2024-2025 Suwannee Sound Subtidal Oyster Mapping

Final Report completed December 11, 2025

Deliverable 2.2 for Florida Fish and Wildlife Conservation Commission (FWC) Contract #PR241565: St. Andrew Bay and Suwannee Sound Subtidal Oyster Reef Mapping 2023-2025

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This document is Deliverable 2.2, the final report on mapping subtidal oysters in Suwannee Sound, Florida. The overall objective of the project, as stated in the contract, was to: "provide FWC managers and researchers with much needed information to improve oyster management and restoration on the Gulf Coast of Florida." Data on subtidal reefs was needed because most previous mapping efforts were based on surveys of intertidal reefs (**Figure 1**). Most of the historic reefs (blue polygons in **Figure 1**) were completely degraded by 2010 (Seavy et al. 2011; Radabaugh et al. 2021), with the major exception of the recently completed restoration of Lone Cabbage Reef (Frederick et al. 2016; Aufmuth et al. 2025). Our surveys in 2022 found the same for the historic offshore reefs but also identified live subtidal oysters in several tidal channels ("gaps") in the Cedar Key area that had not been mapped (Grizzle et al. 2023). Further assessment of these data led to identification of a total of 67 "target polygons" for surveying in the present study with the objective of more fully characterizing subtidal reefs in the region (**Figure 2**).

Mapping Methods

All surveys (2024 and 2025) were conducted aboard Substructure's *Diversity*, a 24-ft Privateer (**Figure 3**). The sonar equipment both years consisted of a Ping DSP 3DSS-iDX-450-Pro multibeam echosounder, an SBG Systems Navsight Ekinox vessel position and motion reference unit (integrated in the 3DSS), an AML Oceanographic MicroX sound velocity sensor (SVS) mounted near the 3DSS, a YSI Castaway conductivity-temperature-depth (CTD) speed of sound profiler, and Hypack/Hysweep hydrographic data acquisition and processing software (see **Appendix A** for details on all acoustic equipment).

The Ping unit is a multibeam echosounder operating at 450 kHz with a nominal beamwidth of 0.4º that provides simultaneous 2D and 3D data outputs. The system includes motion reference units (MRU) that are fully integrated into the sonar transducer package. It also includes a patented signal processing methodology that extends the single angle-of-arrival principle used in interferometric systems to accommodate multiple simultaneous backscatter arrivals (e.g., the seabed, sea surface, water-column, and multipath), resulting in improved wide-swath data, and both 2D (similar to and referred to herein as "side-scan") and 3D bathymetric imagery. The Ping towfish was mounted on a rigid bow-mount fairing about 50 cm below the water surface with known offsets to the SBG Navsight navigation reference point (**Figure 3**). The range-scale for the Ping was set to 50 m for all of the Suwannee Sound survey operations yielding a 2D imagery swath width of ~100 m, with some outer range reduction in softer sediments due to refraction.

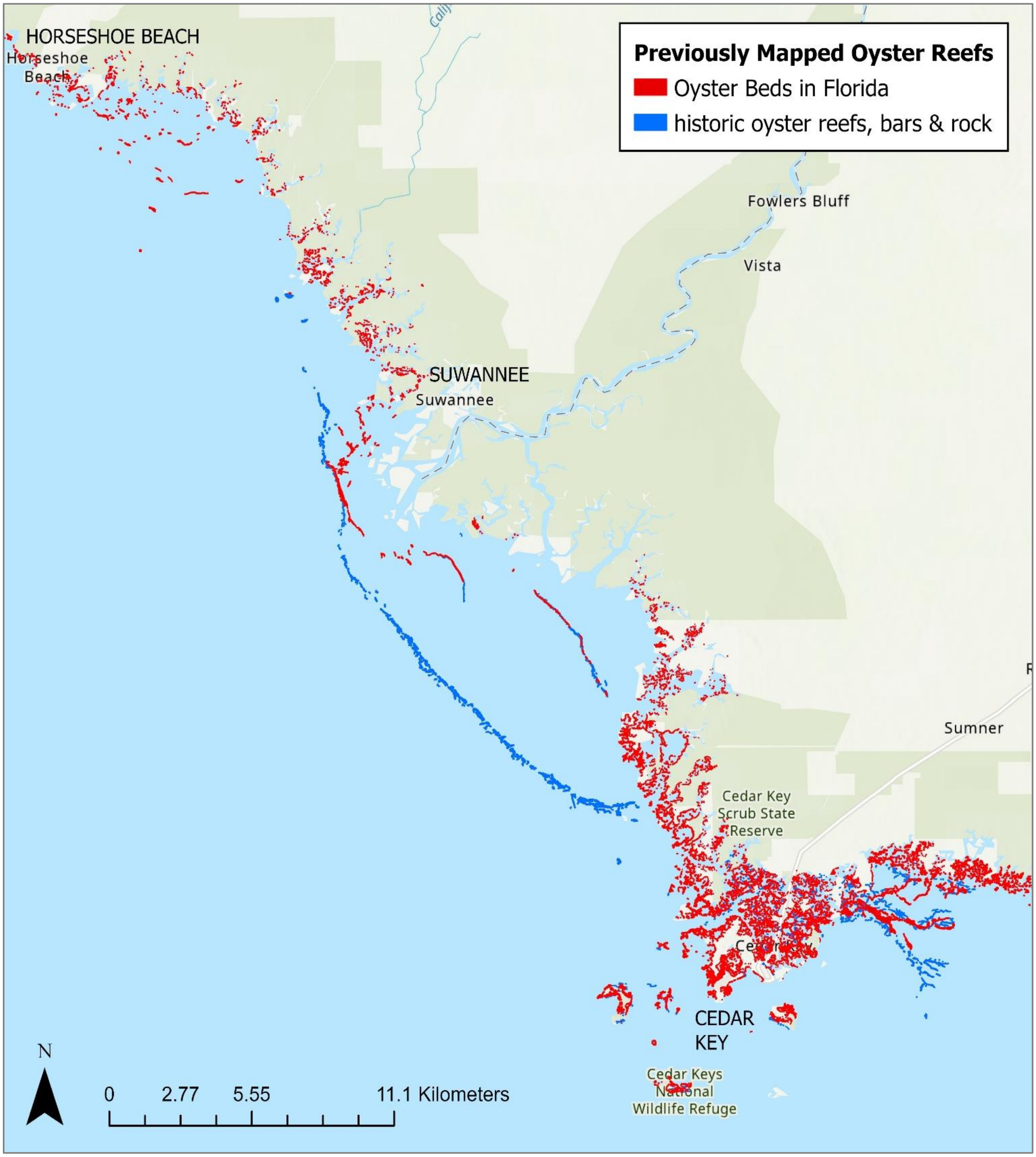

Figure 1. Summary map of knowledge of the spatial extent of current (red polygons) and historic (blue) live oyster reefs before the present study. Note that all reef polygons are exaggerated in scale.

Two general patterns are clearly visible in **Figure 1**: (1) Nearly all offshore reefs have been lost, as quantified by Seavey et al. (2011), and (2) very few inshore intertidal reefs have been mapped southeast of the mouth of the Suwannee River. These patterns will be discussed further in Results section.

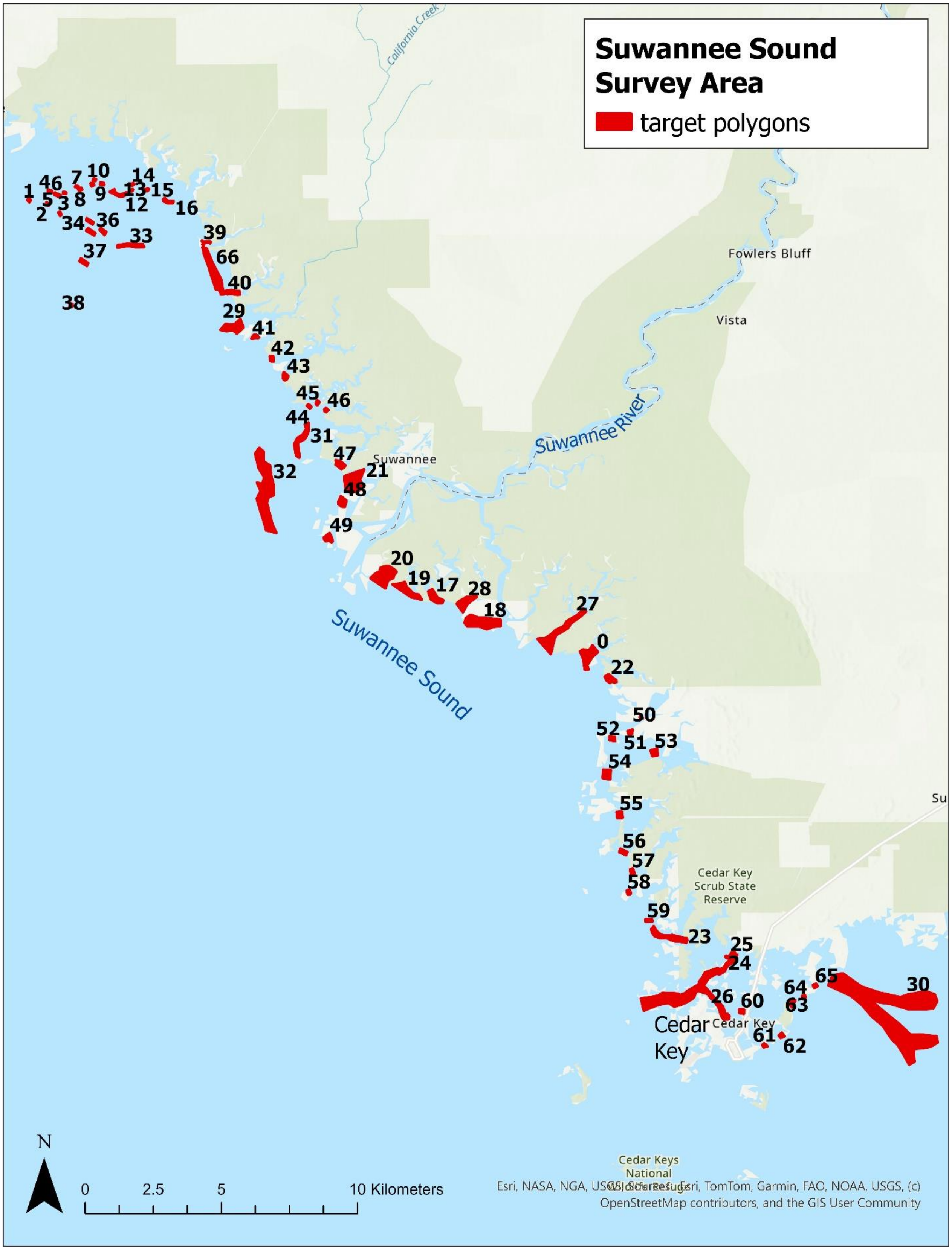

Figure 2. Sixty-seven "target polygons" (red) that were sampled in the present study. These polygons total 2,214 acres in areal coverage.

Figure 3. Left: Acoustic gear on Substructure's *Diversity* with bow-mount and towfish in deployment position. Top: *Diversity* with bow-mount in raised position. Lower: Sonar monitors in wheelhouse.

The resulting 2D imagery displays the relative amount of sound that is absorbed or reflected across the survey area, with high-resolution data across the entire survey swath. Soft, muddy sediments absorb most of the soundwave while hard bottoms of rock or shell are highly reflective. High reflectance bottom types are lighter in color and low reflectance are darker, both displayed herein in shades of tan to dark brown (**Figure 4**). The imagery for 3D bathymetric data displays the sound wave return time from the surface sediments, thus indicating bottom topography that is expressed as water depth displayed along a range of colors from red (shallow) to blue (deeper). The 3D imagery swath was dependent on the water depth and was generally maintained at eight to ten times the water depth. In most areas, survey coverage was limited to water depths where the boat could be safely navigated, resulting in bathymetry coverage ranging from about a quarter to a half of the 2D imagery coverage (**Figure 4**).

Acoustic data are affected by environmental factors such as water density, waves and turbulence, as well as the accuracy of the position (navigation) data. Thus, extensive processing of the data is typically required (see **Appendix A** for details). In brief, all three data types: position and elevation, 3D multibeam bathymetry, and 2D data required some level of processing. The real-time horizontal and vertical accuracy estimates were very good in most areas (generally in the 1-2 cm range), so minimal processing relative to positional accuracy was required. The multibeam bathymetry and side-scan processing included reviewing all navigation data, applying speed of sound data, and extracting final soundings from the full datasets. Imagery mosaics were then produced at 1-m resolution and exported as geoTIF or KMZ files, the latter particularly for use in GoogleEarth and comparison to other imagery.

