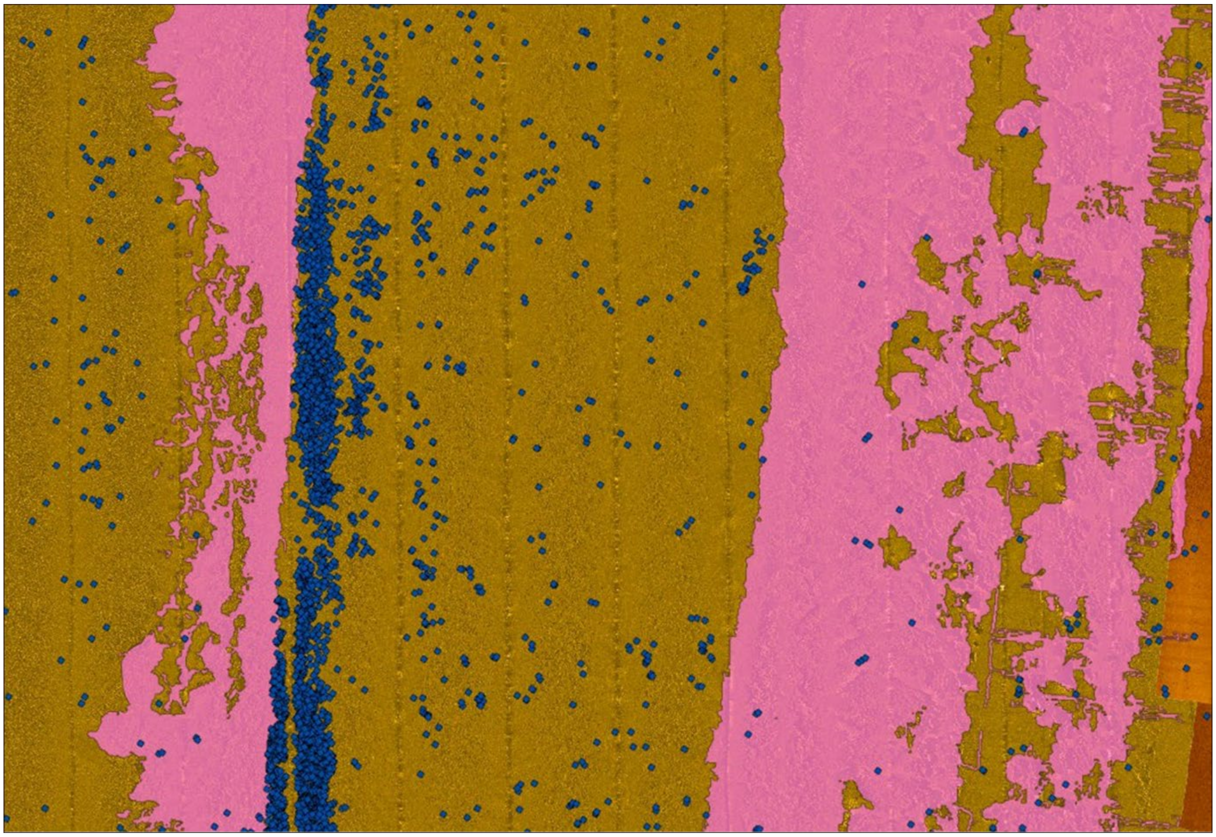
Osborne Tire Reef Restoration Plan, Phases 1 and 2 Report



Florida Department of Environmental Protection

CSA Ocean Sciences Inc.

olsen associates, inc. Coastal Engineering

Osborne Tire Reef Restoration Plan, Phases 1 and 2 Report

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List of Acronyms and Abbreviations

AI	artificial intelligence
CSA	CSA Ocean Sciences Inc.
FDEP	Florida Department of Environmental Protection
GIS	geographic information system
GNSS	global navigation satellite system
DGPS	differential global positioning system
MBES	multibeam echosounder
Olsen	Olsen Associates, Inc.
OTR	Osborne Tire Reef
QA/QC	Quality Assurance/Quality Control
RCNN	Region-Based Convolutional Neural Networks
SSS	side-scan sonar

1 Overview

Florida's Department of Environmental Protection (FDEP) is developing a restoration plan to continue removing tires from the Osborne Tire Reef (OTR) and restore the underlying habitat. In 2019, Olsen Associates, Inc. (Olsen) contracted CSA Ocean Sciences Inc. (CSA) to map the distribution and density of tires resting on and along the middle and outer reef complexes and in the sand areas between and around the reefs herein referred to as the 2019 Survey. Additional surveys of tire distribution on the seafloor beyond the 2019 Survey were needed to inform the feasibility and efficiency of novel removal methods and assess the potential for unauthorized impacts from those methods to living resources associated with the tires themselves and the surrounding environment.

Beginning 27 November 2023, CSA worked as a sub-consultant to Olsen for FDEP to obtain geophysical survey data (Phase 1) and conduct diver ground truthing on the OTR (Phase 2). Also, as part of Phase 2, CSA developed an artificial intelligence (AI) geographic information system (GIS) product on the OTR and adjacent areas to evaluate future tire removal activities and to determine the spatial extent of the tire distribution north and west of the 2019 Survey area. The work was performed under Olsen's FDEP Contract No. CN334. The goal of this scope of work was to collect, process, analyze, and ground truth side-scan sonar (SSS) and multibeam echosounder (MBES) data to develop an AI GIS product to produce a georeferenced map showing the tire distribution and bottom classification of the OTR project area, including:

- Georeferenced photos;
- Figures depicting survey area and tire counts during ground truth operations;
- Spatial distribution of tires in an alpha-numeric grid showing the approximate number of tires;
- Alpha-numeric grid of the seafloor bottom type;
- Production of an Excel spreadsheet of the data set summary; and
- Final report comprising Phase 1 and 2 operations.

It is important to note that CSA was not contracted to re-assess the 2019 Survey area. Data presented in this report as 2019 data are original to that survey.

It is likewise important to note that "tire distribution" represented herein is indicative of spatial surface presentation of tires on the seafloor and does not represent volumetric concentrations of tires across the survey area. That is, where there is concentration of tires in multiple layers, the side-scan data and AI tire counting techniques employed for this assignment are not capable of accurately representing the actual number of tires that may be located within the survey area. The information herein should be used with caution when estimating the total number of tires that may be located at any given location within the survey area.

All Daily Progress Reports are in **Appendix A**, including operational field days on the water for both the geophysical and diver ground truthing surveys. A portable hard drive containing all project data, including geophysical raw and processed data, photos, figures, and ArcGIS Pro files has been delivered to FDEP for uploading onto the FDEP server. CSA will also retain the project data in our digital archives.

2 Survey Equipment and Methods

CSA was provided with the Broward County Summer 2022 hardbottom edge polyline to delineate the western limit of the survey area (**Figure 1**). The eastern limit was set to the 100-ft depth contour. The north-south extent of survey area extended from near FDEP Monument R-049 approximately 4.5 km south to FDEP Monument R-073. During the 2019 Survey, it was observed that tires occurred beyond the contracted survey area, substantially so to the north and to a lesser extent to the west and south. The 2024 survey expanded the northern reach of the 2019 Survey effort an additional 4.2 km, south 0.75 km, and west 1.25 km to the nearshore edge of hard bottom. The new footprint, combined with the 2019 and 2024 surveys, was approximately 20.65 km^2. The exact dimensions of each survey are as follows:

- 2019:
  Sq ft: 31,873,884.00
  Sq km: 3.00

- 2024:
  Sq ft: 190,003,013.92
  Sq km: 17.65

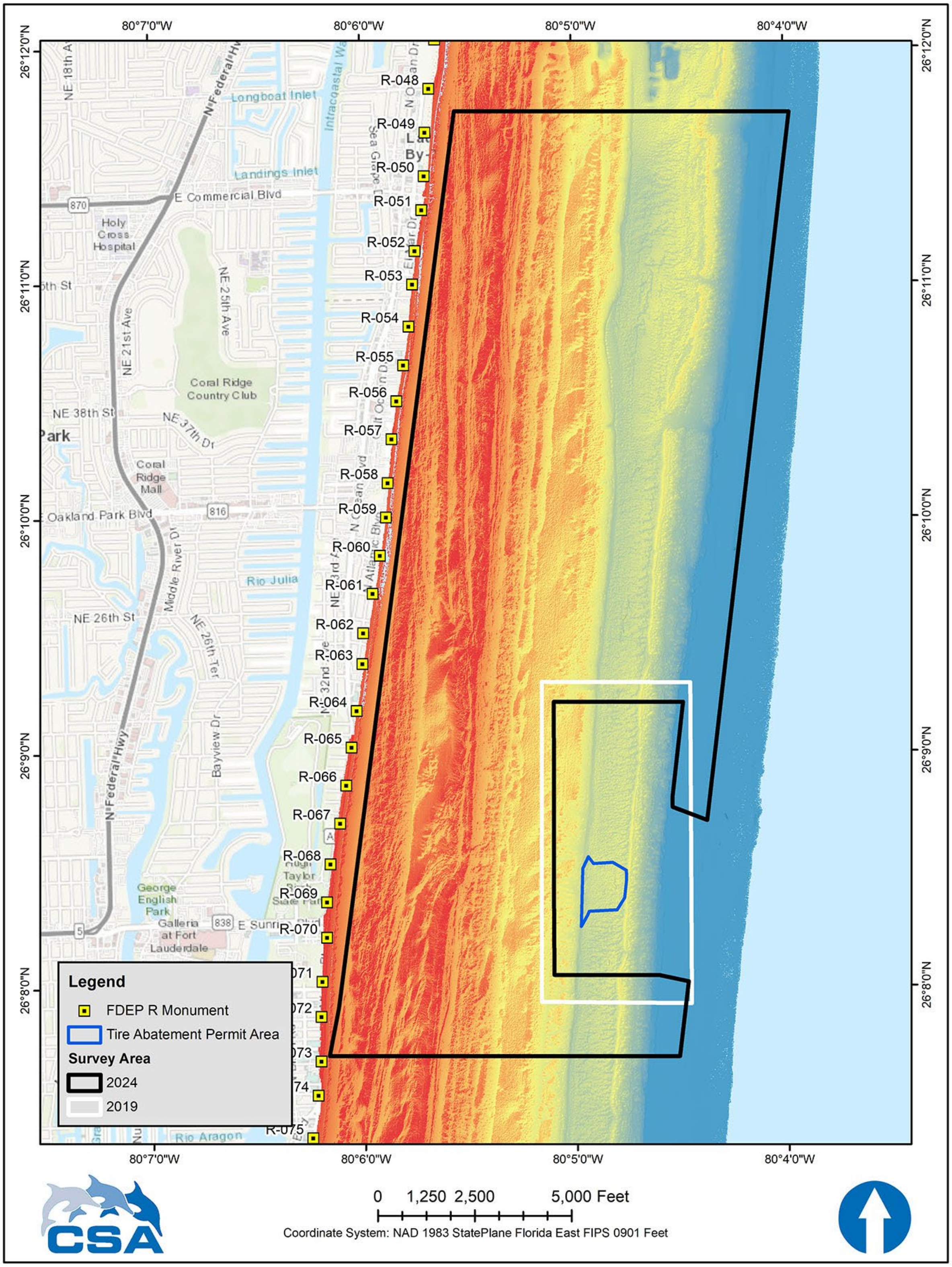


Figure 1. Survey areas for the Osborne Tire Reef (OTR) 2019 and 2024 surveys. The area termed “Tire Abatement Permit Area” (blue polygon) was determined to be a priority area for tire removal due to a high density and multiple layers of tires. Area: 0.12 km^2 (~350 m × 500 m).

3 Field Methods and Data Processing

3.1 SIDE-SCAN SONAR AND MULTIBEAM BATHYMETRIC SURVEY (PHASE 1)

The first step in the survey process was to visualize the seafloor which included both the OTR 2019 survey area and beyond using SSS and MBES techniques. The SSS and MBES survey was conducted between 28 November 2023 and 31 January 2024 (2024 Survey) over the course of 23 field survey days.

