total of ~3,000 individual intertidal reefs ranging in size from 12 m^2 to 5,000 m^2.

Field work was conducted over the periods October 23 – 26, 2020 and June 2 – 6, 2021. Field surveys were conducted by navigating tidal channels near the mapped reefs in an outboard-powered skiff or an airboat. A laptop running ArcGIS with real-time GPS indicated the vessel position relative to the mapped reefs, and notes were made on mapped reef characteristics. The focus was on whether the mapped reef (polygon) was correctly identified as “intertidal oyster reef” (based on six features outlined in the 6540 (“Oyster Bars”) code from the Florida Land Use, Cover and Forms Classification System (FLUCCS), originally developed by the Florida Department of Transportation (FDOT 1999)), but also included information on features such as amount of shell hash, mangroves, and salt marsh plants. Our efforts mapped areas that included vegetation such as cordgrass and mangroves as well as oysters as “oyster reef”. Field work was also conducted October 24, 2020, along the *subtidal*, offshore Suwannee Reef and ground truthing consisted of probing with a PVC pole to determine bottom type and hand tongs were used to confirm areas with live oysters. A total of ~ 245 (GPS) sites were visited overall.

Credits

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Use limitations

There are no access and use limitations for this item.

APPENDIX B – Map Products for Subtidal Reefs

Sound files (UNH_Substructure) – Parent Folder

Files available for Suwannee Sound subtidal oyster reef mapping (folder shared on Dropbox)

2020-2022 Suwannee Sound Files (UNH_Substructure)

Final Report – Suwannee Sound Oyster Reef Mapping, FWC Contract #19286
UNHSubstructure Progress Rep #4 2023 01 21

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  - Diversity_suwannee_samples.xlsx
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  - suwannee_gsr_50cm.tif

Report map jpegs (folder):

This folder contains all map jpegs found in this 2022 Suwannee Sound final report

2020-2022 Suwannee Sound files (folder):

GIS shapefiles & Google Earth kml files (folder):

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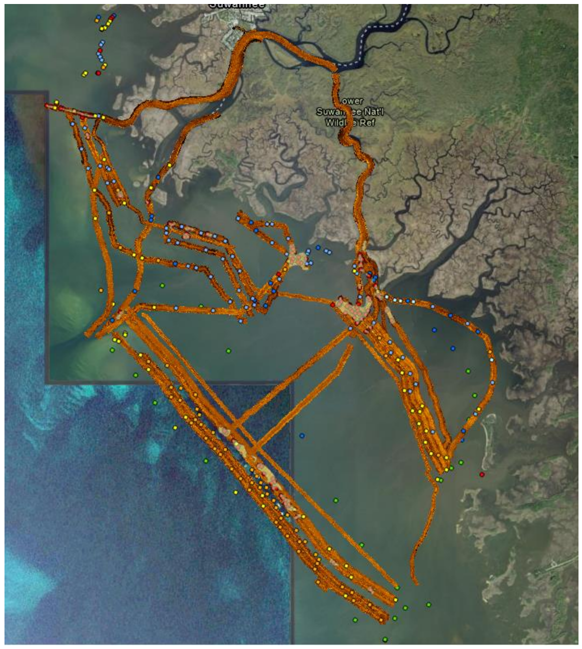

Suwannee Sound Subtidal Reefs (2020-2022)

Tags:
Florida, Big Bend, Suwannee Sound, Cedar Key, intertidal oyster reefs, ground truthing, satellite imagery, Google Earth imagery, Florida Fish and Wildlife Conservation Commission (FWC), oyster reef mapping

Summary:
Maps of subtidal reefs identified within the study area were produced using broad-scale acoustic mapping data (e.g., side-scan sonar imagery, sub-bottom profiling, and single-beam bathymetry) in conjunction with ground-truth bottom sampling (e.g., bottom probing and tonging). The surveyed areas focused on areas where subtidal oysters were thought to exist, and represented only a small percentage of overall subtidal area. Potentially significant subtidal oysters might also exist in many of the deeper tidal channels (or "gaps"), but these areas were investigated in a quick reconnaissance-level effort that was not sufficient to map the extent of any oysters that were identified.

Description:
The March 2021 sub-bottom and side-scan sonar survey operations were conducted from Substructure's survey vessel *Diversity* outfitted with a Klein 3500 side-scan sonar system, an Innomar SES-2000 parametric sub-bottom profiler, an Applanix V5 POSMV vessel navigation and inertial measurement unit, a YSI Castaway conductivity-temperature-depth (CTD) speed of sound profiler, and Hypack HYSWEEP and Klein SonarPro hydrographic data acquisition and processing software. The initial acoustic survey efforts were focused primarily in areas that had been identified as likely areas to hold subtidal oysters, including Great Suwannee Reef, Lone Cabbage Reef, Halfmoon Reef, and the major Suwannee River outlets. The processed side-scan sonar mosaics, the bathymetric point data, and ground-truthing results were used in combination to manually draw polygons around areas that could be classified as "live oyster/oyster shell" bottom. Because only a small subset of available subtidal area was surveyed, there are likely other subtidal oysters within the main study area

A brief follow-on survey was conducted in May 2022 in order to perform an initial assessment of the presence of subtidal oysters in a subsample of the tidal channels that had been identified as potentially having subtidal oyster populations. During a four-day survey period in May 2022 single-beam and side-scan sonar operations were conducted from an FWC sampling skiff outfitted with a Klein 3500 side-scan sonar system, a Knudsen 3200 dual-frequency single-beam echosounder, a Trimble R10 GNSS receiver, a YSI Castaway conductivity-temperature-depth (CTD) speed of sound profiler, and Hypack HYSWEEP and Klein SonarPro hydrographic data acquisition and processing software. In addition, probing was used to assess substrate during the acoustic data collection, and physical samples were collected in some areas where probing indicated hard bottom.

This mapping effort was the initial major component of a larger, longer-term effort being conducted by Florida Fish and Wildlife Conservation Commission (FWC) aimed at restoring degraded oyster reefs in the Suwannee Sound area. The overall aim of the mapping in this area was to provide current information on the spatial extent of live oyster reefs and bottom types potentially suitable for reef construction/restoration activities.

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Use limitations:

There are no access and use limitations for this item.