Figure 4. Acoustic survey data from Bumblebee Creek comparing the initial reconnaissance single-beam track line bathymetry (narrowest shiptracks) and multibeam imagery. The full multibeam 2D (side-scan) imagery swath was 100m (50m per side), while the full multibeam 3D bathymetry swath was generally limited to about eight times the water depth (or ~25m in 3m of water).

The mapping focused on live oysters, but dead shell, rock, and sand were also mapped together as "hard" or "firm" bottom. Sand, rock, and dead shell were of interest mainly because they represent potential restoration areas that might be improved by cultching with shell or rock. Hard bottom types covered by a thin layer of mud were also mapped in some areas because they might be suitable for cultching. All bottom types, however, required ground-truthing to assess the accuracy of the bottom type inferred from the acoustic data. The major method used in all areas was probing the bottom with an extendable aluminum pole (**Figure 5**). All hard bottom types are easily distinguishable from muddy sediments by probing, and although there are clear differences in "feel" among the bottom types, extractive sampling with handheld tongs and/or underwater photography was also used. If the acoustic data or probing indicated live oysters, their presence was confirmed (or refuted) in most cases with tongs and/or photography.

Final map products were a synthesis of acoustic and ground-truthing data. Data from each of the target polygons where live oysters or hard bottom were found were processed individually. Note that although bathymetric and side-scan data were acquired in most areas, side-scan provided the major acoustic data used in final map production due to its much greater bottom coverage (see above discussion and **Figure 4**). The side-scan data were converted into GeoTIFF files with 1-m pixel resolution that were analyzed to produce the final maps. As discussed above, bottom areas consisting mostly of soft, muddy sediments absorbed much of the sonar signal and are shown in the final maps in dark shades of brown. In contrast, "hard bottom" (which could be live oysters, shell, sand, and/or rock) was identified by lighter shades of brown to almost white resulting from high reflectance of the sonar signal. Thus, the primary criterion for preliminarily identifying hard bottom in the final GeoTIFF images was color.

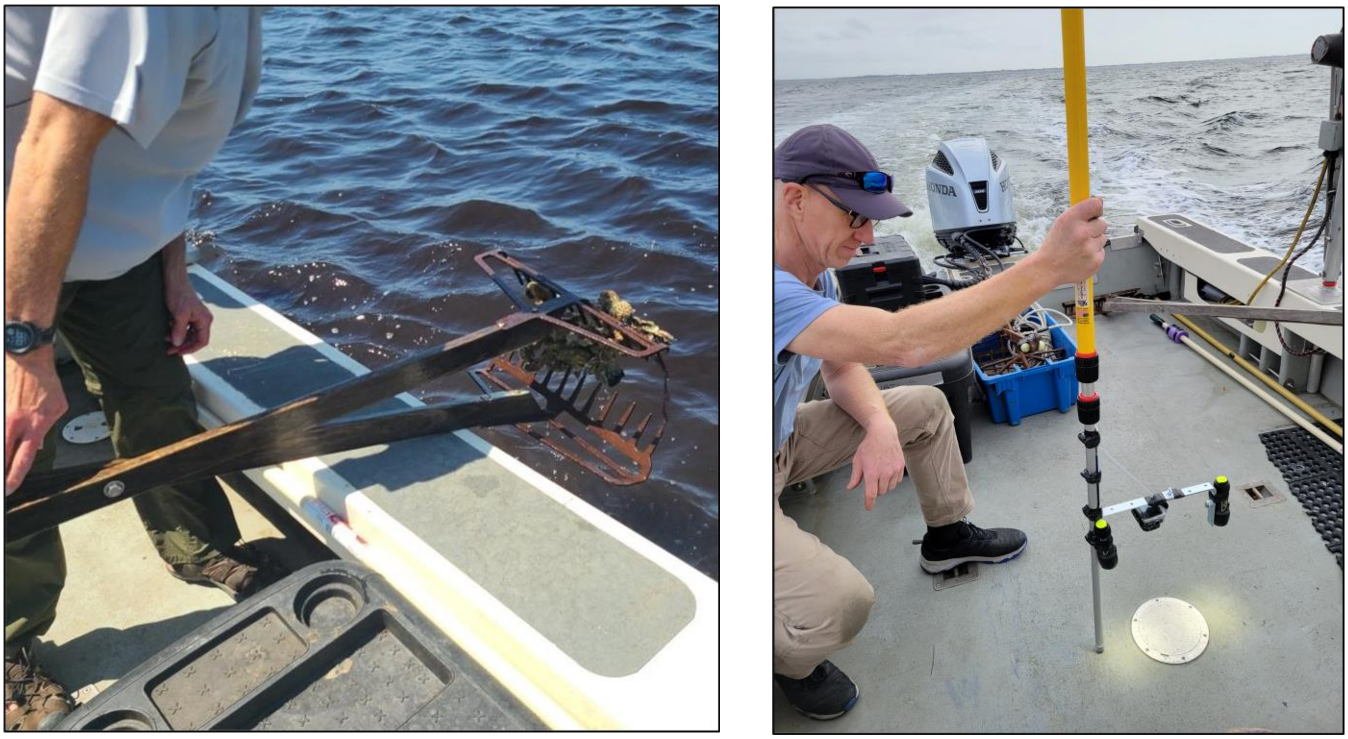

Figure 5. Handheld tongs containing several clusters of live oysters, and one of the extendable probes with GoPro camera and lights attached used in ground-truthing the acoustics data.

The sonar signal, however, can be strongly affected by some environmental conditions (see Appendix A for details). For example, waves, boat wakes or sharp turns in the vessel can produce artifacts in the image that resemble high reflectance of bottom features. Additionally, the side-scan transducer sends out and receives signals in an arc extending outward on both sides of the transducer and it has a "dead zone" (nadir gap) directly underneath. The result is a swath of bottom under the transducer that typically resembles the low reflectance (dark brown in this report) of muddy sediments in the imagery. If high reflectance/hard bottom occurred on both sides of the dead zone, it was assumed that hard bottom was also in the dead zone.

The final step in map production involved incorporating ground-truthing "point" data with the 2D side-scan sonar data to differentiate among the four types of hard bottom and determine their areal extent. In some areas, LiDAR data available online were also used in final map production. In those areas our ground-truthing data were combined with LiDAR to produce the final maps. For final map production, if live oysters were confirmed by one or more tong or GoPro photo samples, the entire polygon was designated as live oysters. If other ground-truthing samples within that polygon indicated other bottom types, they were noted as present but the area of the entire polygon was classified as live oysters. Finally, the total areal coverage of live oyster polygons was determined in ArcGIS.

Results & Discussion

Our previous subtidal reef mapping efforts in 2020-2022 (Grizzle et al. 2023) provided new data that in part was the basis for design of the present effort. Although the present report focuses on new mapping in 2024 and 2025, all mapping data collected from 2020-2025 are included where appropriate below to provide a more comprehensive dataset on subtidal oysters and hard substrate in Suwannee Sound.

Acoustics Overview

Single-beam acoustics data were acquired within or close to all 67 target polygons and along shiptracks while navigating among the target polygons (**Figure 6**). Side-scan data sufficient for map production, however, was only acquired within 12 of the target polygons (**Table 1**).

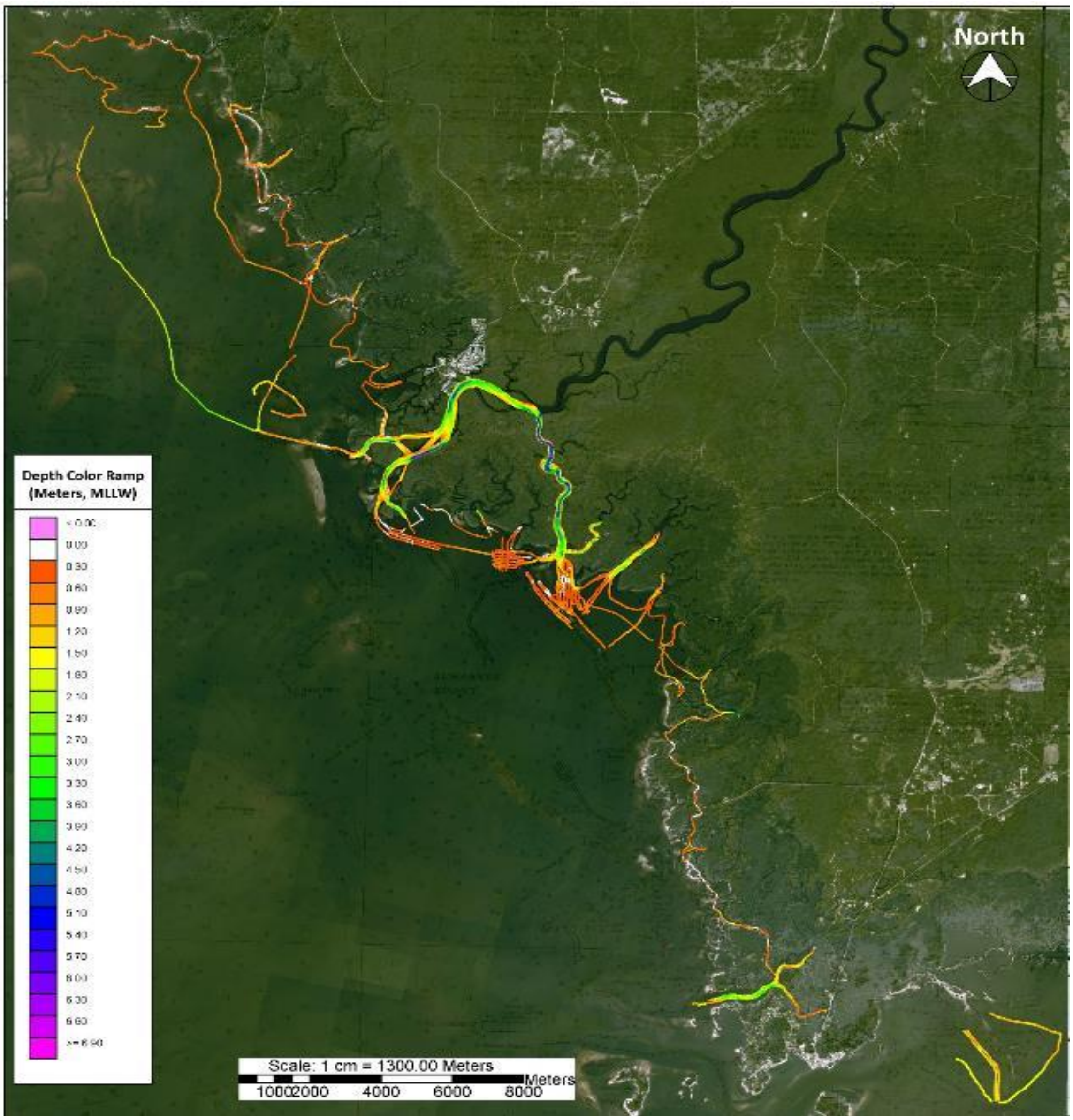

Figure 6. Overview of 2024 survey results of bathymetric data based on a mix of both multibeam and single-beam. Note the narrow swath widths in most areas due to water depths <1 m (see inset: white to orange in color).

A second field visit was conducted November 12 – 16, 2025 to re-survey and/or expand the areal coverage of the 2024 survey in selected areas where live oysters had been found. The 2025 survey mainly resulted in expansion of and better overall characterization of areal coverage of subtidal oysters in the selected areas. Although some acoustics data were acquired from nearly all target polygons, complete coverage was limited due to shallow-water conditions. LiDAR (Light Detection and Ranging, a remote sensing method that uses pulsed laser light) 3D imagery was acquired online for the entire study area. These data confirmed the extent of shallow water in the study area, but LiDAR data were only used in a few areas to supplement our acoustics data (**Figure 7**).