A Tri-Frequency EdgeTech 4205 system was used to collect all SSS data. The SSS was operated at 540 kHz and 850 kHz, yielding an effective slant range of 150 m. System components included an in-water towfish, slash-proof transceiver processor unit, and data acquisition computer with software interface. EdgeTech's native Discovery interface was used for SSS data acquisition while real-time navigation and data processing was accomplished using HYPACK Survey, HYPACK MBMAX64 (data processing and quality control module) and SonarWiz 7 (SSS data processing). The MBES system was comprised of an R2 Sonic 2024 echosounder with an integrated surface sound velocity probe and a top side SIM (computer controller unit). The MBES was operated at 400 kHz. Manufacturer equipment specification sheets for all equipment used during the 2024 Survey can be found in **Appendix B**.

The SSS towfish was deployed on a winch-deployed line via a sheave block mounted on the vessel's stern davit. The MBES sonar head was mounted to the starboard rail using an OTS Mini Mount, a Marine Survey Fabrication product (**Image 1**).

Image 1. Side-scan sonar deployed over the stern of the survey vessel with a davit and sheave block. Multibeam echosounder system on the side pole mounted on the starboard rail in the deployed position.

SSS and MBES bathymetry data were recorded along 65 evenly spaced generally north–south parallel transect lines. The survey lines held a 7-degree angle to the northeast to allow the vessel to better follow the natural contours. This resulted in more consistent towfish depth along any given survey line due to the variation in depth across the three distinct reef lines. Transect line spacing was 40 m and in some places set to 60 m. All spacing provided the required 100% SSS overlap.

Use of SBG Systems Apogree Subsea series hardware integrated position and motion tracking system were used to supplement the acoustic hardware and provide real-time motion-corrected location and motion data during MBES data collection. These components were physically installed on the survey vessel platform (38-ft Parker with twin 300 Yamaha outboards, SeaKeeper Gyro Stabilizer). All spatial offsets between the acoustic and navigation hardware and recording sensors were measured during mobilization. These offsets were then programmed into the SBG, HYPACK Survey (integrated navigation software), and HYSWEEP (equipment for geometry offset solutions) before acquisition. Position and heading were provided by the system's global navigation satellite system (GNSS) data and GNSS azimuth measurement system; motion was detected and output via an inertial measurement unit. During the survey, real-time kinematic corrections were incorporated into the navigation system via Starlink satellite high-speed internet connection to the Florida Department of Transportation (FDOT) Florida

Permanent Reference Network (FPRN). The geophysical equipment was set up in an enclosed climate-controlled cabin on the survey vessel (**Image 2**). The SBG Apogee Marine inertial navigation system was set to log data for calculating improved horizontal and vertical positioning using SBG Qinertia software during post processing to produce smoothed best estimate of trajectory solutions. The project virtual reference station and Hypack geodesy were both referenced to the Florida State Plane Coordinate System, East Zone, North American Datum of 1983, 2011 adjustment and to the North American Vertical Datum of 1988 (feet). The Surveyors Control Report is provided in **Appendix C**.

Image 2. Geophysical equipment set up in the cabin of the survey vessel offshore of Fort Lauderdale, Florida.

The speed of sound through the water column was measured at the beginning and the end of each survey day with an AML Base independent sound velocity profiler. These data were applied during post-processing to refine the soundings taken by the MBES.

Settings in the SSS acquisition software (Edgetech) allowed real-time determination of the towfish position by combining the amount of cable out (layback) with both depth and altitude data captured by sensors on the towfish. The system's total propagated uncertainty (TPU) applied time-varied gain and slant-range corrections in real time, while a survey technician also monitored real-time deployment to ensure the highest quality imagery acquisition.

3.1.1 Survey Data Processing and Production of a Preliminary Map (Phase 1)

SonarWiz 7 was used for post processing of the raw .JSF files. Processed and mosaicked SSS data were combined with bathymetry derived from the MBES to visualize depth changes, seafloor features, bottom types, and occurrence and spatial surface distribution of tires. Quality Assurance/Quality Control (QA/QC) of the SSS and MBES data was performed along the overlapping edges of the 2019 Survey footprint and the new limit of the 2024 Survey area. In these overlapping extents, both horizontal and vertical alignments were verified, as well as the presence of previously located features such as shipwrecks, individual tires and other natural hardbottom features during the post processing task (**Image 3**).

Image 3. Processing of the multibeam echosounder and side-scan sonar raw data for final deliverable.

During this post-processing, data products from remote sensing acquisition and processing programs were migrated into a project GIS database. Sonar files were input in TIFF, ASC, and XYZ formats for analysis. These files were overlaid with recorded vessel tracks during acoustic surveys. Objects of interest and feature identifications/delineations were developed as point, line, and polygon feature classes. All available Phase 1 data produced a detailed Preliminary Map covering the expanded OTR. Notable features in the Preliminary Map included a long pipe (**Figure 2**), natural reef structures, and sunken vessels and debris used to form artificial reefs (**Figure 3**).

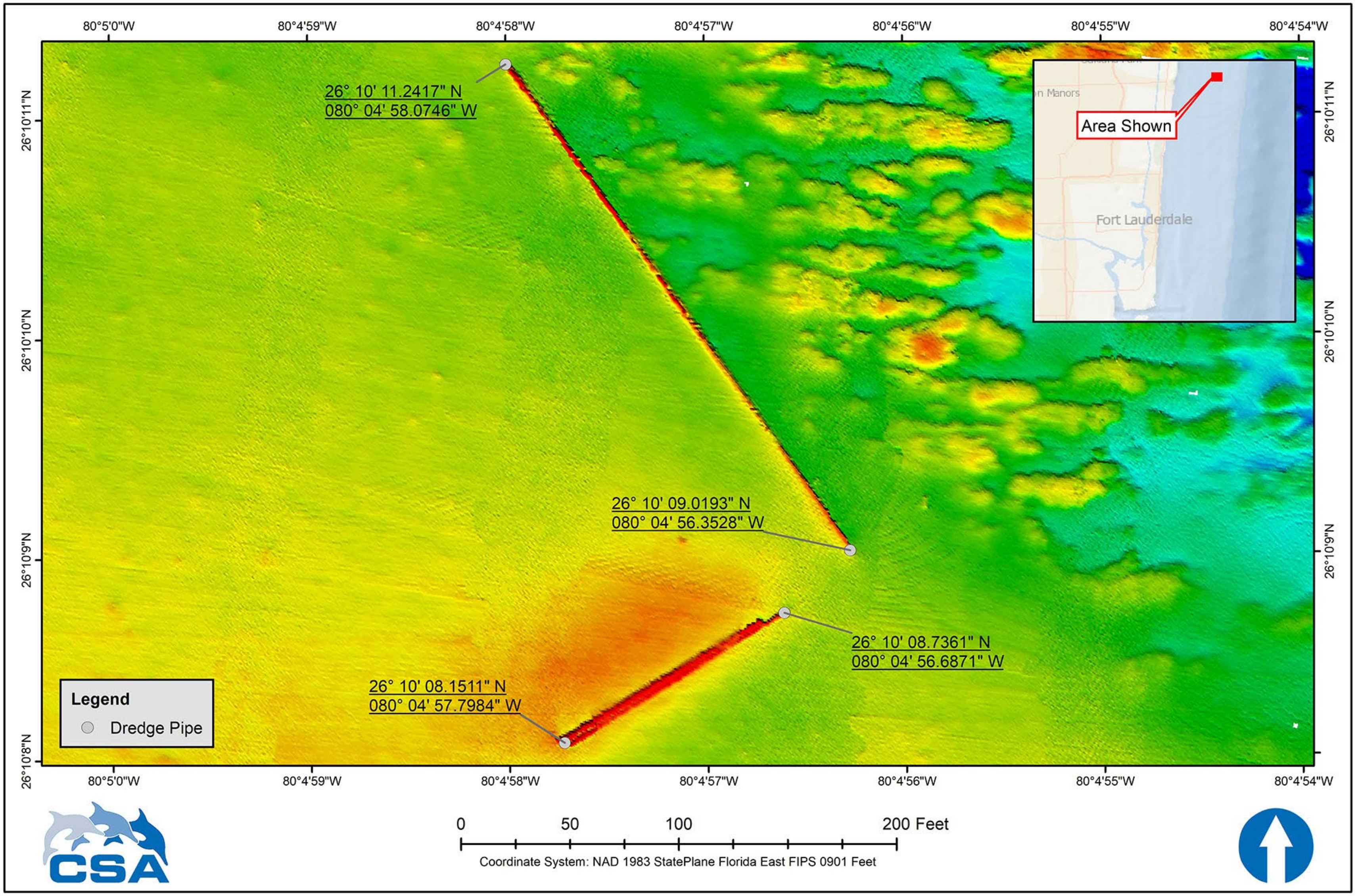


Figure 2. Multibeam image of suspected dredge pipe with a total length of 500 feet in three sections.

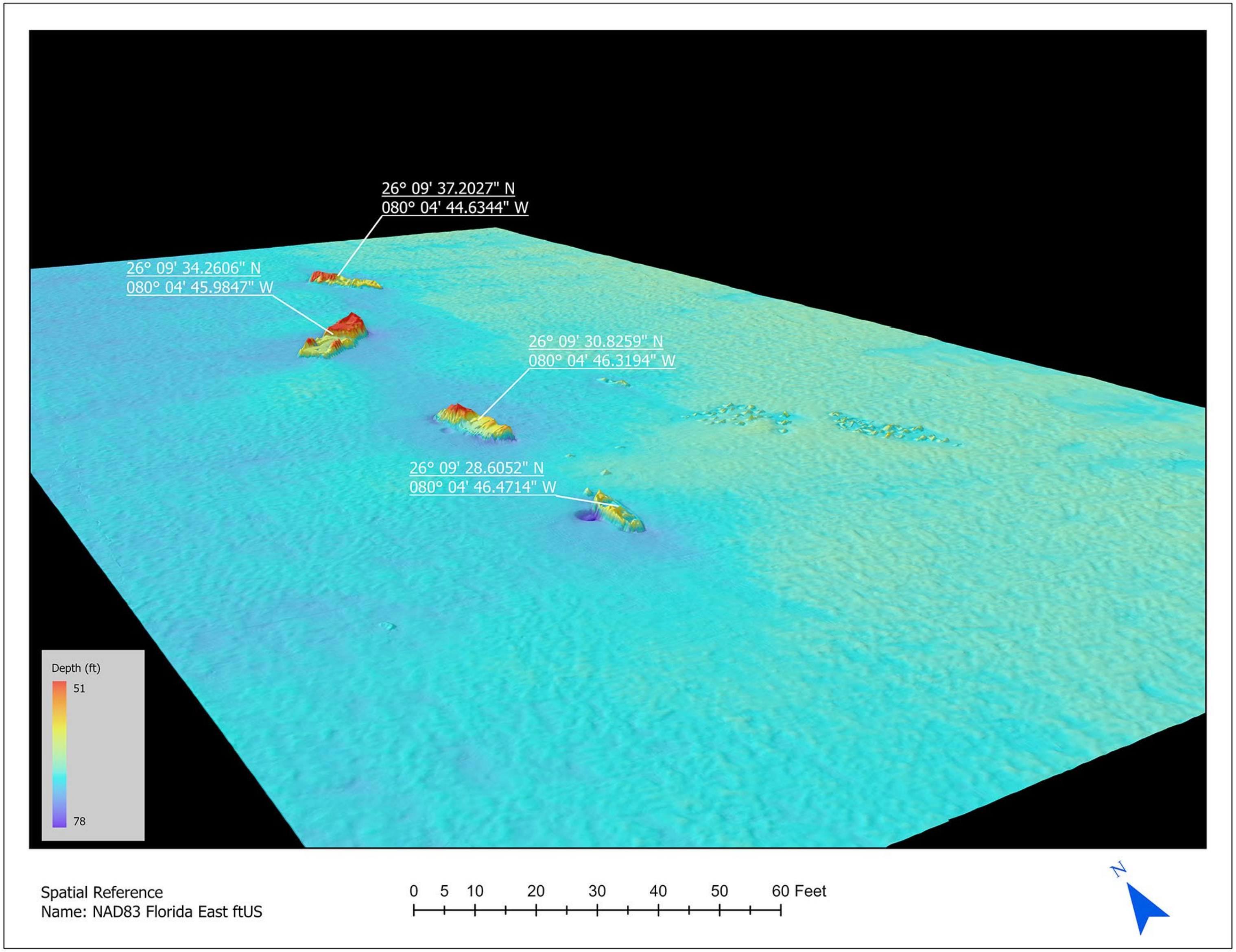


Figure 3. Multibeam image of vessels sunk to form artificial reef for diving and fishing along with other debris.