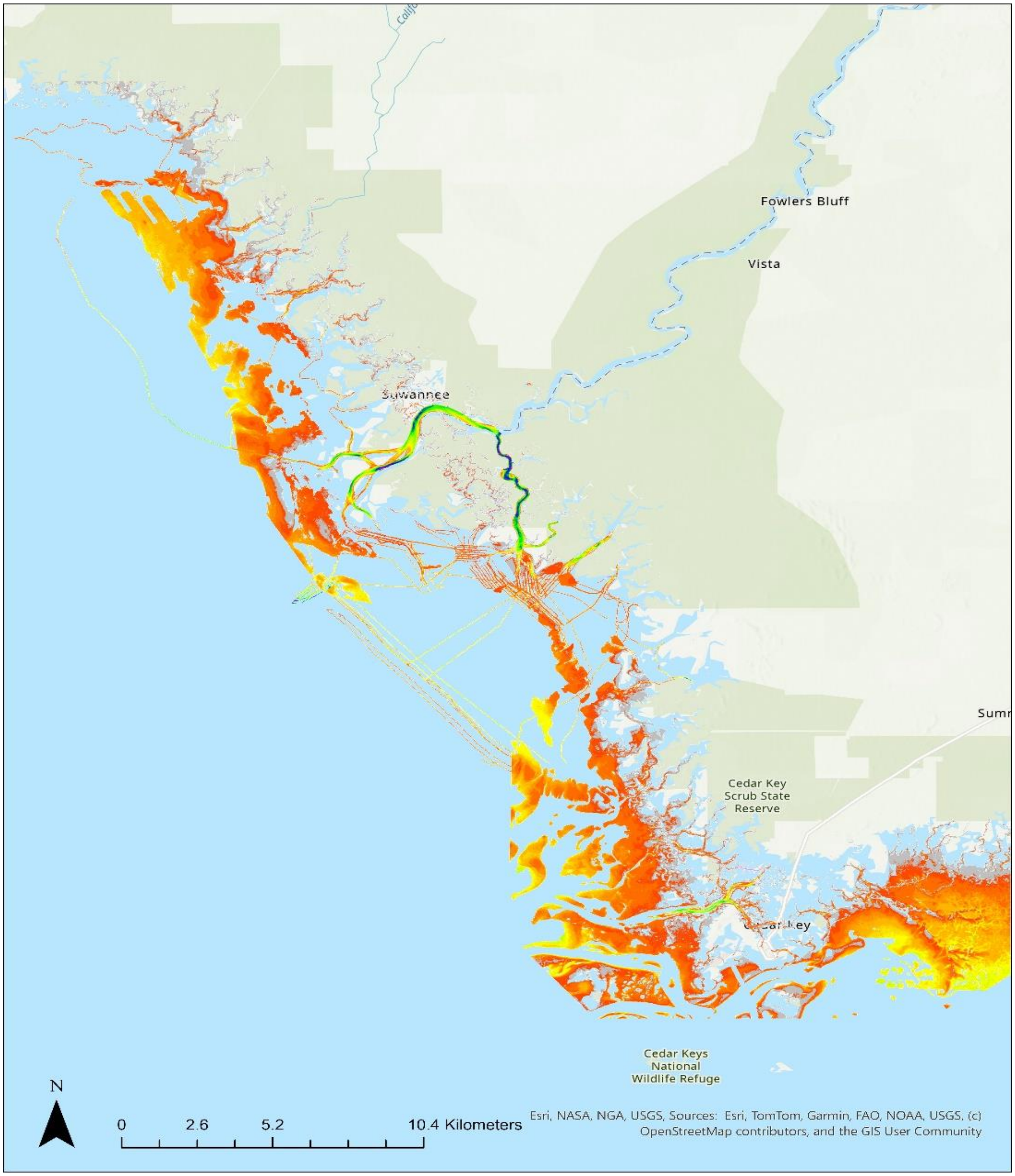

Figure 7. LiDAR data overlaid on our 3D multibeam data for the overall study area. Water depth is color coded from shallow (orange) to deep (yellow to dark blue).

Ground-Truthing

Sixty of the 67 target polygons (**Figure 2**) were visited and one or more ground-truth samples were acquired from each in 2024-2025 (**Figure 6**; **Table 1**). A total of ~1,000 ground-truth data points (probe, tongs, or underwater photography) were collected in 2024-2025. A total of ~700 samples were taken in 2020-2022 and are described in our previous project (Grizzle et al. 2023). **Figure 8** shows the location and bottom type for all ground-truth samples taken in 2020-2025. The black rectangles delimit four areas (A – D) for detailed analysis of side-scan imagery and ground-truth data (see below).

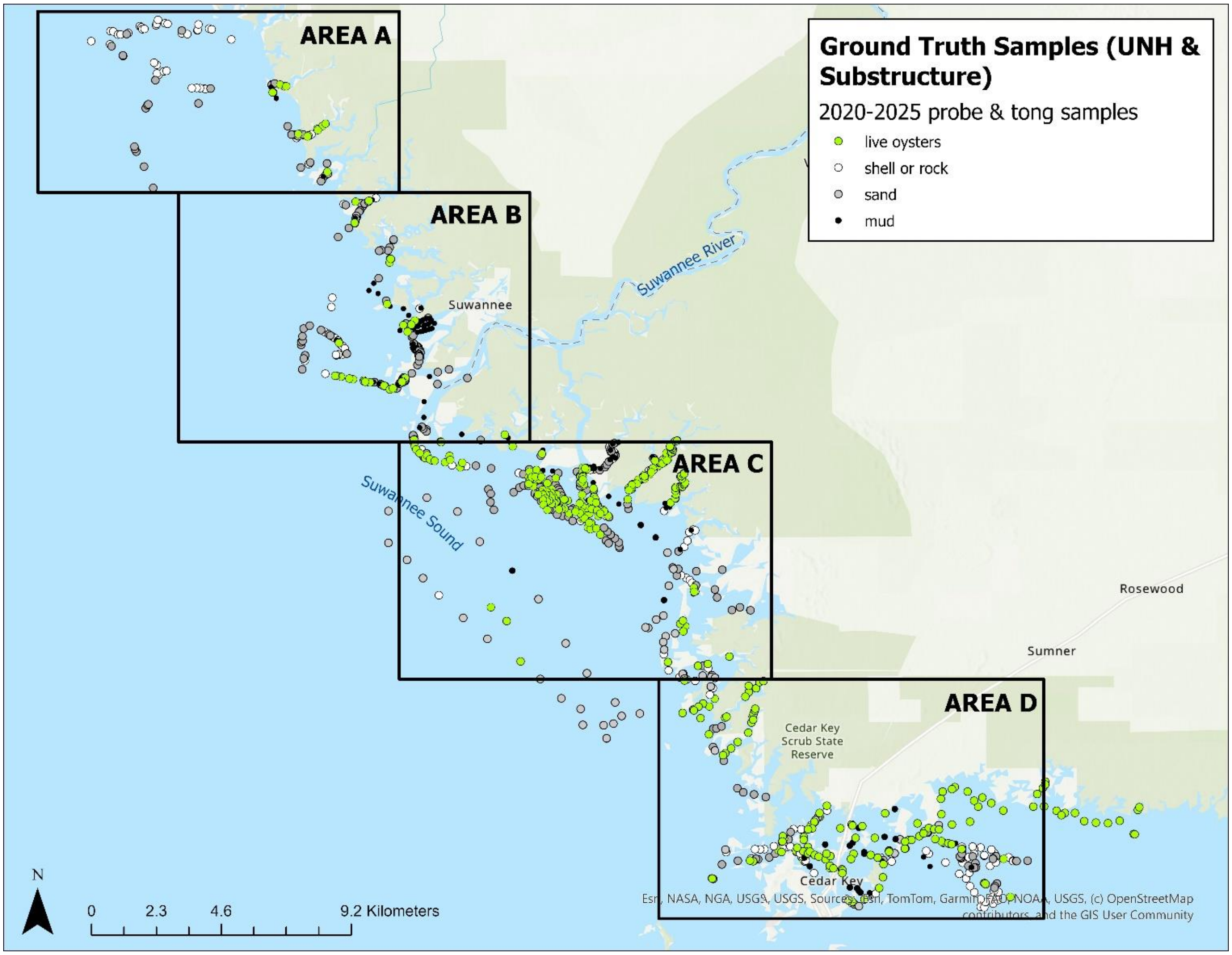

Figure 8. Overview of ground-truthing samples from 2020-2025. "Live Oysters" (green dots) represent probe, tong, and video samples combined. Black rectangles delimit four **Areas** (**A – D**) for detailed analysis of side-scan and ground-truthing data (see below).

Focusing on live oysters (green dots), live subtidal oysters were found throughout study area. However, the major concentration and areal coverage (see below) occurred in nearshore waters and two tidal channels (Barnett and Big Trout Creeks) at the mouth of the Suwannee River (Areas B and C). Subtidal oysters were only found in tidal channels in the Horseshoe Cove region (Area A) and mainly in tidal channels in the Cedar Key area (Area D). This overall pattern reflects the long-term trend for intertidal reefs where the major losses have occurred in offshore reefs (Seavey et al. 2011; Radabaugh et al. 2021). **Table 1** summarizes the ground-truthing data in the context of the target polygons.

Table 1. Data summary for 2024 and 2025 surveys of target polygons and adjacent areas focusing on live oysters and hard bottom.

Nearest Target Polygon #	Survey Area	General Location	Lat_DD	Long_DD	Date Surveyed	# Ground-Truthing Points	Side-Scan Imagery	Live Oysters Present?	Sand Present?	Shell Present?	Rock Present?	Intertidal Oysters Present?
1	A - Horseshoe Beach	Offshore	29.4138646°N	83.2685879°W	4/14/2024	1	No	No	No	Yes	No	Yes
2	A - Horseshoe Beach	Offshore	29.4125693°N	83.2624558°W	4/14/2024	2	No	No	Yes	Yes	No	Yes
3	A - Horseshoe Beach	Offshore	29.4094899°N	83.2583848°W	4/14/2024	2	No	No	Yes	No	No	Yes
4	A - Horseshoe Beach	Offshore	29.4168098°N	83.2616693°W	4/14/2024	2	No	No	No	Yes	No	Yes
5	A - Horseshoe Beach	Offshore	29.4155143°N	83.2591700°W	4/14/2024	2	No	No	No	Yes	No	Yes
6	A - Horseshoe Beach	Offshore	29.4162095°N	83.2568666°W	4/14/2024	2	No	No	Yes	Yes	No	Yes
7	A - Horseshoe Beach	Offshore	29.4182448°N	83.2528112°W	4/14/2024	2	No	No	No	Yes	No	Yes
8	A - Horseshoe Beach	Offshore	29.4174320°N	83.2517625°W	4/14/2024	2	No	No	No	Yes	No	Yes
9	A - Horseshoe Beach	Offshore	29.4189678°N	83.2477339°W	4/14/2024	2	No	No	No	Yes	No	Yes
10	A - Horseshoe Beach	Offshore	29.4204862°N	83.2470070°W	4/14/2024	1	No	No	No	Yes	No	Yes
11	A - Horseshoe Beach	Offshore	29.4192216°N	83.2444462°W	4/14/2024	2	No	No	No	Yes	No	Yes
12	A - Horseshoe Beach	Offshore	29.4159442°N	83.2391912°W	4/14/2024	2	No	No	No	Yes	No	Yes
13	A - Horseshoe Beach	Offshore	29.4171167°N	83.2345918°W	4/14/2024	2	No	No	No	Yes	No	Yes
14	A - Horseshoe Beach	Offshore	29.4190114°N	83.2344068°W	4/14/2024	1	No	No	No	Yes	No	Yes
15	A - Horseshoe Beach	Nearshore	29.4172266°N	83.2300197°W	4/14/2024	2	No	No	No	Yes	No	No
16	A - Horseshoe Beach	Nearshore	29.4134817°N	83.2228591°W	4/14/2024	1	No	No	No	Yes	No	No
33	A - Horseshoe Beach	Offshore	29.3991389°N	83.2348374°W	4/14/2024	6	No	No	Yes	Yes	No	Yes
34	A - Horseshoe Beach	Offshore	29.4035839°N	83.2482298°W	4/14/2024	2	No	No	No	Yes	No	Yes
35	A - Horseshoe Beach	Offshore	29.4069723°N	83.2485170°W	4/14/2024	2	No	No	No	Yes	No	Yes
36	A - Horseshoe Beach	Offshore	29.4036934°N	83.2441815°W	4/14/2024	2	No	No	No	Yes	No	Yes
37	A - Horseshoe Beach	Offshore	29.3937244°N	83.2505267°W	4/14/2024	2	No	No	Yes	No	No	Yes
38	A - Horseshoe Beach	Offshore	29.3798022°N	83.2546975°W	4/14/2024	2	No	No	Yes	No	No	Yes
39	A - Horseshoe Beach	Tidal Channel	29.4001326°N	83.2102074°W	4/8/2024	3	Yes	No	Yes	Yes	No	No
40	A - Horseshoe Beach	Tidal Channel	29.3839323°N	83.2023130°W	4/8/2024	11	Yes	Yes	Yes	Yes	Yes	Yes
66	A - Horseshoe Beach	Nearshore	29.3908343°N	83.2078374°W	4/8/2024	4	Yes	Yes	Yes	No	No	No
29	A - Horseshoe Beach	Tidal Channel	29.3726069°N	83.2010857°W	4/8/2024	4	No	No	Yes	Yes	No	Yes
41	A - Horseshoe Beach	Tidal Channel	29.3694903°N	83.1940225°W	4/8/2024	3	No	No	Yes	Yes	No	Yes
42	A - Horseshoe Beach	Tidal Channel	29.3623700°N	83.1884910°W	4/8/2024	1	No	No	No	Yes	No	Yes
43	A - Horseshoe Beach	Tidal Channel	29.3565692°N	83.1841130°W	4/8/2024	5	Yes	Yes	Yes	No	No	No
44	B - Suwannee River	Tidal Channel	29.3468663°N	83.1761490°W	4/8/2024	2	No	No	Yes	No	No	No
45	B - Suwannee River	Tidal Channel	29.3480284°N	83.1734190°W	4/8/2025	1	No	No	Yes	No	No	Yes
46	B - Suwannee River	Tidal Channel	29.3456958°N	83.1706070°W		0	No	-	-	-	-	No
31	B - Suwannee River	Offshore	29.3359857°N	83.1788375°W	4/8/2025	3	No	No	Yes	No	No	No
32	B - Suwannee River	Offshore	29.3195424°N	83.1906884°W	4/14/2024	14	Yes	Yes	Yes	Yes	No	Yes
47	B - Suwannee River	Tidal Channel	29.3279327°N	83.1659048°W		0	No	-	-	-	-	No
21	B - Suwannee River	Tidal Channel	29.3223671°N	83.1615106°W	4/8/2024	16	No	No	Yes	No	No	No
48	B - Suwannee River	Tidal Channel	29.3157751°N	83.1652423°W	4/8/2024	14	Yes	No	Yes	No	No	No
49	B - Suwannee River	Tidal Channel	29.3040919°N	83.1698066°W	4/18/2024	10	Yes	Yes	Yes	Yes	No	No
20	B - Suwannee River	Tidal Channel	29.2918153°N	83.1514433°W	4/10/2024	1	No	No	No	No	No	No
19	B - Suwannee River	Tidal Channel	29.2870460°N	83.1439378°W	4/10/2024	1	No	No	Yes	No	No	No
17	B - Suwannee River	Tidal Channel	29.2848456°N	83.1346999°W	4/10/2024	2	No	Yes	No	No	No	Yes
28	B - Suwannee River	Tidal Channel	29.2831451°N	83.1246921°W	4/10/2024	4	No	Yes	Yes	No	No	Yes
18	B - Suwannee River	Tidal Channel	29.2767244°N	83.1191277°W	4/10/2024_4/23/2024	4	Yes	No	Yes	No	No	No
27	C - Suwannee Sound	Tidal Channel	29.2731829°N	83.0940429°W	4/19/2024	37	Yes	Yes	No	Yes	Yes	No
0	C - Suwannee Sound	Tidal Channel	29.2657913°N	83.0841296°W	4/9/2024_4/10/2024_04/20/2024	9	Yes	Yes	No	No	Yes	Yes
22	C - Suwannee Sound	Tidal Channel	29.2582923°N	83.0768406°W	4/17/2024	3	No	No	No	No	Yes	Yes
50	C - Suwannee Sound	Tidal Channel	29.2458012°N	83.0666425°W		0	No	-	-	-	-	No
51	C - Suwannee Sound	Tidal Channel	29.2410635°N	83.0702307°W		0	No	-	-	-	-	No
52	C - Suwannee Sound	Tidal Channel	29.2389273°N	83.0761838°W	4/17/2024	2	No	Yes	No	Yes	No	No
53	C - Suwannee Sound	Tidal Channel	29.2344494°N	83.0622723°W	4/9/2024	1	No	No	Yes	No	No	No
54	C - Suwannee Sound	Tidal Channel	29.2273625°N	83.0780080°W	4/9/2024	1	No	Yes	No	No	No	No
55	C - Suwannee Sound	Tidal Channel	29.2141825°N	83.0737353°W	4/9/2024	1	No	No	Yes	No	No	No
56	C - Suwannee Sound	Tidal Channel	29.2021321°N	83.0725501°W	4/9/2024	1	No	Yes	No	No	No	Yes
57	D - Cedar Key	Tidal Channel	29.1957154°N	83.0695952°W	4/9/2024	1	No	No	Yes	No	No	No
58	D - Cedar Key	Tidal Channel	29.1890353°N	83.0707519°W	4/9/2024	1	No	No	Yes	No	No	Yes
59	D - Cedar Key	Tidal Channel	29.1798841°N	83.0641221°W		0	No	-	-	-	-	Yes
23	D - Cedar Key	Tidal Channel	29.1746203°N	83.0575720°W	4/9/2024	4	No	No	Yes	No	No	Yes
24	D - Cedar Key	Tidal Channel	29.1567656°N	83.0531206°W	4/9/2024_4/16/2024	24	Yes	Yes	Yes	Yes	Yes	Yes
25	D - Cedar Key	Tidal Channel	29.1687849°N	83.0369451°W		0	No	-	-	-	-	Yes
26	D - Cedar Key	Tidal Channel	29.1528797°N	83.0418959°W	4/16/2024	13	Yes	Yes	Yes	Yes	No	Yes
60	D - Cedar Key	Tidal Channel	29.1503569°N	83.0334860°W	4/9/2025	2	No	Yes	No	No	No	No
61	D - Cedar Key	Tidal Channel	29.1392547°N	83.0259197°W	4/13/2024	3	No	No	Yes	Yes	No	Yes
62	D - Cedar Key	Tidal Channel	29.1424935°N	83.0203264°W	4/13/2024	2	No	No	No	No	No	Yes
63	D - Cedar Key	Tidal Channel	29.1530358°N	83.0168652°W	4/13/2024	2	No	No	Yes	No	No	Yes
64	D - Cedar Key	Tidal Channel	29.1550677°N	83.0129852°W	4/13/2024	2	No	Yes	Yes	No	No	Yes
65	D - Cedar Key	Tidal Channel	29.1586720°N	83.0092484°W	4/13/2024	3	No	Yes	No	No	No	Yes
30	D - Cedar Key	Offshore	29.1499392°N	82.9843330°W	4/16/2024	65	No	Yes	Yes	Yes	Yes	Yes

Acoustics and Ground-Truthing by Region

The overall study area was divided into four geographic regions for detailed analysis and map presentation (**Figure 8**). Each of the regional maps below (**Figures 9 - 16**) is discussed with respect to where live oysters were found in the context of three factors: (1) the target polygons; (2) historic oyster maps (blue polygons); and (3) current online Oyster Beds in Florida maps (red polygons).

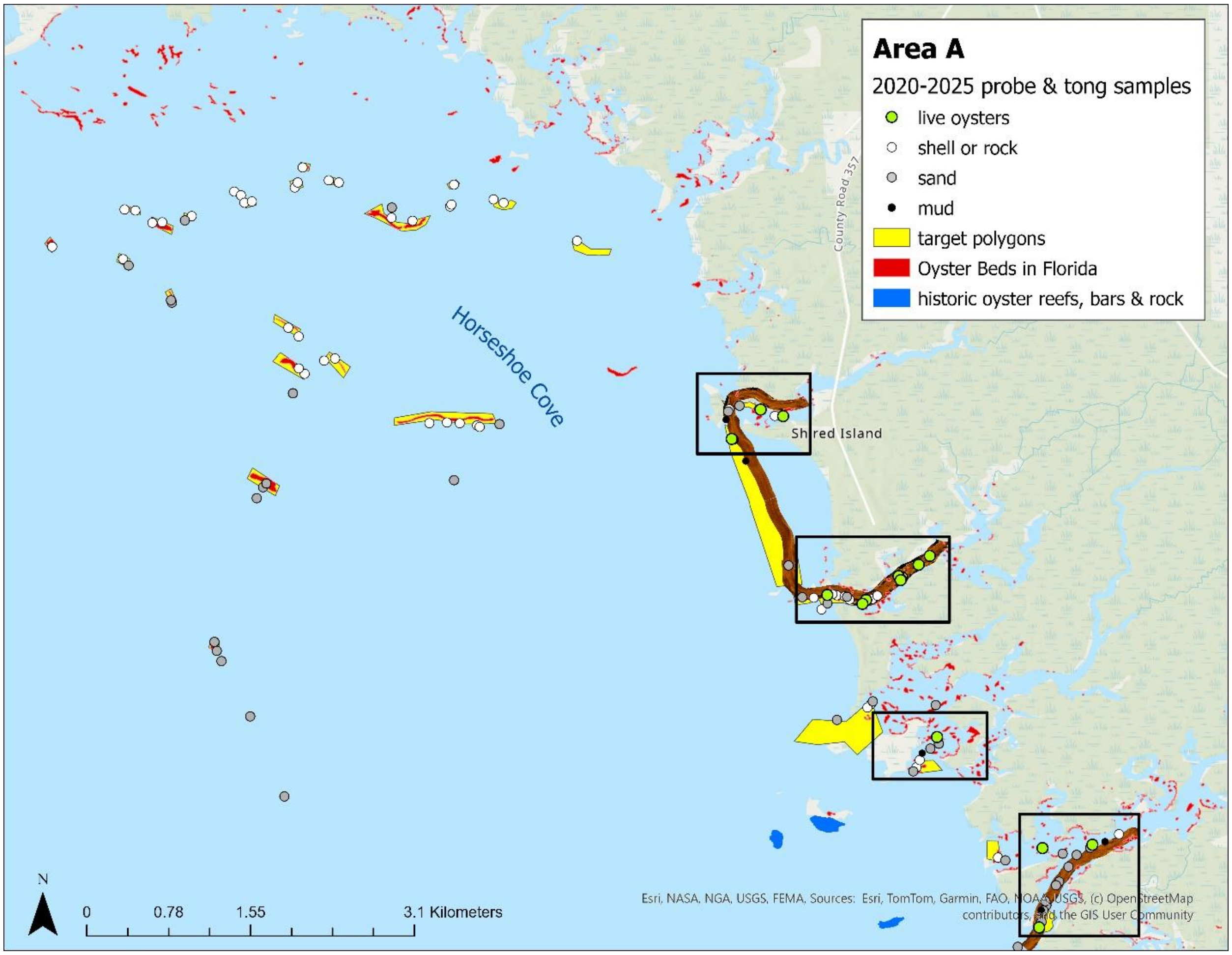

Figure 9. Ground-truthing samples taken in **Area A** (Horseshoe Cove area; see **Figure 8**) overlaid on Oyster Beds in Florida (red polygons), historic oyster maps (blue polygons), and target polygons for present study (yellow). Black rectangles are areas where live oysters were found; two are combined with sonar data in Figure 10 below.

No live oysters were found in any of the dozen or so offshore target polygons in Horseshoe Cove but shell was found in most, suggesting historic reefs. These findings are in line with previous assessments of the spatial pattern of relatively recent (late 1900s) historical degradation of oyster reefs in Suwannee Sound overall (Seavy et al. 2011; Radabaugh et al. 2021). Live subtidal oysters were only found in inshore tidal channels in four areas (indicated by black rectangles in **Figure 9**) and all were in or near target polygons. Historical maps only indicated live oysters (blue polygons) in three areas but none were surveyed.

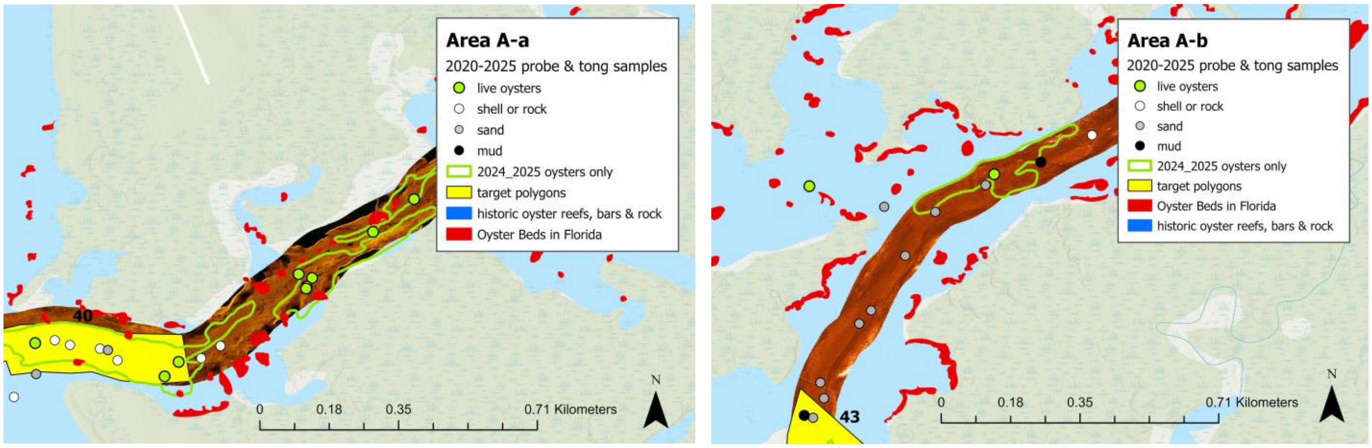

Figure 10. Closeups of two areas in **Area A** where live oysters were found combined with side-scan imagery, manually drawn live oyster polygons (green), ground truthing data points color-coded by type (see insets), portions of the target polygons (yellow) and intertidal oysters from online Oyster Beds in Florida (red polygons).