3.2 IN SITU DIVER GROUND TRUTHING OF SPECIFIC TARGETS (PHASE 2)

Seventy-one dive locations were selected and pre-plotted within the 2024 survey area for dive team ground truthing of features (**Figure 4**). Due to the short turnaround time between the final remote sensing data being processed and the submission deadline, divers performed ground truthing prior to application of an Esri Deep Learning extension[1] computation. Sites were determined after carefully reviewing the processed survey data specifically choosing areas that CSA's GIS team felt would warrant further investigation to aid the AI program's learning. In the 2024 survey area, GIS analysts directed divers to inspect areas with partially buried tires, multiple exposed tires, and objects that appeared as tires to verify their composition and inform decisions on removal of objects from the AI count total. Dive teams then conducted in situ ground truthing of as many of the features as possible during the 2-day survey. Selected bottom features included potential tires, hard bottom outcrops, and other unidentifiable items visible in the SSS mosaic of the surveyed area. Diving activities were conducted by a team of four CSA divers from a 28-ft CSA dive vessel equipped with a Hypack navigation system. All dive team members utilized enriched air nitrox mixes to maximize bottom time and decrease required diver surface intervals during the survey. Diver surveys were completed at a total of 61 of the 71 potential targets dispersed throughout the project area.

At sites selected for feature identification and ground truthing, a weighted buoy was first deployed to mark the specific location. The dive team then entered the water equipped with a GoPro Hero 9 video and still camera to collect video and/or still photos to document identification of the features. The dive team obtained oblique video or still images of targeted bottom features observed at each selected site and recorded substrate type and a description of any other observed items. Example images from the diver ground truthing can be found in **Image 4**. Take note of the various stages of burial that the tires present themselves on the bottom.

At the completion of each field day, all video and still photo data were downloaded and reviewed and then copied onto multiple storage devices for security and redundancy. Data files that accompany this report include an interactive georeferenced photo data file depicting what the divers discovered at each of the 61 ground truth sites. Notable features identified for further investigation during the diver ground truthing are found in **Image 5**.

[1] https://pro.arcgis.com/en/pro-app/latest/help/analysis/deep-learning/deep-learning-in-arcgis-pro.htm

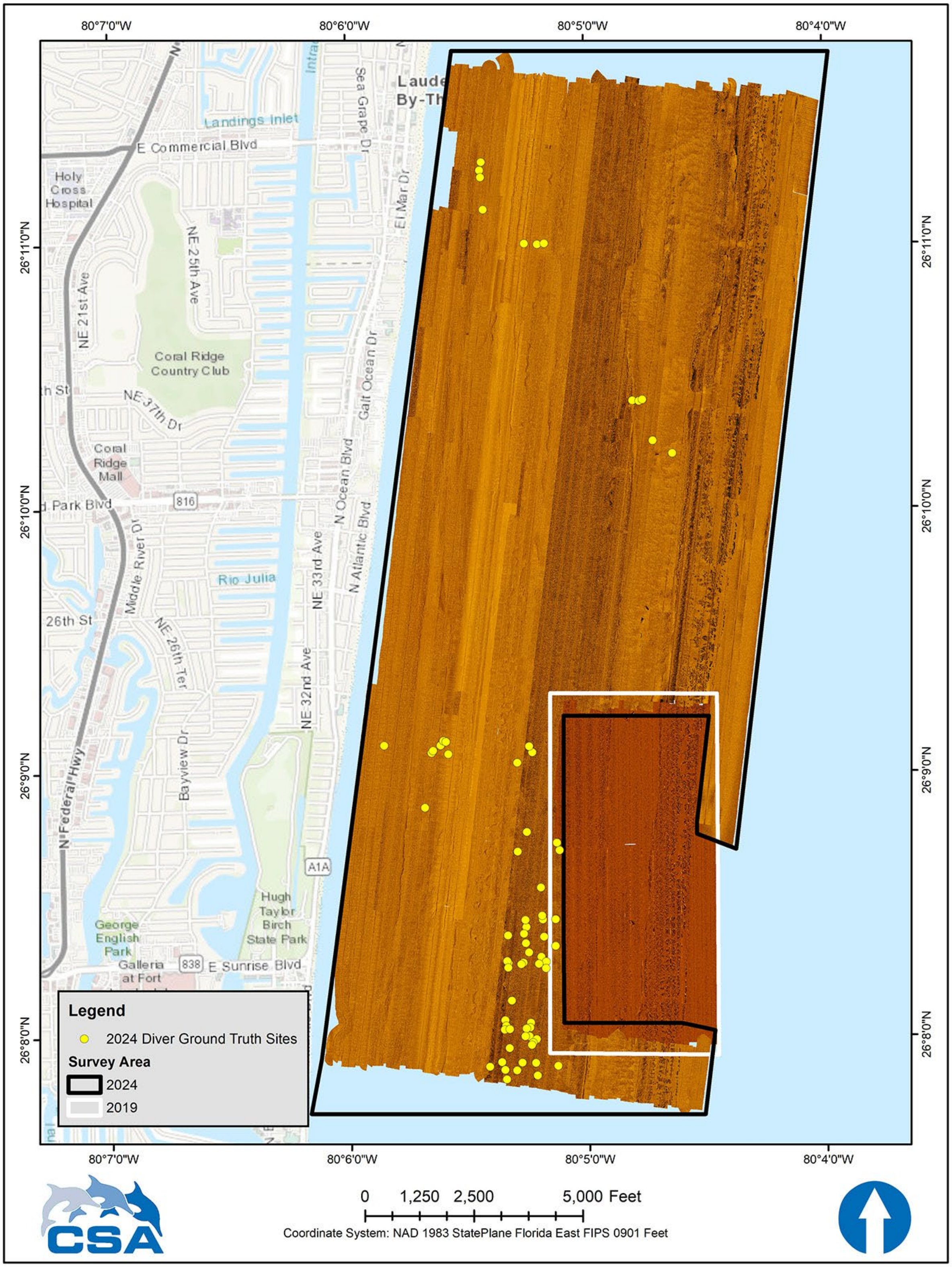
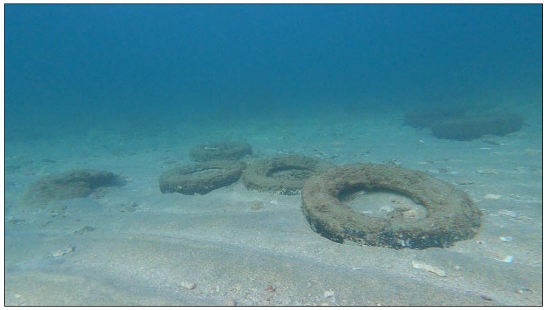


Figure 4. Diver ground truth sites during the Osborne Tire Reef 2024 Survey overlayed on the side-scan sonar mosaic.


Multiple tires in shallow water


Single tire with heavy hydroid growth


Single tire barely exposed


Single tire amongst exposed hardbottom outcrops.


A pair of loggerhead sponges


Barrel sponge on low-relief hardbottom

Image 4. Identified features of tires in various states along with sponges that resembled tires.

Large (3 ft) metal box

Lobster trap

Large dive platform

Clump of tangled line

Image 5. Objects that appeared in the geophysical data which warranted further investigation.

3.2.1 Artificial Intelligence Algorithm Generation (Phase 2)

CSA developed a Region-Based Convolutional Neural Networks (RCNN[2]) Mask model (RCNN model) within the Esri ArcGIS Pro Deep Learning extension to automate the identification of surface tires represented by the SSS imagery collected over the seafloor. This included an automated process for initial feature detection using processed SSS data as an input and creating point features as an output. These results were reviewed and refined by a GIS analyst.

Surface tires were identified from data collected by a Klein 3900 SSS operating at a high frequency of 900 kHz in the 2019 survey data set and an EdgeTech Tri-Frequency 4205 SSS operating at 850 kHz in 2024 survey data. SSS mosaics were applied to the Deep Learning extension within the ArcGIS Pro Imagery Analyst geoprocessing module. This method used the RCNN model that was trained to identify tires on seafloor imagery. These locations were marked and manually reviewed by a data processor. Results generated by the Deep Learning extension were then augmented with attribute information such as coordinates, depth, and grid location.

Methods outlined in the procedures section detail the following workflow steps:

1. Import processed, SSS mosaic at 0.25-meter cell resolution into ArcGIS Pro Project;
2. Execute Region-based Convolutional Neural Network (RCNN) model within the Esri's Deep Learning extension;

[2] https://developers.arcgis.com/python/guide/faster-rcnn-object-detector/

3. Convert polygons to point features at polygon centroid;
4. QA/QC output Point features; and
5. Attribute point features created.

The RCNN model in the Deep Learning extension was applied on the post processed geophysical data acquired from the vessel. The RCNN model approach used here combined the strengths of RCNN and mask prediction techniques, making it particularly effective in object detection and segmentation tasks. The output product featured detected surface tires represented as point features, accompanied by an attribute table with a unique ID for each tire detected, which was the requested deliverable.

Use of the Deep Learning extension and RCNN model in ArcGIS Pro represents a significant advancement in automating object identification within imagery. However, it is crucial to acknowledge the challenges inherent in using this technology, especially when analyzing SSS imagery. Interpreting SSS imagery presents difficulties due to acoustic shadows (hard bottom reef), seabed clutter, and varying object orientations. Moreover, the SSS imagery only represents objects that are present on the seafloor surface. Additionally, factors like water conditions, sensor characteristics, and seabed composition can affect the image quality. These factors significantly impact the model's effectiveness, hindering its ability to represent detected objects accurately.

Due to many of the factors mentioned, the model encountered challenges, specifically in the 2019 survey area. Impacted by sensor characteristics and the “Nadir” line (the line directly beneath the sonar sensor's path), the model struggled to capture potential tires in regions of poor image quality. **Figure 5** presents an example of complications experienced while analyzing the 2019 survey data. In the image (2019 Survey), we can see the SSS imagery with detected tires, and the Nadir line. Due to the low resolution or blurry imagery, the model detected tires of adequate clarity.

The Deep Learning extension is limited by the type of imagery to which it is applied. That is, these models cannot characterize conditions in three dimension if only a two-dimensional image or dataset is available. In this instance, the SSS data only represents conditions that are surface presentations. This limits the ability of this method to accurately estimate the total quantity of tires remaining offshore of Broward County where it is known that there are large concentrations of multiple layers of tires. Additionally, the model may fail to detect every individual tire when identifiers such as rims or inner circumferences are missing or overlapped by another tire. As a result, the model will not detect tires that are not fully visible in the SSS images.

In **Figure 6**, we observed a significant number of tires in this image from the 2019 SSS survey data. Although the model did not detect every individual surface tire, it successfully captured the majority of tires in the image.

The model successfully detected most surface tires with significant tire identifiers, where the rims or inner circumferences w distinguishable. However, when tires are buried or are visually obstructed (i.e., where there are multiple layers of tires), the model cannot detect their presence. Tire orientation may have also influenced detection, but this was not tested. **Figure 7** demonstrates tires in various stages of burial. Areas outlined in yellow contain tires that are nearly entirely covered with sand with the outer edges not visible but with central depressions somewhat discernible. The model could not identify an object as a tire if all of the identifiers were not associated. While the model could provide an estimation without the characteristics of a tire, the model was not set up to do so.

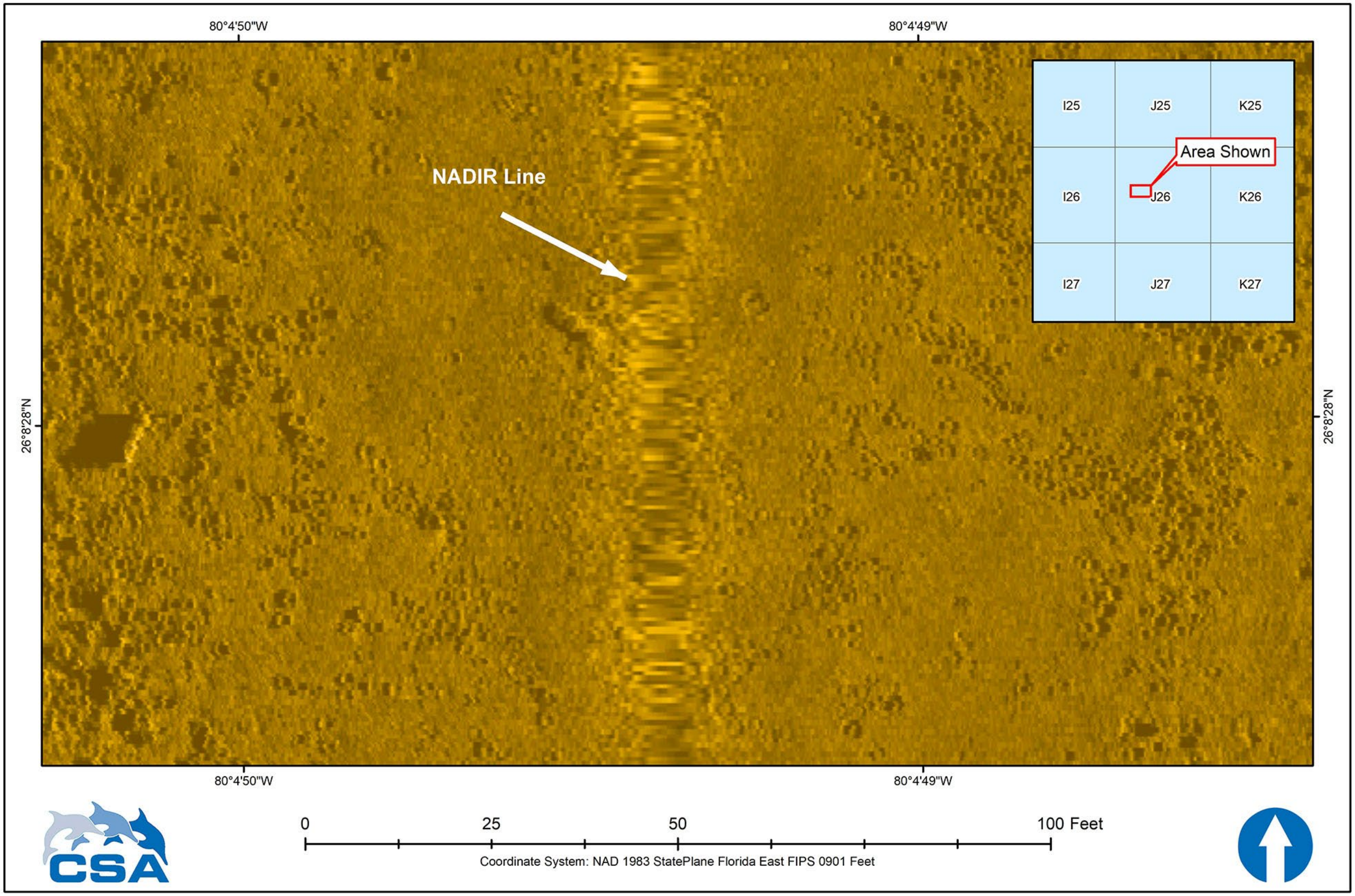


Figure 5. Example of image quality impacted by the presence of the nadir line.

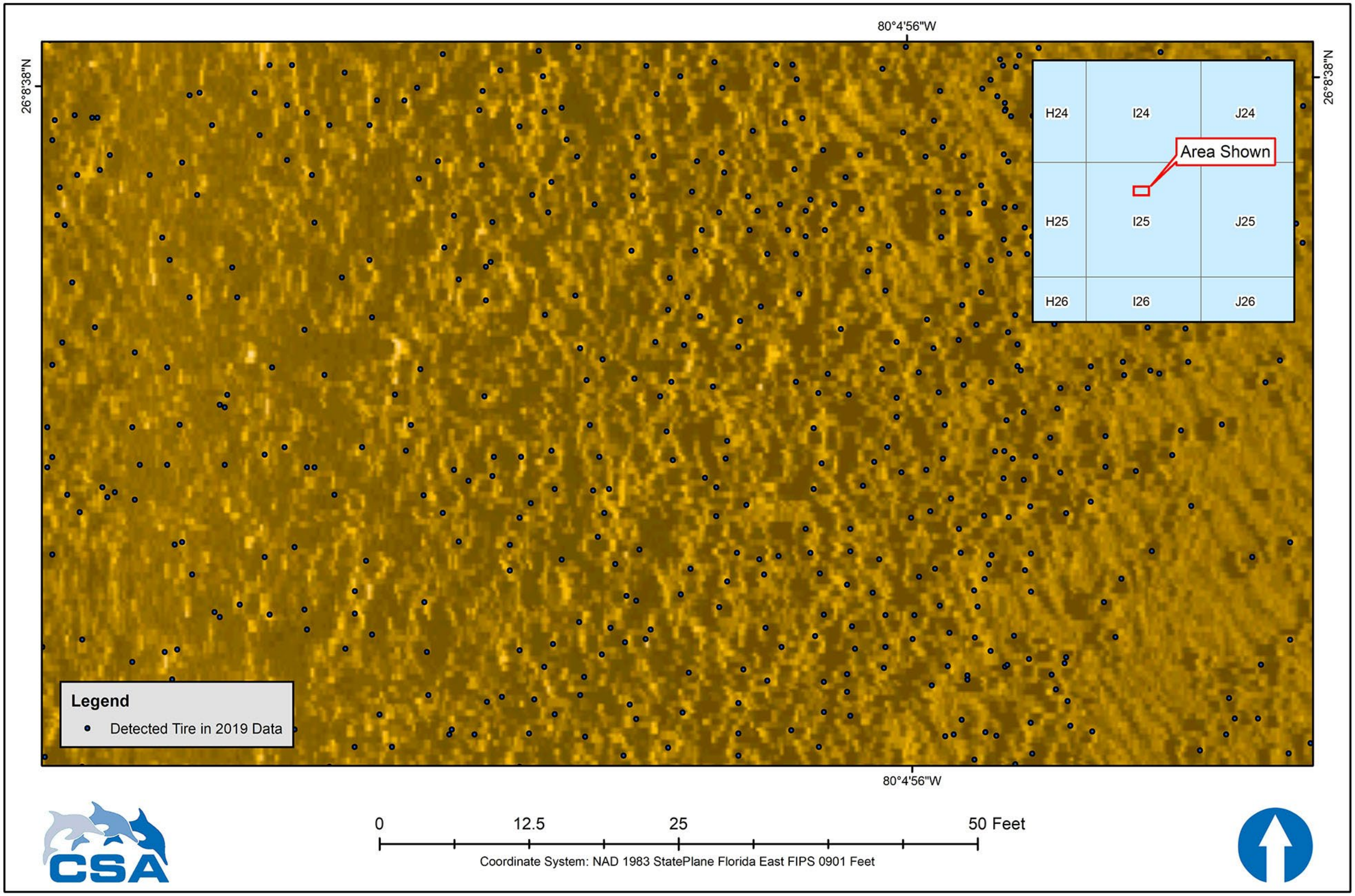


Figure 6. Example of a mound of tires. Data taken during the 2019 Survey.

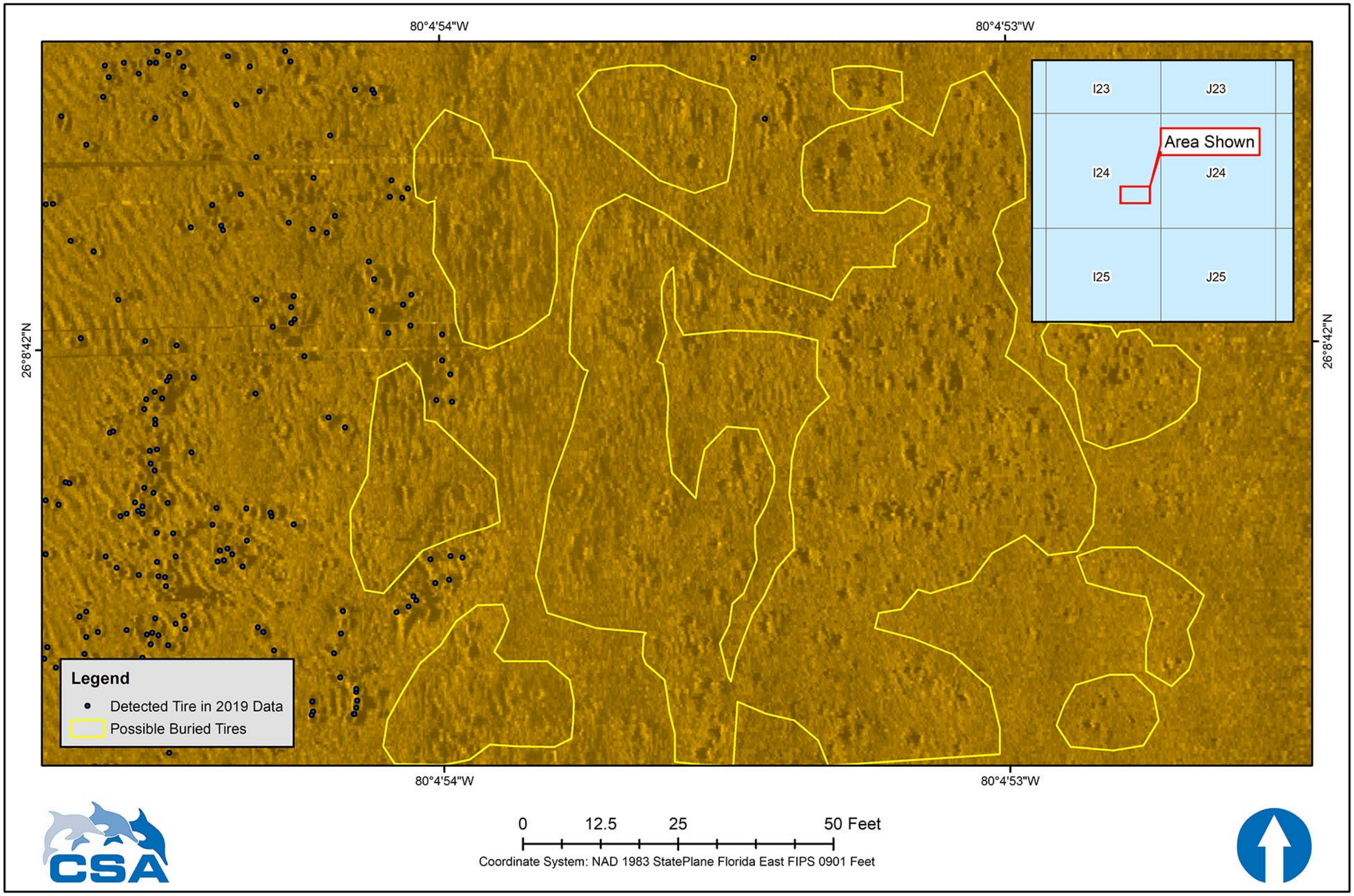


Figure 7. Example where the model struggled to detect partially buried tires.