The closeups in **Figure 10** illustrate what was found in other areas: live oysters extended well outside the target polygons. Although side-scan data could not be acquired from many target polygons, as much side-scan data as possible was recorded in all areas when live oysters were detected. Another potentially important point to note for design of restoration projects, and as also shown in some maps below, was the close proximity between previously mapped intertidal oysters and subtidal oysters. Perhaps the division ecologically between the two reef types in shallow waters that is sometimes assumed is mainly a result of mapping methods?

Much remains to be learned about the ecological relationships among oyster reefs regardless of where they occur. The concepts of "source" and "sink" populations has received a lot of attention theoretically and should certainly be considered in designing restoration projects. But there is not a good understanding of spatial scales involved, particularly with respect to recruitment potential. Our new maps might be useful in identifying potential restoration sites (see more discussion below)

Live oysters were found throughout Area B, including nearshore, inshore and tidal channels, but the major concentrations occurred in nearshore, open-Gulf waters within the northern and main channels of the Suwannee River (black rectangles; **Figure 11**). At least some oysters occurred in 5 of the target polygons but acoustic data could not be acquired in most. Historic reefs (blue polygons) in Area B were mainly in the northern portion of the Great Suwannee Reef, and live subtidal oysters occurred only in isolated patches at the north end (target polygon 32).

The general area outside the north and main channels of the Suwannee River is particularly challenging for mapping because it is a dynamic area with respect to shoaling and water depths. Although the channels in most areas are marked they are not maintained, so deployment of acoustics gear is risky. Oysters were detected by probing or tongs and side-scan data was acquired along the main channels in both areas, but not outside the main channels. Thus, the historical mapping data (blue polygons) and current online Oyster Beds in Florida (red polygons) south of target polygon 32 were not surveyed.

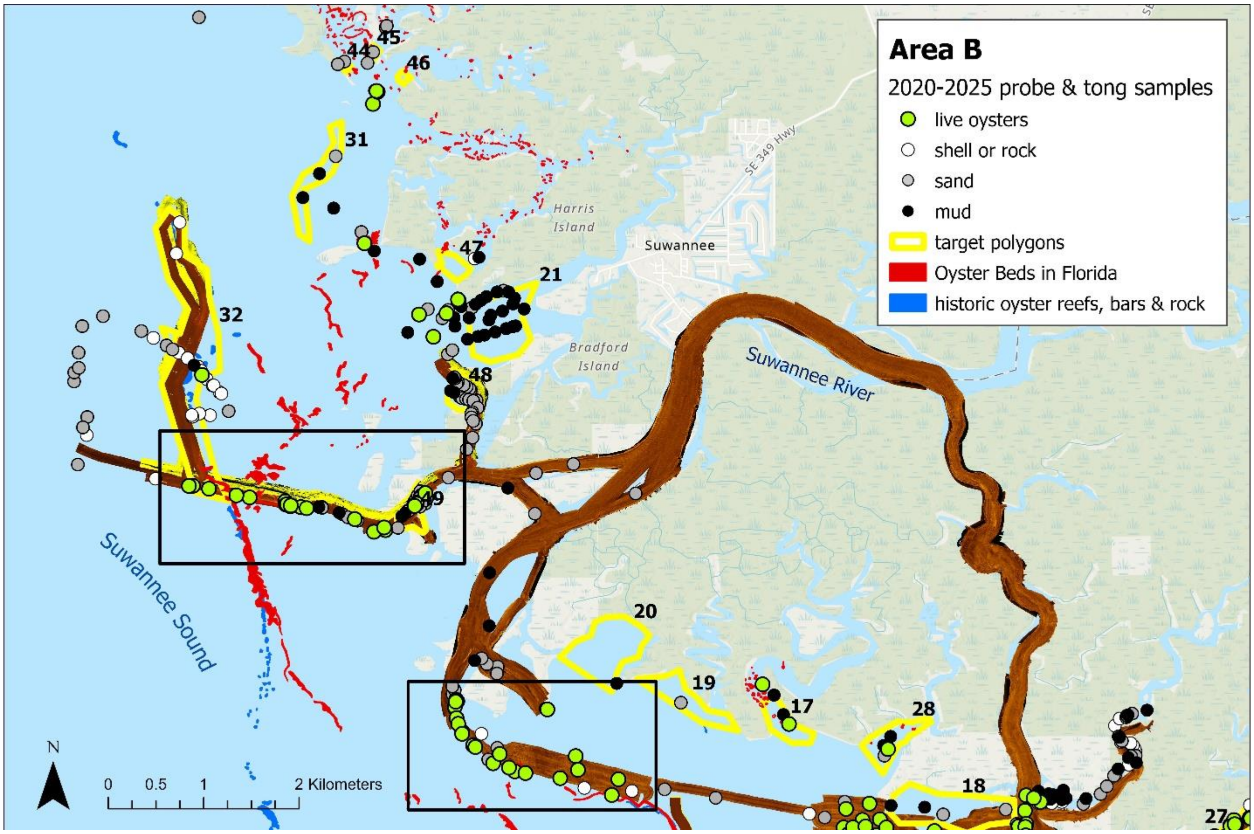

Figure 11. Ground-truthing samples in **Area B** (mouth of the Suwannee River) overlaid on Oyster Beds in Florida (red polygons), historic oyster maps (blue polygons), and target polygons for present study (yellow).

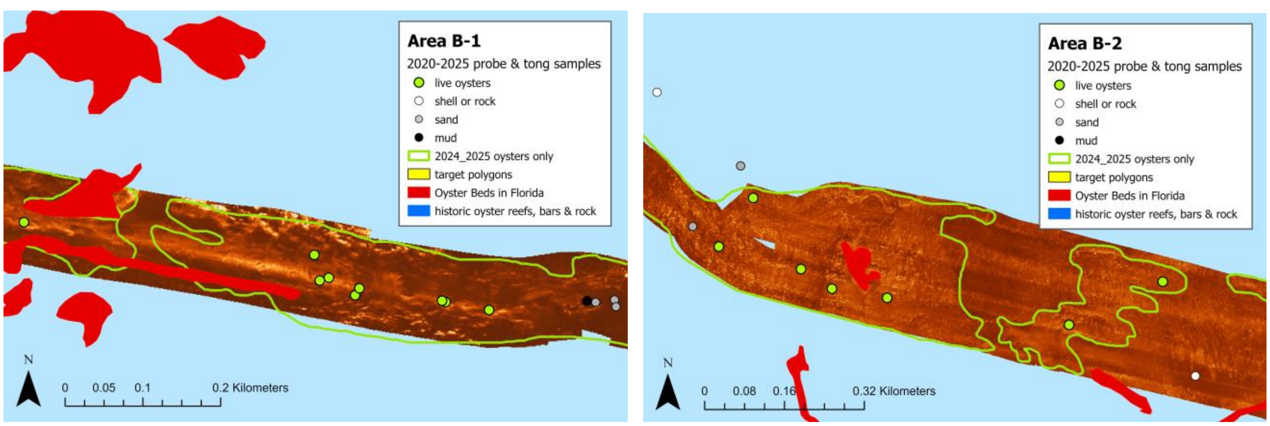

Figure 12. Closeups of two areas in **Area B** where live oysters were found combined with side-scan imagery, manually drawn live oyster polygons (green), ground truthing data points color-code by type (see inset), and intertidal oysters from online Oyster Beds in Florida (red polygons).

Live oysters were found throughout Area C, but mainly in inshore waters and tidal channels. At least some live oysters occurred in 9 of the target polygons but acoustic data could only be acquired in about half, and most live oysters occurred in areas outside target polygons, including open-Gulf waters and far upstream in two tidal channels (**Figure 13**). The historic reefs in this area were mainly parts of the Lone Cabbage and Great Suwannee Reefs. Acoustics and ground-truthing data were acquired just inshore of both, but live oysters were only found in isolated patches.

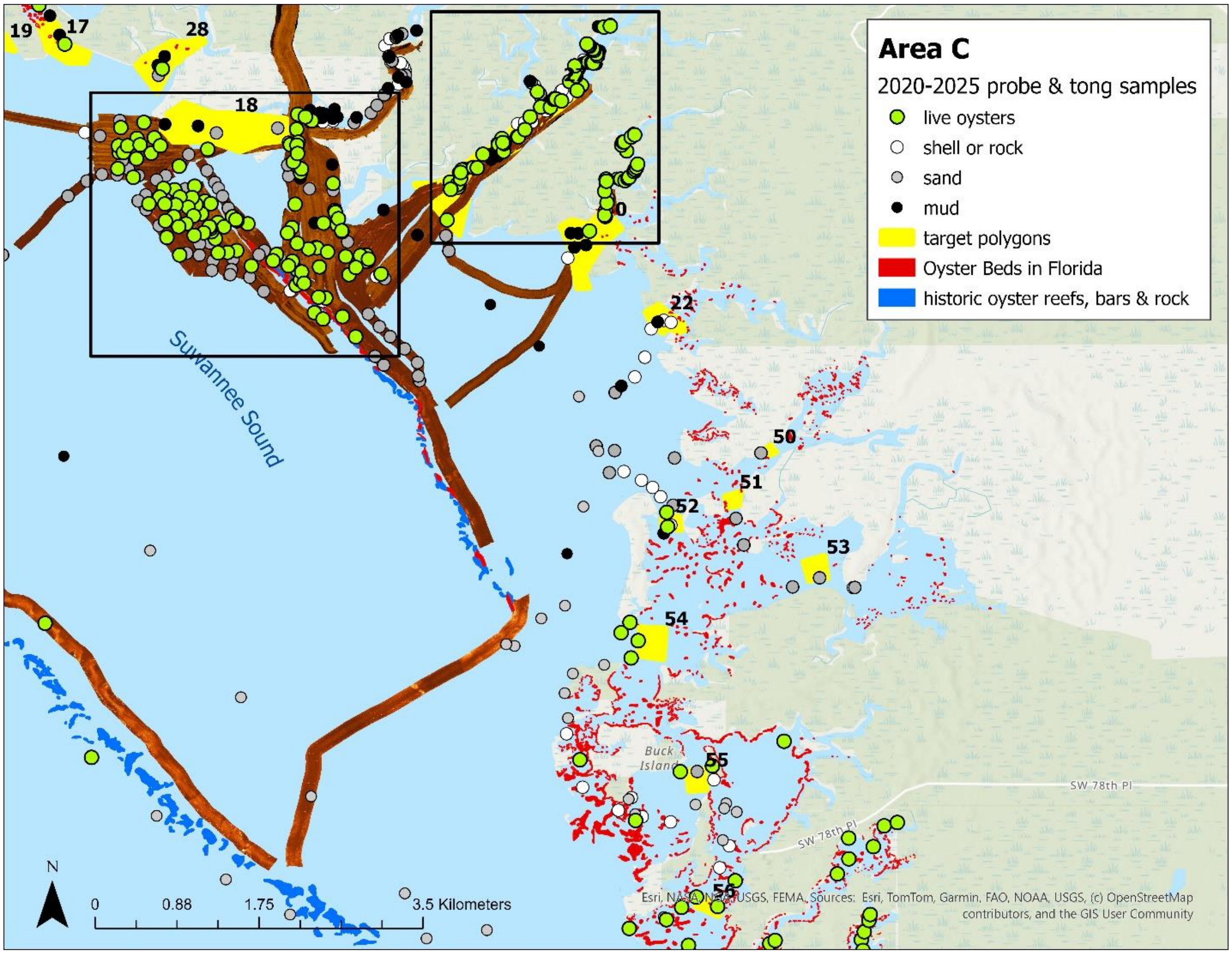

Figure 13. Ground-truthing samples taken in **Area C** overlaid on Oyster Beds in Florida (red polygons), historic oyster maps (blue polygons), and target polygons for present study (yellow).

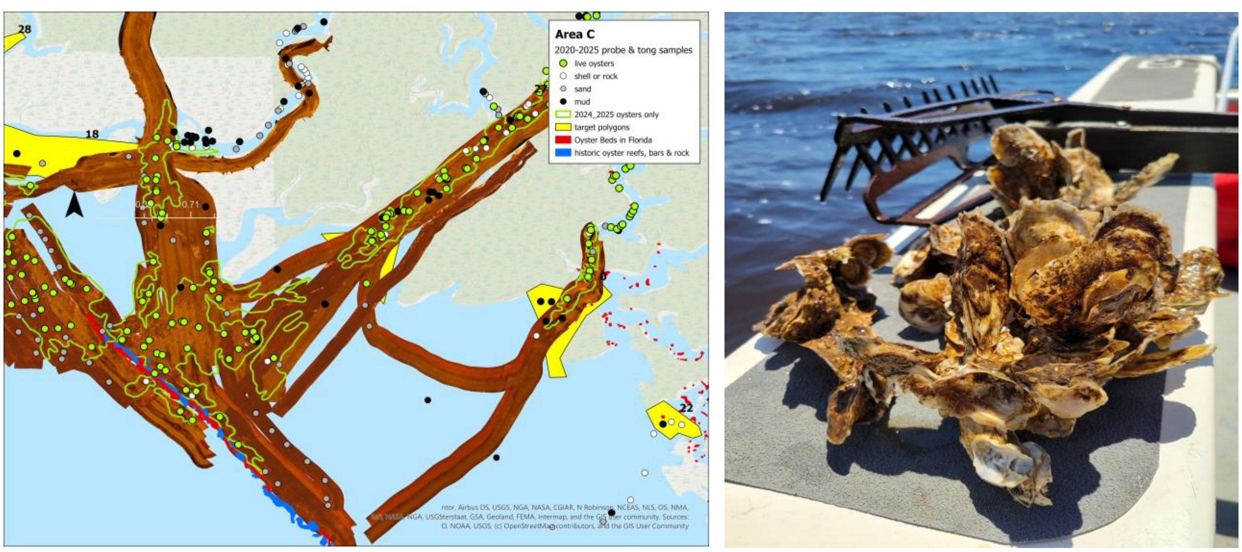

Figure 14. Closeup **Area C** where major concentration of live oysters were found combined with ground truthing data points color-coded by type (see inset), target polygons (yellow) and intertidal oysters from online Oyster Beds in Florida (red polygons). Live oyster cluster tonged from Area C.