A post-hoc accuracy assessment quality control check was performed by a GIS analyst on the tire counts returned by the algorithm. A GIS analyst randomly selected 10, 5 × 5 quadrats in the 2019 survey area representing a range of tire densities identified in the AI process (i.e., Deep Learning extension and RCNN model application) ranging from 1 to 81 tires per quadrat. Images of the quadrats used by the algorithm were also provided to an experienced scientist who dove on the site repeatedly during this project (approximately 12 dives in 2019 and approximately 25 dives on the site for this survey), but without sharing the algorithm values, and that scientist independently counted all perceived tires. The AI-predicted number of tires per quadrat were regressed on the human-observed number per quadrat and the coefficient of determination (percent of the variability in the predicted value explained by the observed value) was examined as a measure of accuracy assessment.

While the survey and application of the AI tool was able to derive an accurate estimate of the visible tires, these methods are likely a substantial underestimate of total tire abundance because they cannot detect tires due to stacking of tires where the top tires obscure those underneath or where stacked or single tires are buried in the seafloor. To extrapolate the visibly discernable tires to a more realistic estimate of total abundance, previously derived empirical data (FDEP personal communication) were applied to create a probable multiplier of the visibly discernible tires. The previous FDEP estimates of total tire abundance range in the 2019 survey area, supported by diver counts, were utilized. The maximum estimate was used out of an abundance of caution to ensure that the costs associated with future tire removal will not be under-estimated.

To create the multiplier, a 5×5m grid was superimposed on the AI-generated tire count map in a GIS. The number of tires counted by the AI tool in each 5×5 m pixel was exported, designating which grid cells fell on the 2019 survey area and which fell in the 2024 survey area surrounding the 2019 survey area. The AI-generated counts per grid cell were then adjusted with 19% increase (AI adjusted; AI_a) reflecting a correction by regression of AI-counted tires versus human-counted tires (see **Results, 4.3**). The maximum FDEP tire count for the 2019 area (684,461) was divided by the total 5×5m AI_a tire counts in the 2019 area (84,250), yielding a ratio that estimated the tires present, including obscured and buried tires per unit tire observed by the AI tool. This ratio was then applied to the number of tires for each AI_a value in all the 5×5m grid cells in the survey. The total of the grid cells was summed for an estimate of the total number of tires present in the approximately 19,877,400 m^2 combined 2019 and 2024 survey area.

3.3 DATA STORAGE

Data collected by both the geophysical survey (i.e., SSS) and diving ground truthing teams were put on external storage devices (portable hard drives) and transferred to CSA corporate headquarters in Stuart, Florida. Data were then copied to a data storage server; copied and original data were compared to ensure the copy was complete. A hard drive and printed report were delivered to FDEP building 3, located at 3301 Gun Club Rd, West Palm Beach, Florida, 33406. **Figure 8** shows the data structure utilized to organize survey data on the two external hard drive deliverables.

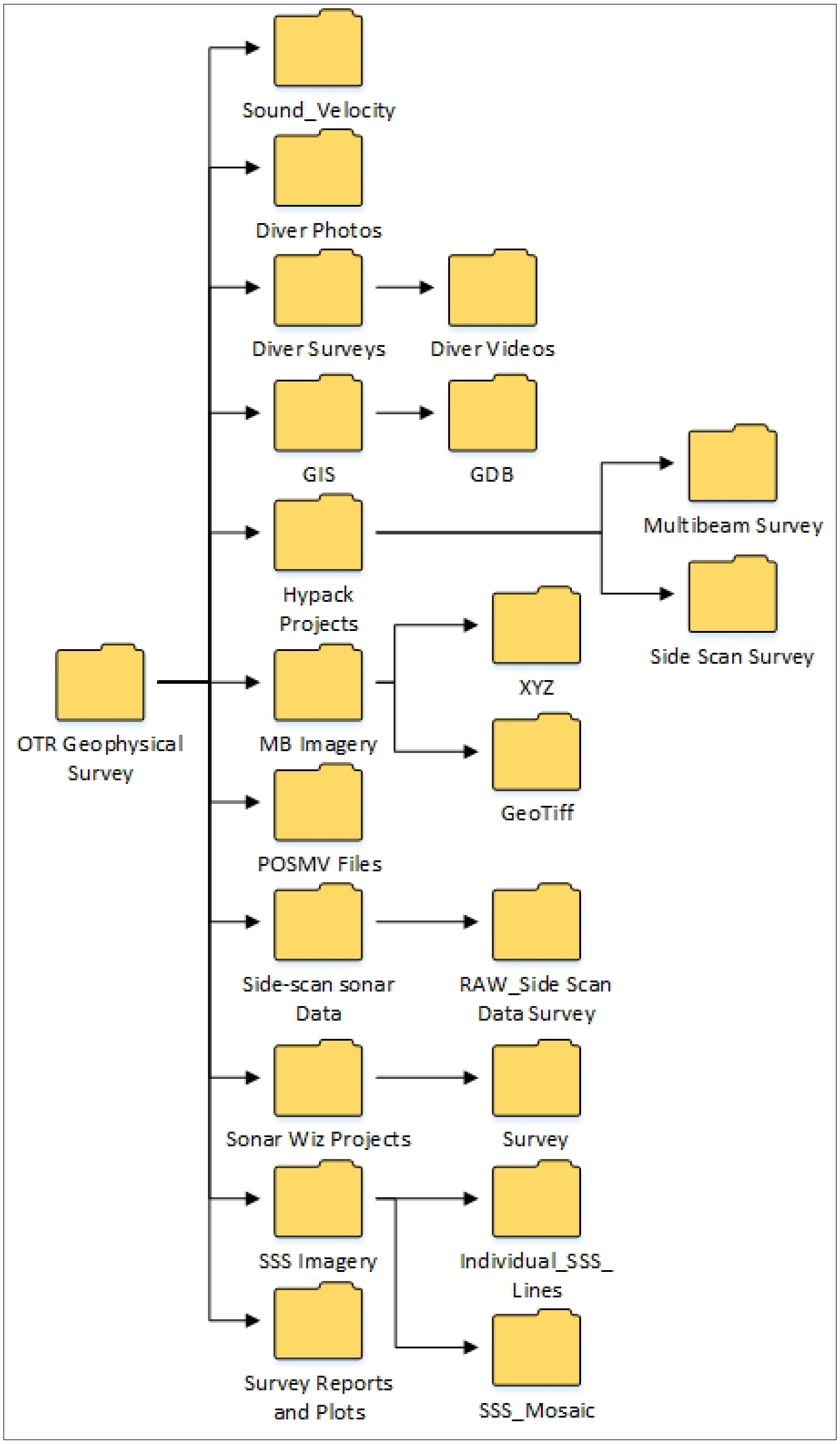


Figure 8. Organizational directory structure for data collected in the field, stored on external hard drives, and delivered to the Florida Department of Environmental Protection (FDEP). Arrows demonstrate the folder opening sequence.

4 Results

4.1 SIDE-SCAN SONAR AND MULTIBEAM SURVEY

The original survey plan was to utilize MBES backscatter data only so that surface tires would be more visible, especially those that may be located atop the hard bottom or in the sand flats. This method would provide a top-looking-down approach. For this effort, the R2 Sonic 2024 echosounder was set to 700-kHz mode for high definition. Depending on water depth, survey lines were variably spaced (75 ft to 25 ft). In 700-kHz mode, tighter line spacing was required to achieve complete data coverage across the survey area. Ultimately, after several days of data collection and during a weather standby period, the data were processed, but the results were not conducive to continuing. Likely, this was due to the poor acoustic reflectance of the tires not providing enough variation in intensity return values (backscatter). Following a meeting with Olsen and FDEP, the decision was made to replicate the method used during the 2019 survey, capturing data using SSS and MBES operating in conjunction. The MBES frequency was set to 400kHz to widen the swath.

SSS became the primary acquisition tool while the MBES processed data was used to adjust the SSS towfish layback offsets. Subsequently, the survey was restarted, beginning over the previously surveyed area. 100% of the survey polygon established by FDEP was covered during the 2024 survey. Due to advancements in SSS technology, a noticeable difference in clarity was observed between the older Klein 3900 used during the 2019 survey and the new EdgeTech 4205 used during the 2024 Survey. SSS line spacing established during the 2019 survey began at 130 ft, which provided 200% data coverage using the EdgeTech system. Because the data quality was more than adequate, line spacing was adjusted to 200 ft to decrease the overall time needed to be on the water, given the weather delays affecting the project completion schedule. **Figure 9** shows the percentage of data overlap for the geophysical survey.

Figure 10 presents survey lines acquired during the 2024 survey overlaid onto the SSS mosaic data. Survey lines were run on a north–south parallel transect. The darker shaded area immediately north of the 2019 Survey area resulted from the tighter line spacing of 700-kHz MBES. In the PDF version of this report, the reader may zoom into the image and observe some of the larger, more obvious seafloor features and anthropogenic materials.

The MBES bathymetric survey data generated the most accurate georeferenced imagery because the DGPS antenna was positioned directly above the vessel-mounted MBES transducer. Fine-tuned positioning adjustments were made to the SSS data by positioning the SSS mosaic over the MBES image, then adjusting the SSS image until significant features were in alignment. It should be noted that even under the best circumstances, there may be minor misalignment of features due to slight lateral motion of the SSS towfish. When determining the precise location of an object or feature, it is important to recognize that the MBES imagery is more accurate.

Utilizing both the SSS and MBES data for the 2019 and 2024 surveys, a GIS figure was created, showing areas of hard bottom and sand with a gridded overlay. **Figure 11** presents an alpha-numeric grid of the dominant (whichever exceeded 50% seafloor coverage per grid cell; Tabulate Intersection Tool, ArcGIS Pro) seafloor bottom type (hard bottom vs. sand) observed in the survey area.

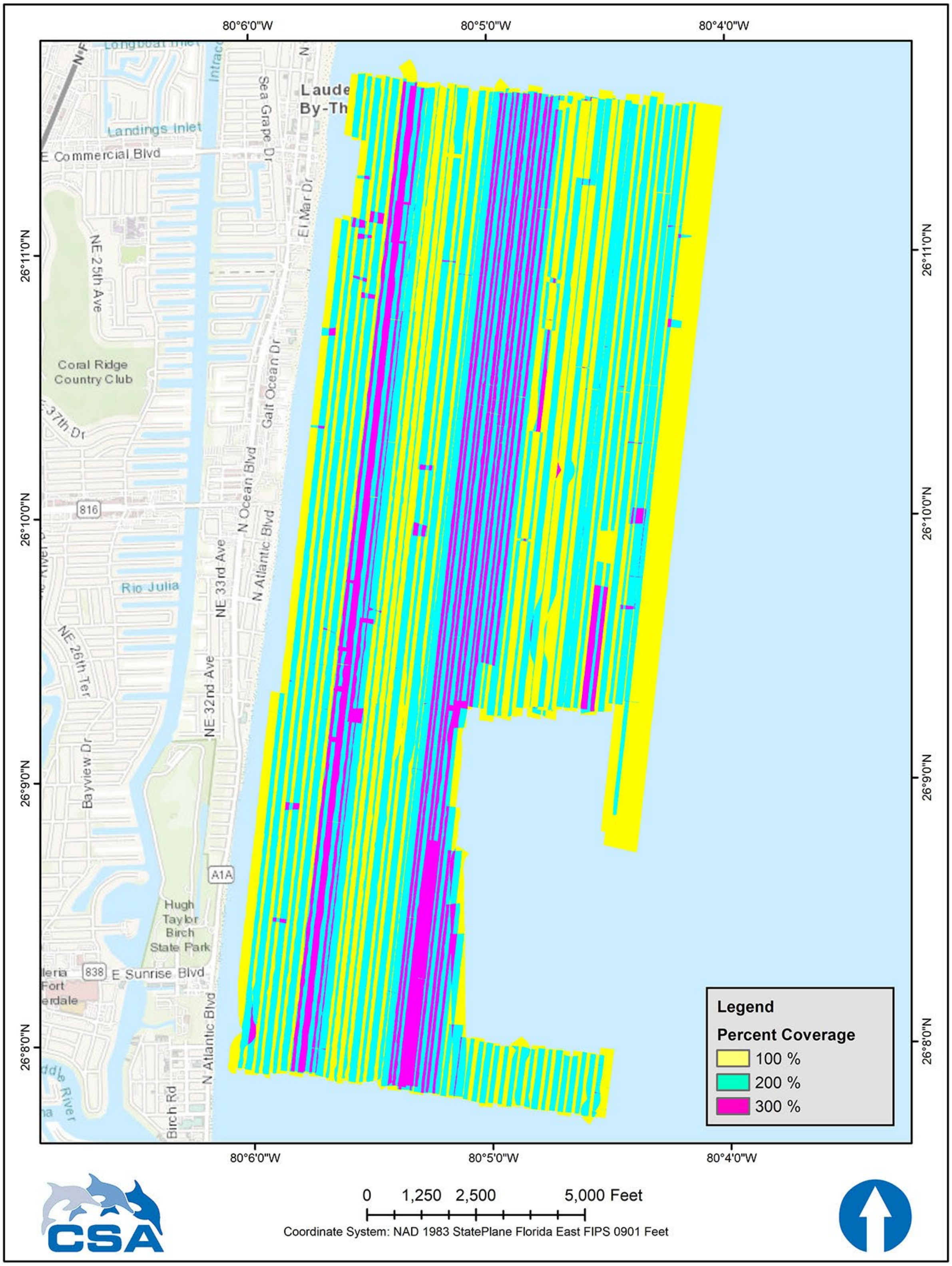


Figure 9. Percentage of data overlap collected by the side-scan sonar and multibeam echosounder during the Osborne Tire Reef 2024 Survey.

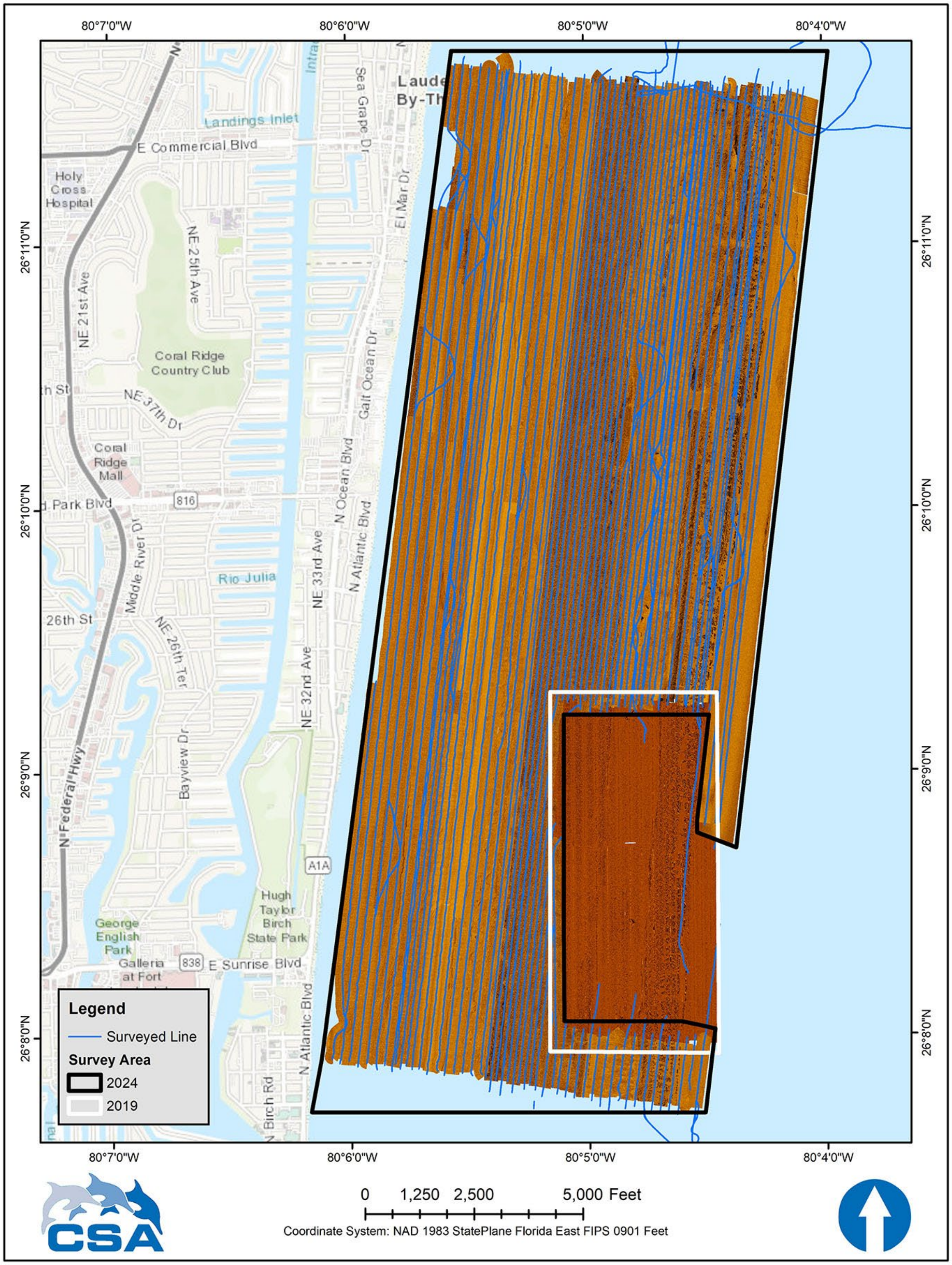


Figure 10. The Osborne Tire Reef 2024 Survey lines overlaid onto the side-scan sonar mosaic data.

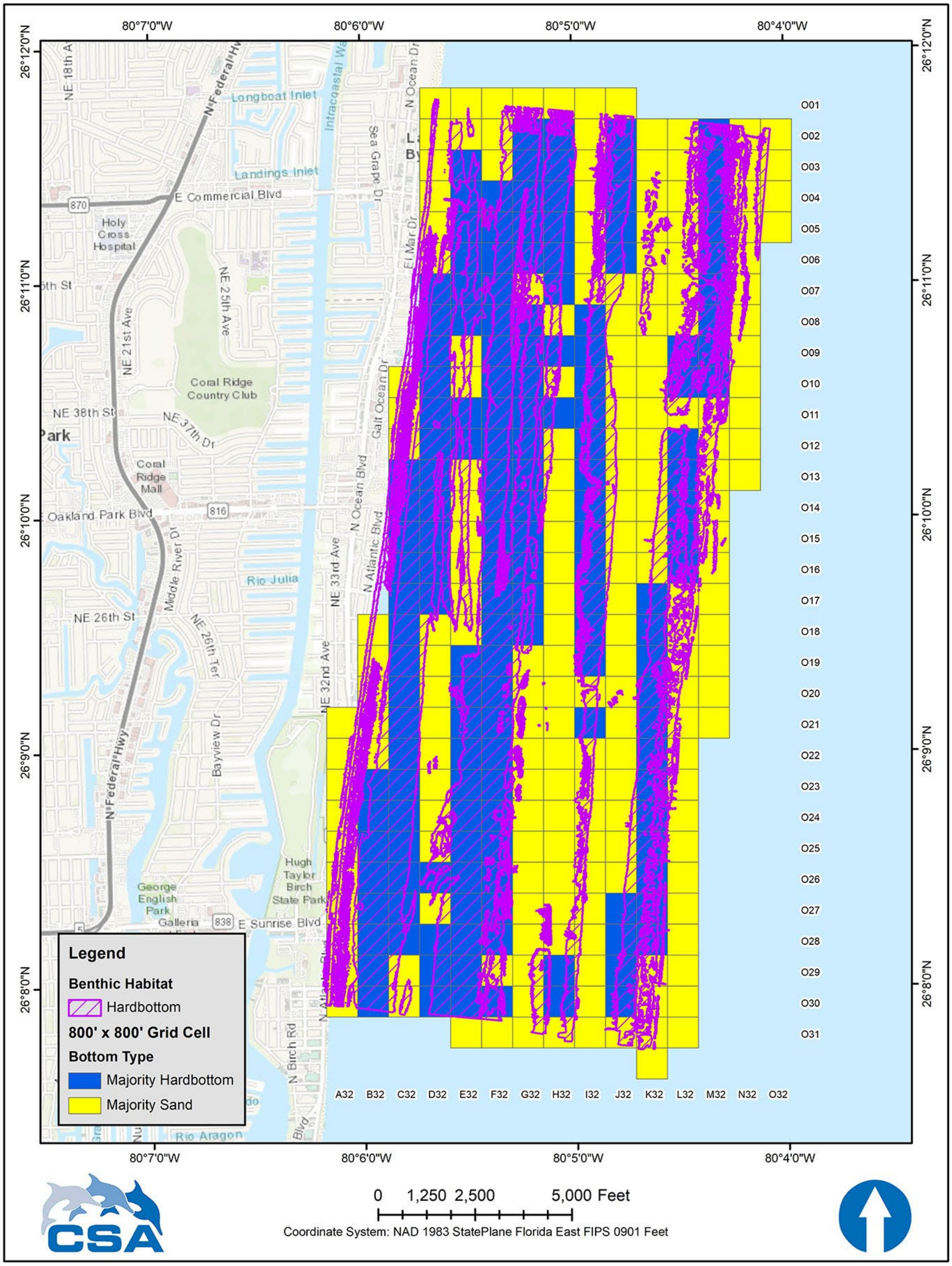


Figure 11. Alpha-numeric grid of the seafloor bottom classification within the Osborne Tire Reef survey area. The benthic habitat layer was developed by CSA using slope analysis methodology and verified using side-scan sonar imagery.

4.2 DIVER VERIFICATION

A total of 61 specific dive locations, many with multiple targets, were surveyed during the diver verification operations. This survey occurred over two days, February 16 and 17, 2024. Most of the diver-identified features appeared to match the positions of targeted items plotted in the SSS mosaic. **Appendix D** lists diver ground truth findings and the description of features noted at each of the visited locations. Targets of dives included various concentrations and groupings of tires, ranging from single tires nearly completely buried in sandy areas to sites with several completely exposed tires. Tires colonized with hydroids, sponges, octocorals, and stony corals were also occasionally observed. Other identified features included several clumps of rope and cable, strings of active lobster traps, a large fiberglass dive platform detached from a boat, a large metal box, and exposed rock and hard bottom patches ranging from low-relief sand-covered areas up to large patch reefs with nearly 1 m of relief.

Additionally, two species of large sponges (S*pheciospongia vesparium* [loggerhead sponge] and *Xestospongia muta* [barrel sponge]) were identified as the potential selected targets at several sites which are identified in **Appendix D** and shown in **Image 4** These large sponges, which ranged in size from approximately 30 to 60 cm in diameter and from 20 to >60 cm in height, have shapes approaching that of a tire and, in many cases, provide a SSS reflection like that of tires.

At Sites GT 01 and GT 02, located at the northern end of the surveyed area in approximately 25-ft water depth, approximately a dozen exposed tires were observed by dive teams within 8 m of each of the two targets despite only one potential tire visible in the SSS mosaic at the locations (**Image 4, upper left**). This may indicate sediment movement occurring in this shallow area between the time of the SSS survey and the diver ground truthing, uncovering many previously buried tires. This difference in tire (or unidentified target) abundance between the SSS signatures and subsequent diver ground truthing observations was not noted at the remaining visited sites located in water depths greater than 30 to 35 ft.