Live oysters were found in inshore waters and tidal channels throughout Area D (**Figure 15**). At least some live oysters occurred in most of the target polygons but acoustics data was only acquired in the major tidal channel in central Cedar Key. Historic reefs mainly occurred in two areas: the south end of Great Suwannee Reef (near Derrick Key) and target polygon 30 which covered much of Corrigan's Reef east of Cedar Key. Only the Corrigan's Reef area was visited and extensive ground-truthing data were acquired. Although no acoustics data could be acquired within target polygon 30, LiDAR data were available for the entire area (**Figure 16**). Our ground-truthing data confirmed that most of the reef consisted of shell and sand, but with sparse live oysters in scattered deeper areas near the degraded former reef which was mostly intertidal. Our data also indicated that the areas currently in Oyster Beds in Florida (red polygons) should be deleted.

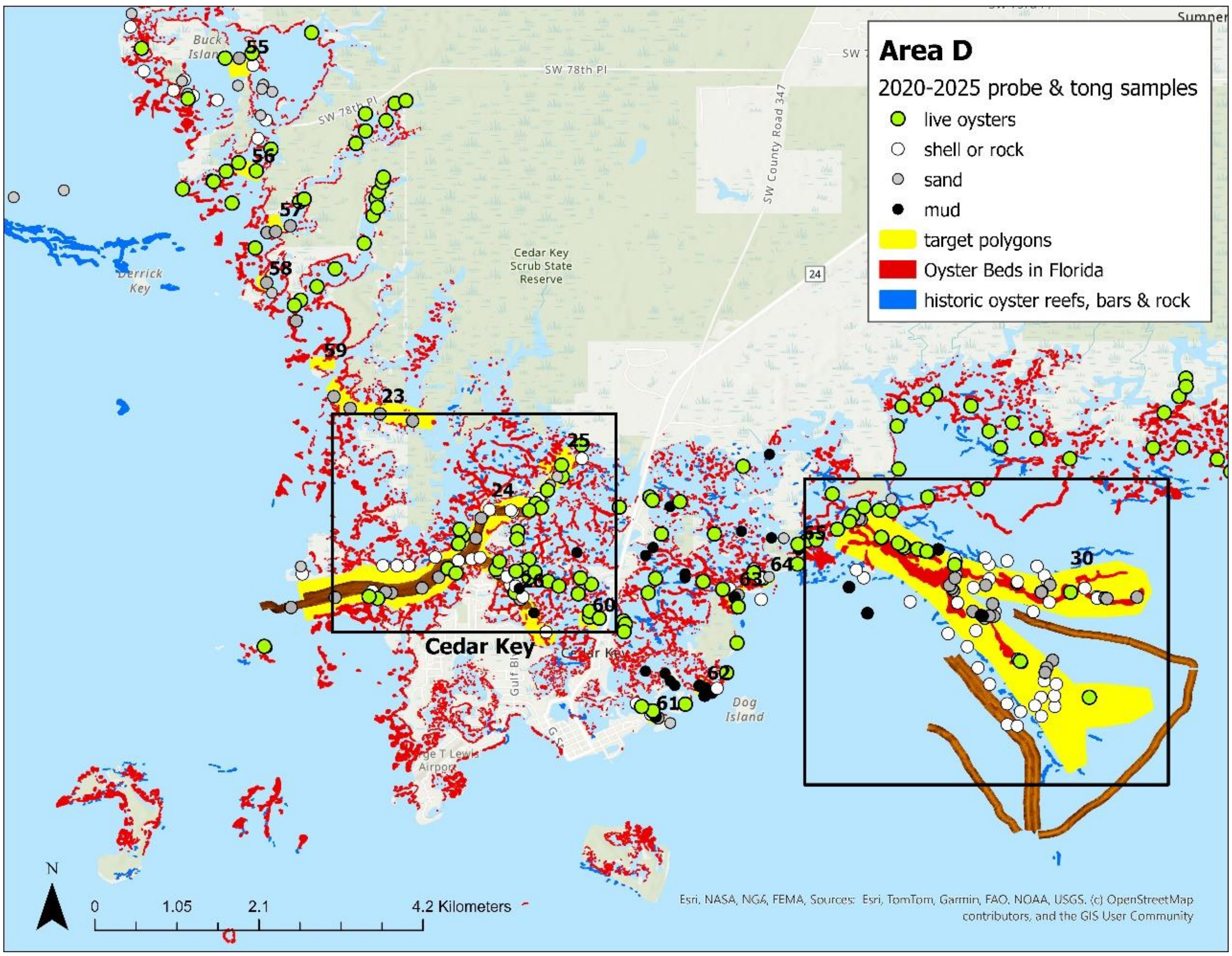

Figure 15. Ground-truthing samples taken in **Area D** (Cedar Key area) overlaid on Oyster Beds in Florida (red polygons), historic oyster maps (blue polygons), and target polygons for present study (yellow).

An important point to note regarding live subtidal oysters in Area D, is the lack of acoustics data acquired due to shallow-water conditions in most areas that prevented deployment of the sonar gear. This made quantification of the areal coverage of the many live oysters (green dots) throughout the area not possible. Additionally, all live oysters found by ground-truthing north and east of Corrigan's Reef were found in our 2020-2021 study and not part of the present project. Thus, much of the subtidal oyster resource east of Cedar Key remains unmapped.

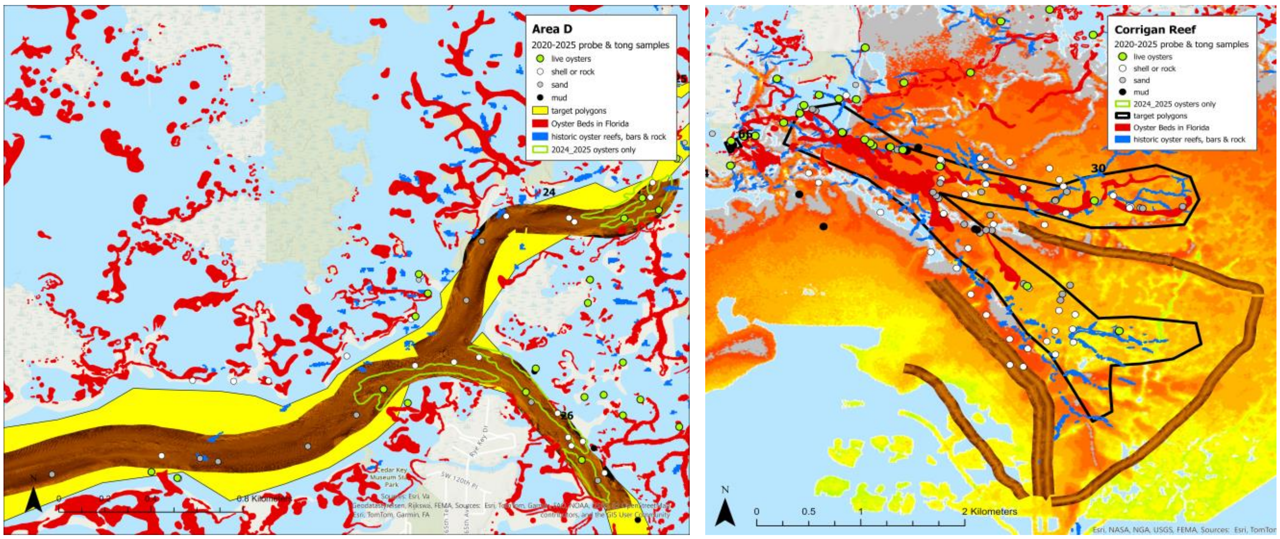

Figure 16. Closeups of two areas in Cedar Key in **Area D** where live oysters were found combined with side-scan imagery, manually drawn live oyster polygons (green), ground truthing data points color-code by type (see insets), and intertidal oysters from online Oyster Beds in Florida (red polygons). Left: central tidal channel in Cedar Key. Right: Corrigan's Reef.

The once extensive Corrigan's Reef (and the Lone Cabbage and Great Suwannee Reefs; see Grizzle et al. 2023 for discussion and photos) has suffered major degradations in the 1900s (Berquist et al. 2006; Seavey et al. 2011; Frederick et al. 2016). Corrigan's and Great Suwannee Reefs currently mainly consist of eroded/transported shell and sand that is easily visible in recent satellite imagery. Thus, a major portion of intertidal reefs in the overall Suwannee Sound study area were lost in recent decades. For Corrigan's and Great Suwannee Reefs, our surveys only found scattered small patches of live oysters in deeper (mostly subtidal) waters. Lone Cabbage Reef, however, has been extensively restored and its long-term development is being monitored (Frederick et al. 2016; Aufmuth et al. 2025)

Acoustics and Ground-Truthing Synthesis

The maps below were produced from a synthesis of new acoustics (sonar) and ground-truthing data delineating the distribution of subtidal oysters (**Figure 17**) hard bottom types (**Figure 18**), and subtidal oysters compared to current online Oyster Beds in Florida intertidal oysters (**Figure 19**) in the overall study area. <u>The mapped bottom areas with live oysters totaled 807 acres. As noted above and the figures below show, many areas where live oysters were detected could not be surveyed with side-scan. Thus, the live oyster resources in the study area are likely much greater.</u>

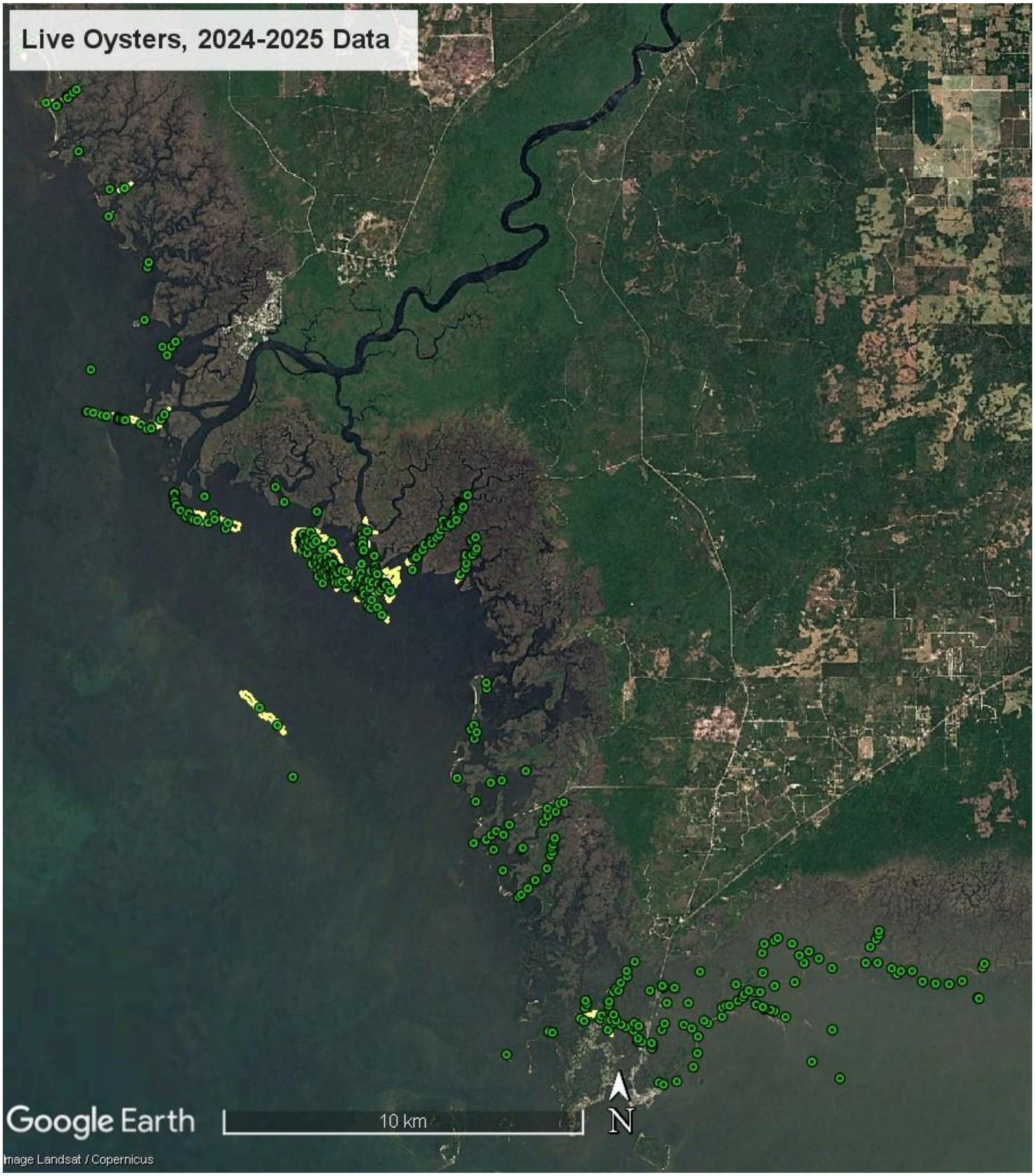

Figure 17. Ground-truthing points (green dots) where subtidal live oysters were found with probe, tongs, and/or video, and 2D polygons (yellow) showing the areal extent of live oysters where sufficient acoustics data were available to combine with the ground-truthing data.