4.3 ARTIFICIAL INTELLIGENCE SURFACE TIRE COUNT

Once the geophysical data were fully processed and the area evaluated, several discussions were held with FDEP to determine the actual size to represent the alphanumeric grid best. It was determined that an 800 ft × 800 ft grid size would be used (**Figure 12**). This sizing is consistent across all figures with a grid overlay.

The RCNN model within the ArcGIS Pro Deep Learning extension was run numerous times on both the 2019 and 2024 data sets, with each run of the model detecting new information. This allowed a point density map to be developed, showing the location, extent, and distribution of surficial tires over the OTR. It is important to note that the AI algorithm cannot calculate an accurate number of tires as only a surface mapping of tires is being used in the model. Where tires are stacked atop one another in multiple layers, the model cannot estimate total tire quantity in those area. This was also the same for tires that were partially or fully buried in the sand.

A post-hoc accuracy assessment check was performed where AI-identified tire abundance was cross-checked by human counting. A GIS analyst randomly placed 5 × 5 m grids over the 2019 survey area, which represented a range of locations with varying tire densities. The tires in the quadrats were enumerated both by the AI process and independently by the aforementioned scientist with diving experience. A linear regression of the AI-predicted tire abundance versus that of human-observed had an r^2 = 96.5 (predicted = [0.8064*observed]-0.022), demonstrating very consistent performance of the algorithm. However, while the relationship was linear, the AI consistently under-reported tire abundance by approximately 19%.

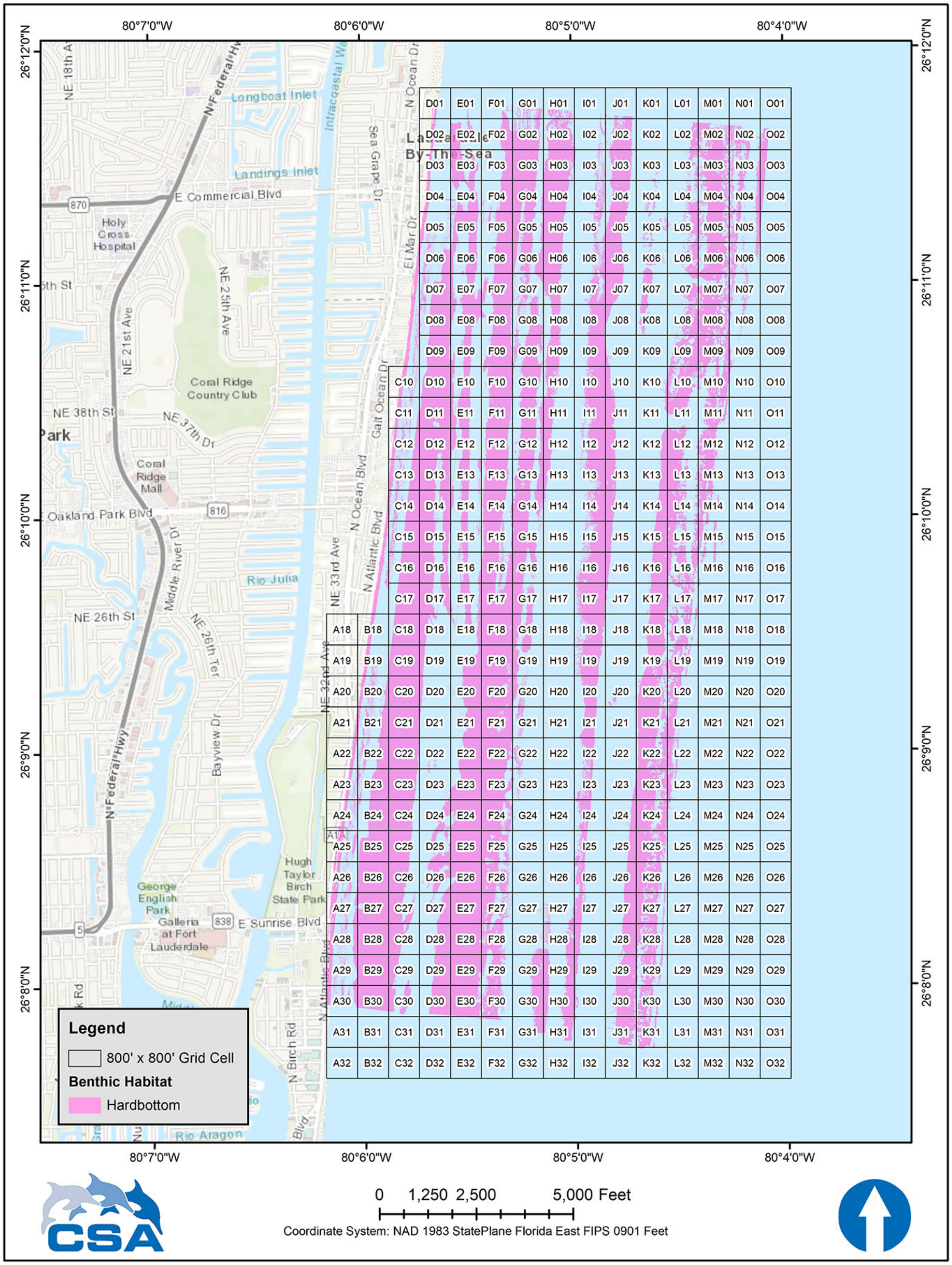


Figure 12. Alphanumeric grid (800 ft × 800 ft) used to identify tire concentration count of the Osborne Tire Reef survey area.

The processed SSS mosaic data show tires located across the full extent of the 2019 and 2024 survey area. **Figure 13** is the 2019 survey data point density map showing concentrations of tires located north of the Tire Abatement Permit Area along the outer eastern edge of the second reef. **Figure 14** shows similar results from analysis of the 2024 survey data, excluding the 2019 survey area. Ultimately, both data sets were combined, and the point density map provided in **Figure 15** displays the entire area utilizing both 2019 and 2024 data.

Overall, the 2019 and 2024 data sets show that tires are located throughout the entire OTR survey area. These data sets likewise show that the spatial distribution of the tires varies considerably across the areas. **Figure 16** shows the combined data sets for both the 2019 and 2024 surveys and where the RCNN model identified tires from the post-processed data.

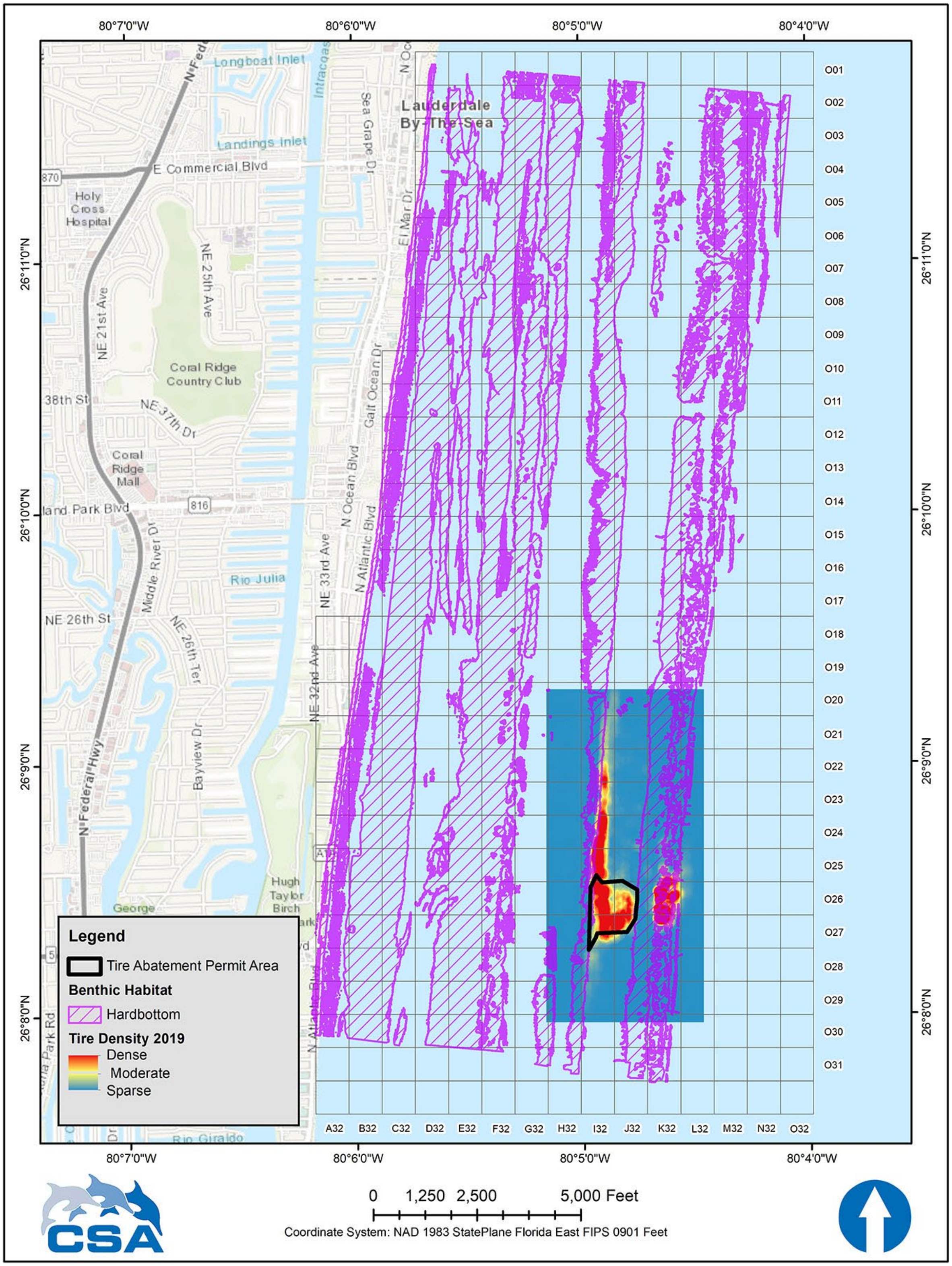


Figure 13. Point density map of the Osborne Tire Reef 2019 Survey area showing concentration of tires.