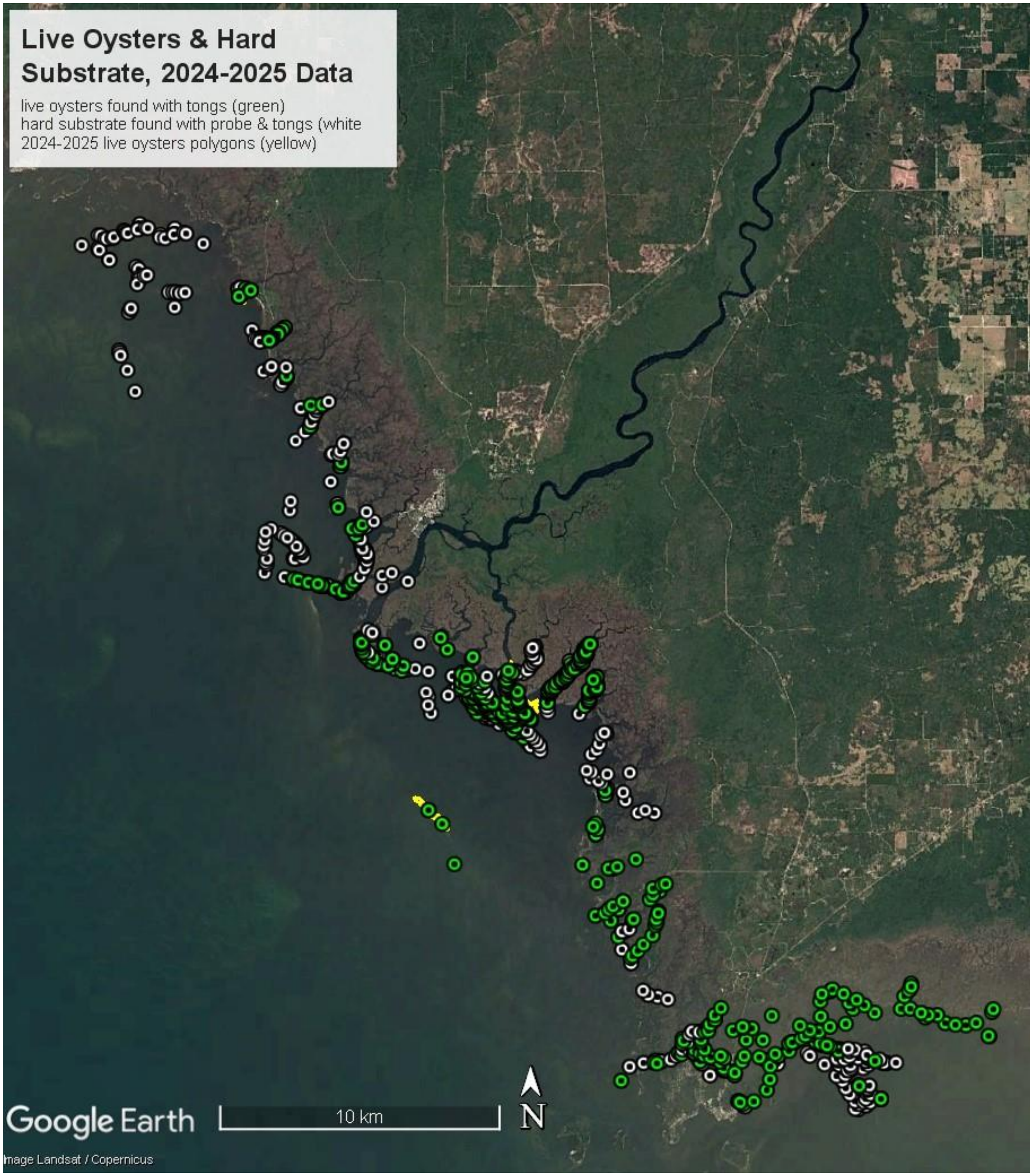

Figure 18. Ground-truthing points (green dots) where subtidal live oysters were found with probe, tongs, and/or video, and 2D polygons (blue) showing the areal of extent of hard bottom where sufficient acoustics data were available to combine with the ground-truthing data.

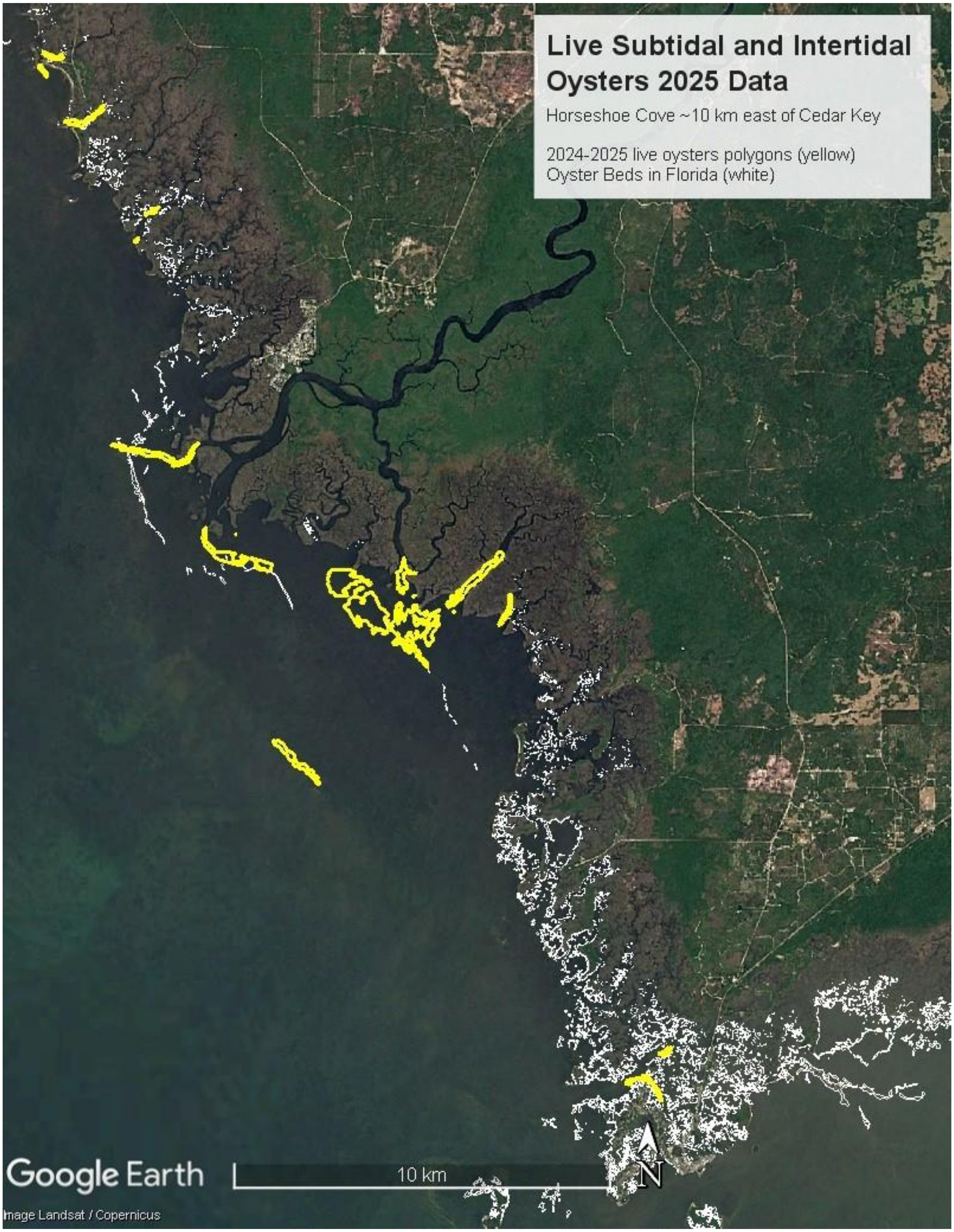

Figure 19. Areal coverage of subtidal live oysters (yellow polygons) overlaid on intertidal oysters (white polygons) from Oyster Beds in Florida.

Although the effect of human harvest on live subtidal oyster distributions was not part of the present study, a cursory inspection of a map of shellfish harvesting areas in the study area suggests a relationship. Our target areas and sampling included some “Conditionally Approved” waters but were mainly in inshore waters that are classified as “Prohibited” for human harvest (**Figure 20**). Nonetheless, the major concentration of live subtidal oysters was found in Prohibited waters near the mouth of the Suwannee River. No causal relationship can be assumed, but it suggests that human harvest should be considered in designing future restoration projects.

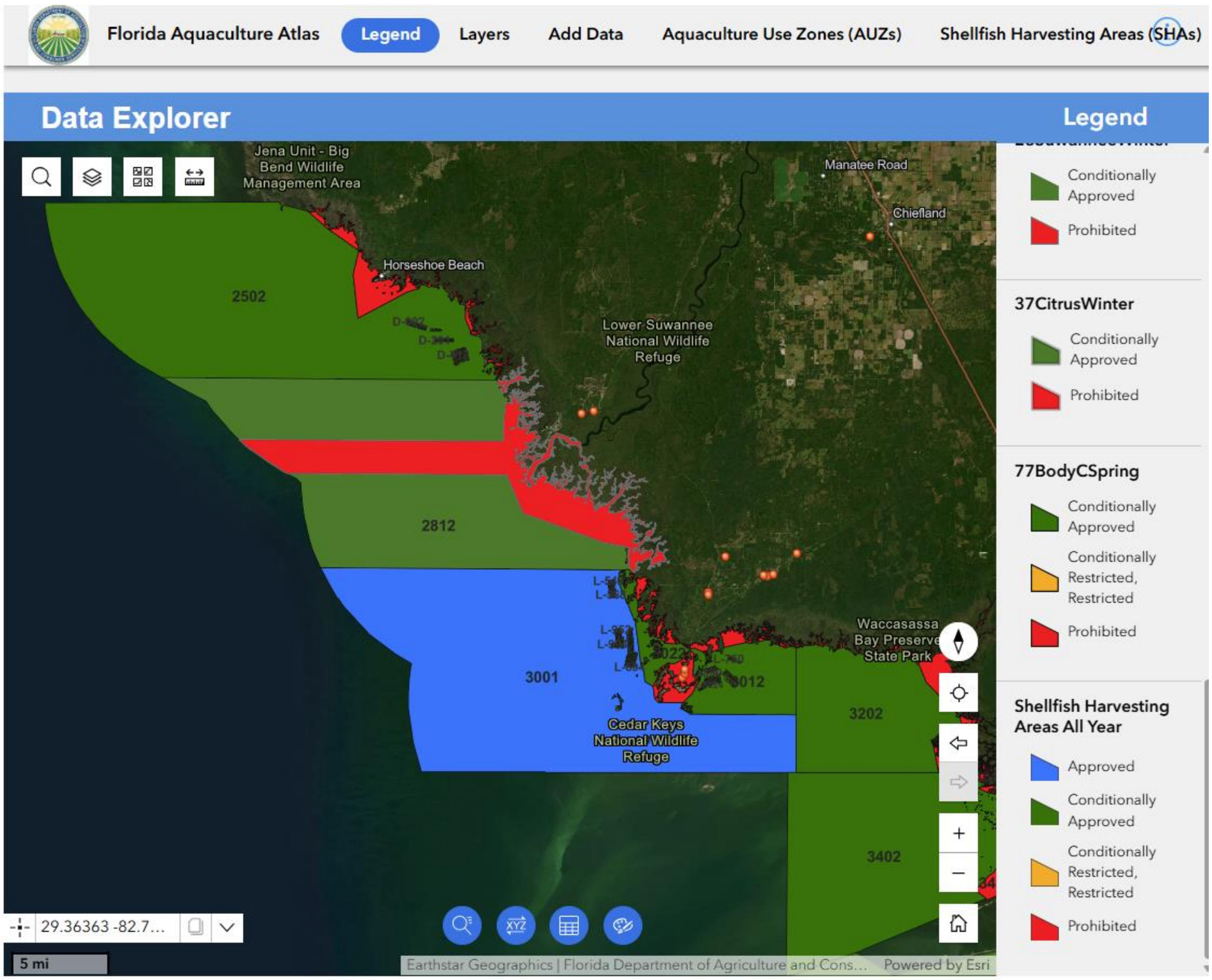

Figure 20. Classification of shellfish harvesting waters in the study area. Note that all inshore areas and tidal channels are classified “Prohibited” to harvest under all conditions, and the greatest spatial extent of prohibited waters is at the mouth of the Suwannee River (area 2812).

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Appendix A - Suwannee Sound Acoustic Methods

All surveys (2024 and 2025) were conducted aboard Substructure's *Diversity*, a 24-ft Privateer (**Figure 1**). The sonar equipment both years consisted of a Ping DSP 3DSS-iDX-450-Pro multibeam echosounder, an SBG Systems Navsight Ekinox vessel position and motion reference unit (integrated in the 3DSS), an AML Oceanographic MicroX sound velocity sensor (SVS) mounted near the 3DSS, a YSI Castaway conductivity-temperature-depth (CTD) speed of sound profiler, and Hypack/Hysweep hydrographic data acquisition and processing software.

Figure 1. Left: Acoustic gear on Substructure's *Diversity* with bow-mount and towfish in deployment position. Top: *Diversity* with bow-mount in raised position. Lower: Sonar monitors in wheelhouse.

Acoustics Equipment

The PingDSP 3DSS-iDX is a multibeam echosounder operating at 450 kHz with a nominal beamwidth of 0.4º. The system includes an AML SVS and SBG motion reference unit (MRU) that are fully integrated into the subsea sonar transducer package. The 3DSS-iDX incorporates a patented signal processing methodology that extends the single angle-of-arrival principle used in interferometric systems to accommodate multiple simultaneous backscatter arrivals (e.g., the seabed, sea surface, water-column, and multipath), resulting in improved wide-swath bathymetry, and both 2D and 3D acoustic imagery.

For this survey, the sonar towfish was mounted on a rigid bow-mount fairing about 50 cm below the water surface with known, fixed offsets to the primary SBG Navsight navigation reference point.

The range-scale for the Ping was set to 50-meters for all of the Suwannee Sound survey operations yielding a 2D imagery swath width of approximately 100 m (with some outer range reduction in softer sediments due to refraction). The bathymetry and 3D imagery swath were dependent on the water-depth and were generally maintained at eight to ten times the water depth. Where practical, the primary line-spacing was set to 80 m and was intended to provide at least 100% 2D imagery coverage. However, in most of the gap areas, the survey coverage was generally dictated by water depths where the boat could be safely navigated. Depending on the survey depths, the resulting bathymetry and 3D imagery coverage generally ranged from about a quarter to a half of the 2D imagery coverage.

Survey Horizontal and Vertical Positioning

To ensure accurate real-time positioning, the SBG primary Septentrio Global Navigation Satellite System (GNSS) receiver was configured to receive real-time kinematic (RTK) differential correctors from the Florida Department of Transportation's (FDOT) Florida Permanent Reference Network (FPRN) broadcast service. The cellular broadband connection was reliable on the survey vessel throughout the survey period, and the FPRN provided continuous RTK DGNSS correctors to the SBG's GNSS that were used as part of the tightly coupled vessel navigation and orientation solution. During the survey, a NAD83 Universal Transverse Mercator (UTM-meters) coordinate system Zone 17N and a Mean Lower Low Water (MLLW) vertical datum were used. NGS Geoid Model18 was used to transform the NAD83 GNSS ellipsoidal heights to NAVD88 orthometric heights, and the published NAVD88 to MLLW offset (0.687 m) for the Cedar Key tide gauge were used to compute MLLW tide heights. In addition to the continuous GNSS-derived water-level observations on the survey boat, the data from the NOAA Cedar Key tide station was also incorporated into the data processing review.

Based on DGNSS correctors received from the FPRN, the SBG operated in the Fixed Narrow Lane RTK mode throughout almost all of the survey operations, with position and elevation root mean square (RMS) error estimates that were consistently at the few-centimeter level. There were only a few short intermittent periods when the SBG operated in the non-fixed mode, mainly in the remote areas toward Shired Island. Because of the greater uncertainty in the GNSS elevations, the real-time DGNSS vertical reference data was only updated when the SBG was operating in the Fixed-Narrow Lane mode. Throughout the survey period, the SBG raw observable data were always recorded to enable post-processing with the SBG Qinertia software as needed.

Speed of Sound

A YSI Castaway CTD profiler was used to acquire periodic speed of sound profiles during the survey operations. In addition, the AML MicroX SVS included on the 3DSS provided continuous near-surface speed of sound readings that were recorded with the raw sonar data. Before the start of daily survey operations and at routine intervals throughout each survey day, water column speed of sound profiles were acquired with the Castaway and entered directly into the Hypack data acquisition package (**Figure 2**). Comparisons between the MicroX near-surface speed of sound values and the near-surface speed of sound values from the periodic Castaway CTD profiles showed strong agreement throughout the survey period. Speed of sound variability was mainly driven by salinity differences, but there were only a few instances where significant differences (up to 25 m/s) were observed. These stratified conditions were most noticeable in areas just outside of the main Suwannee River discharges (e.g., East Pass and West Pass). Refraction caused by large water-column speed of sound differences had some impact on the acoustic imagery data quality in a few areas, but did not limit the ability to delineate hard bottom features across the full swath.

Survey Data Processing

To ensure the accuracy and consistency of the navigation and elevation solution, Qinertia software was used to review and assess the real-time SBG Navsight solution. The primary reason for re-processing the SBG solution was to improve the vertical resolution so that the needed water-level reductions could be computed and applied to the bathymetric data. Qinertia utilized the raw observable data from the SBG Navsight, as well as static GNSS data from the relevant continuously operating reference stations (CORS) throughout the region, to re-compute the complete Navsight solution on the survey vessel using both forward and backward processing. The resulting Smoothed Best Estimate of Trajectory (SBET) file was then re-applied to the multibeam data to improve the accuracy and consistency of the final horizontal and vertical measurements. The real-time horizontal and vertical RMS accuracy estimates were very strong throughout the survey period (generally in the 2-4 cm range), so Qinertia was often only used to evaluate and confirm the real-time results.

Multibeam and Single-Beam Bathymetric Processing

After application of the SBET file if necessary, initial processing of the multibeam and single-beam bathymetry 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 to assess data coverage and conduct cross-check comparisons. Additional processing of the multibeam data was required to evaluate the coverage across the swath and to edit the outer beam areas as needed. The primary preliminary bathymetric products created from the bathymetric data were coarsely gridded (3m) datasets that could be used during the sampling operations to help determine the sampling plan and technique. The final gridded soundings were extracted from the full dataset using two different selection methods: 1) average of all soundings in the 1-m cell assigned to the cell center and 2) sounding nearest to the center of the 3-m grid cell assigned to its true position. An initial overview figure was created to show the overall acoustic survey coverage over the full project area.

Multibeam Imagery Processing

After application of the SBET file if necessary, initial processing of the multibeam imagery data included reviewing the raw sensor and navigation data, reviewing and updating the bottom-tracking, clipping any data as needed, applying a variety of gain adjustments, and creating preliminary imagery mosaic data products to assess data coverage. All of the acoustic imagery data processing was conducted in Chesapeake Technology SonarWiz. The 50-m imagery range setting was used during all data acquisition, and in open areas, survey lines were run to provide full-bottom imagery coverage. In the gap areas where the sonar could be safely operated, the overall imagery coverage was usually dictated by the limits of safe navigation. Preliminary imagery mosaics for the different survey areas were initially exported as geoTIFs and KMZs at a 1-meter resolution. The geoTIFs were then used within Hypack during the physical sampling operations to help plan and select specific target locations. The acoustic imagery KMZs were viewed in GoogleEarth to help assess the overall coverage and also to compare the acoustic imagery results against the aerial imagery, particularly in the nearshore areas.

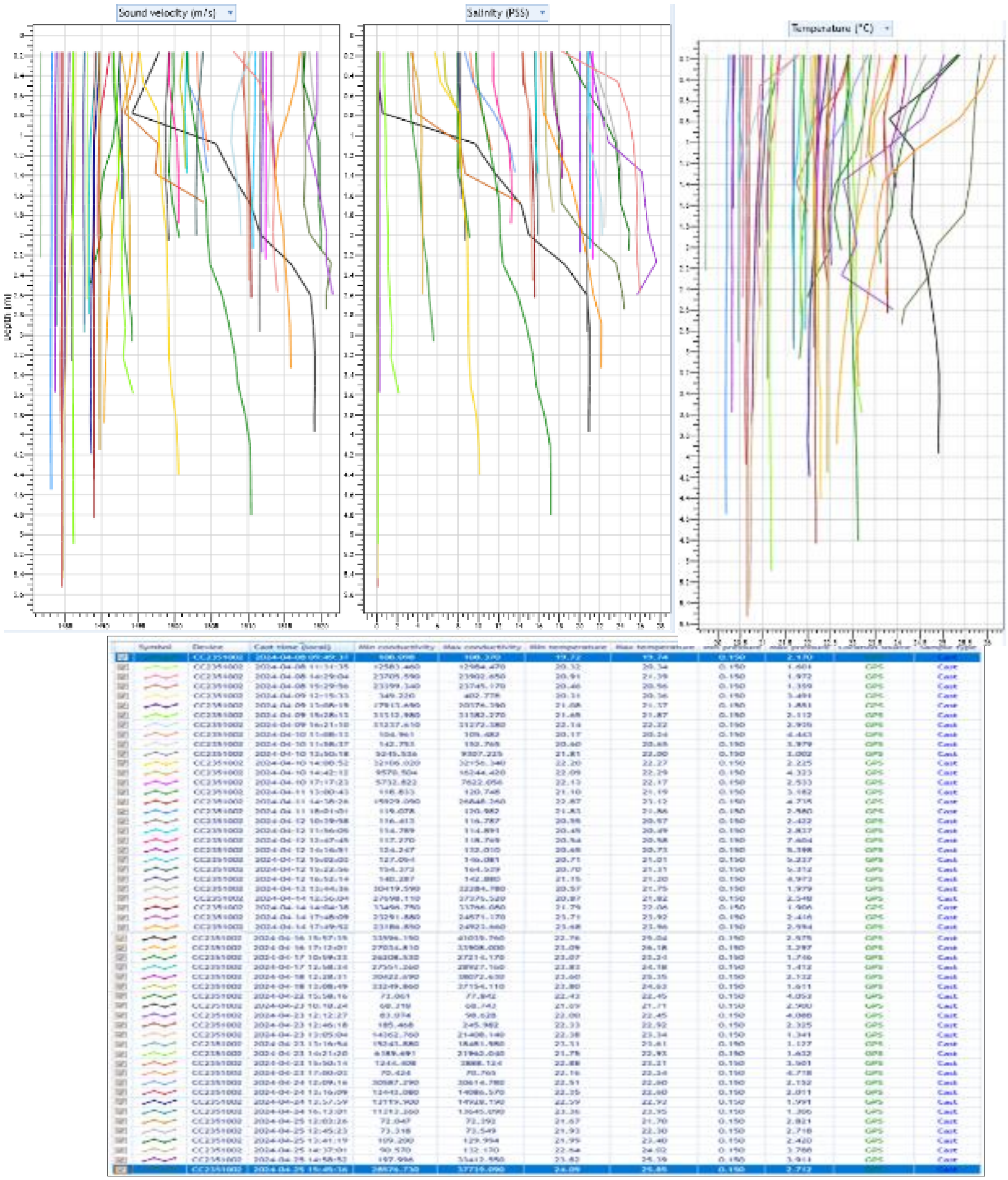

Figure 2. Overview of the CTD casts that were taken in the Suwannee Sound area during the various phases of the acoustic survey from 4/8/2024 through 4/25/2024. Speed of sound variability was mainly driven by salinity differences, but there were a few instances where significant differences (up to 25 m/s) were observed. These stratified conditions were most noticeable in areas just outside of the main Suwannee River discharges. Refraction caused by large water-column speed of sound differences had some impact on the acoustic imagery data quality, but did not limit the ability to delineate hard bottom features across the full swath.