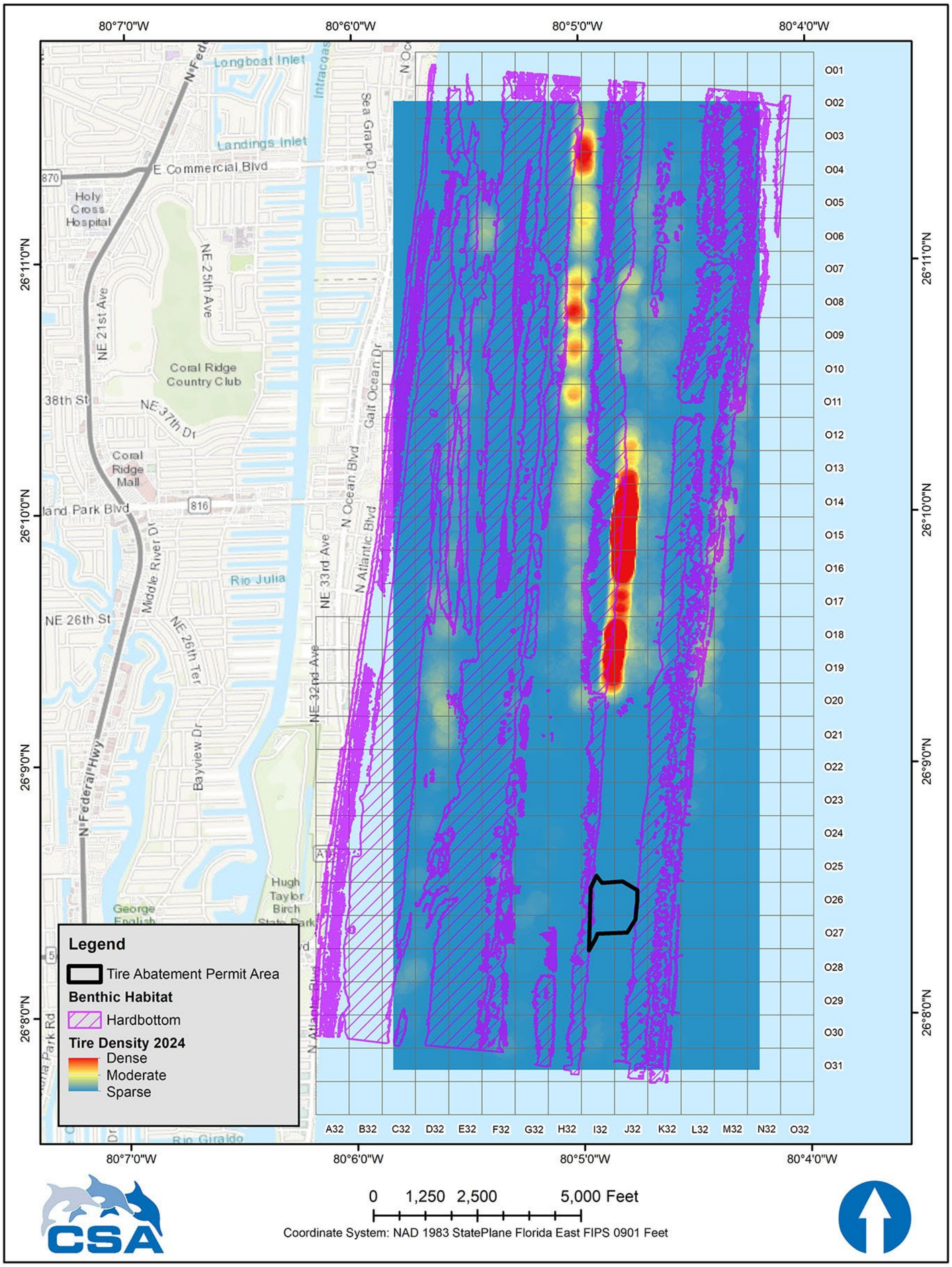


Figure 14. Point density map of the Osborne Tire Reef 2024 Survey area, excluding the 2019 Survey data, showing the extent of tire migration.

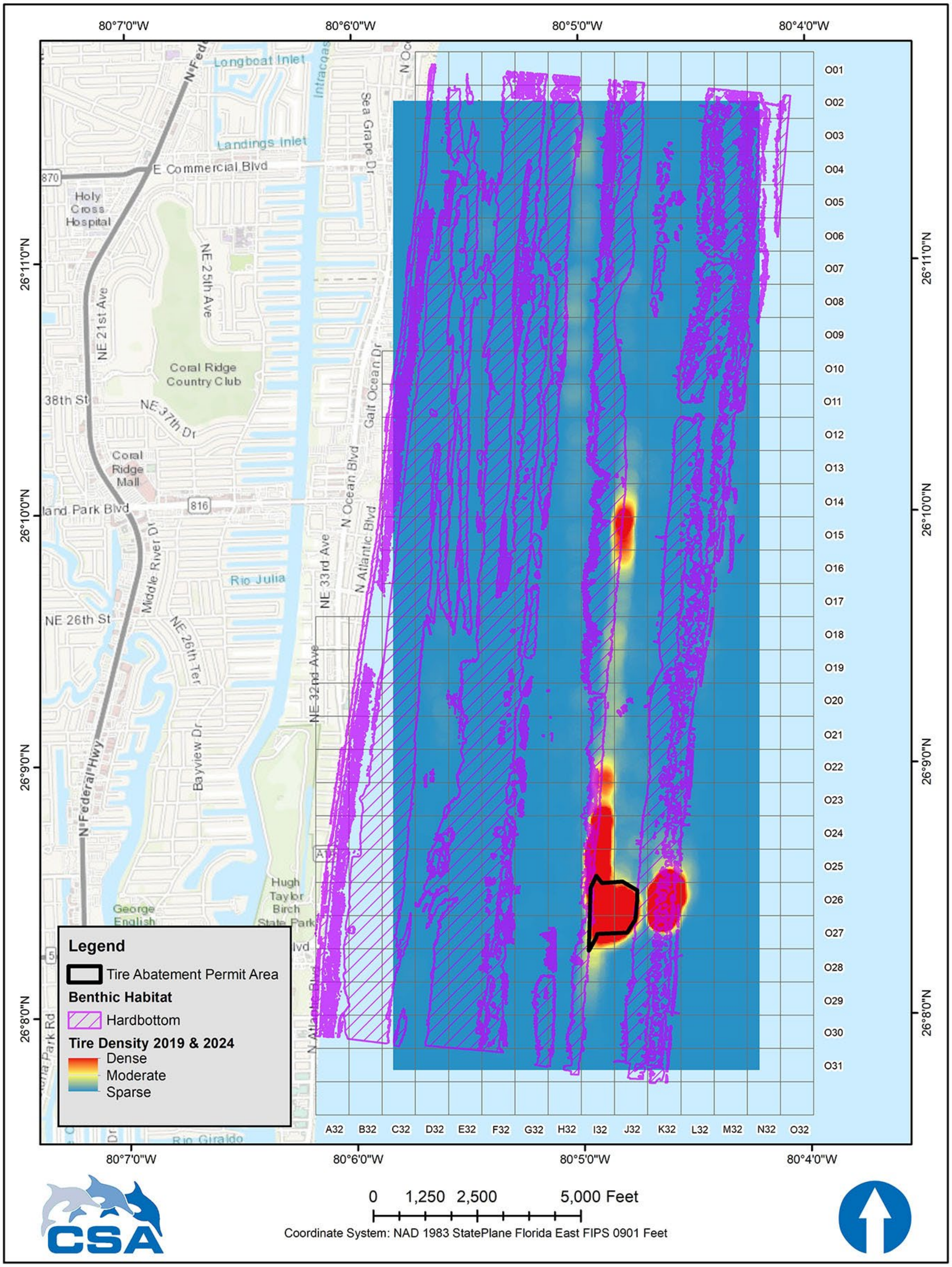


Figure 15. Point density map of the combined Osborne Tire Reef 2019 and 2024 Survey areas, providing the best view of the extent of tire migration.

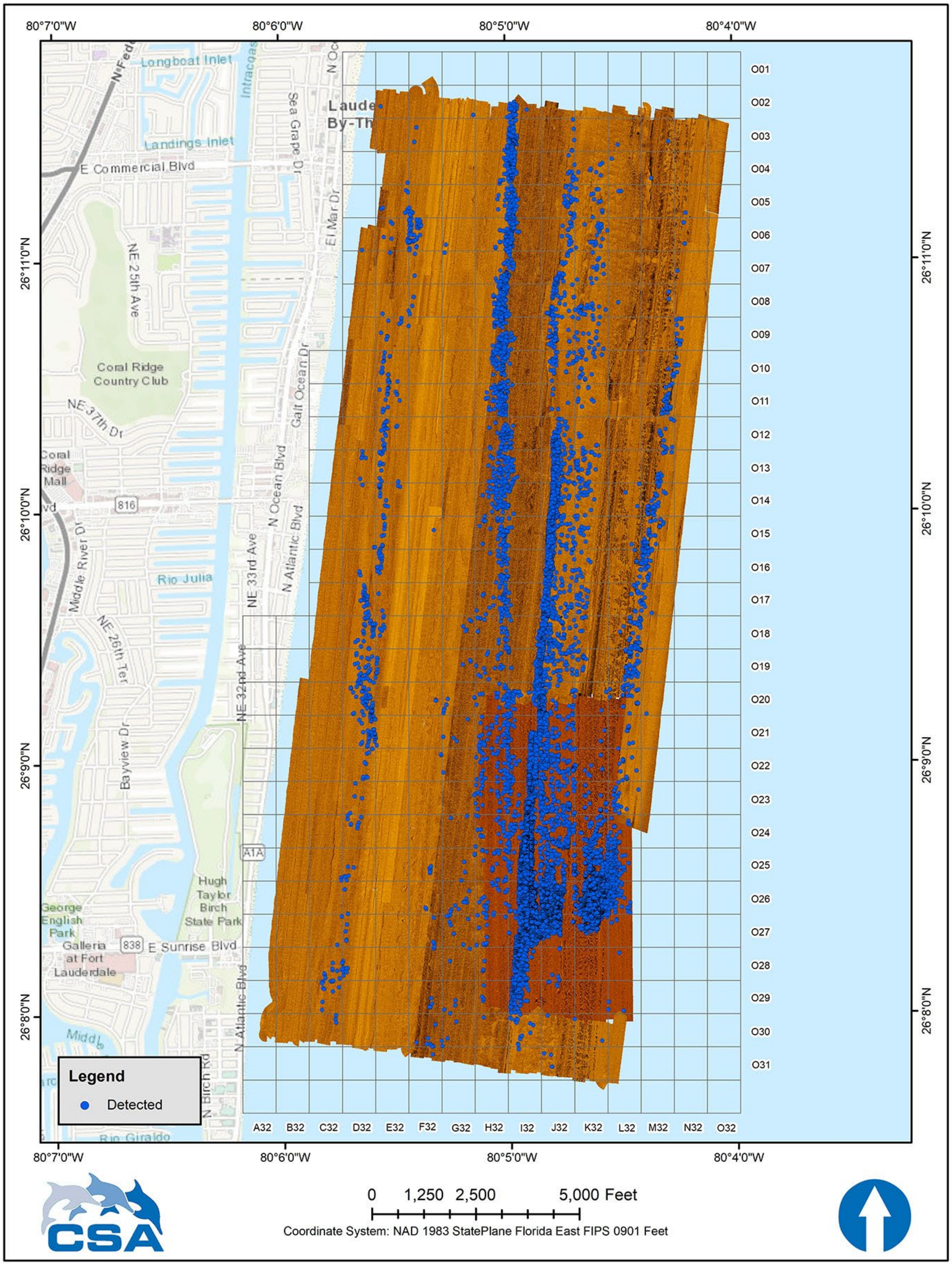


Figure 16. Overview of tire locations identified by the Artificial Intelligence using side-scan sonar imagery from the 2019 and 2024 surveys.

The following figures compare the RCNN model results to the SSS survey data sets in graphical form. **Figure 17** shows the 2019 survey data combined alphanumeric grid and an overview figure of the location. The bottom image is the processed data, and the upper shows detected tires (red circles). **Figure 18** depicts the 2024 survey, combining the alphanumeric grid with an overview map of the location. The color variation between **Figures 17** and **18** was the result of different acquisition sonar systems used during the two surveys. An overall alphanumeric grid is presented in **Appendix E** that breaks down each 800 ft × 800 ft grid cell by identification, approximate number of tires, bottom type, and latitude and longitude (four corners and center).

The AI tire count and subsequent QA/QC verification suggests that the SSS data sets depict a total of about 80,000 tires across the surveyed area. Again, this estimate only represents the number of tires on the seafloor surface (single layer) or top layer of tires where there are multiple layers. As discussed by CSA (2019), it is well known that there are areas of very dense tire concentrations, with locations identified and marked as shown in **Figure 16**. In the 2019 data set, 70,799 surface tires were identified. In the 2024 data, 8,787 surface tires were detected with the AI methodology. As previously discussed, tires that were buried, half submerged in sand, or piled atop one another were not counted by the AI tool. This number represents the visible tires the algorithm detected in the combined survey areas. Importantly, the accuracy assessment showed a consistent under-counting of surface tires by the algorithm (19%). Significant additional training of the model would be required to reduce this discrepancy. Consequently, the number of visually discernible surface tires within the survey area was estimated at 94,707.

The number of visible tires counted by the AI tool does not represent the total number of tires remaining in the OTR since tires stacked in multiple layers are not counted. As such, an attempt is made to estimate the probable total quantity of tires that may remain in the 2024 survey area using available information. The approach applied here for estimating the total amount of remaining tires in the 2024 survey is as follows:

- The AI tool estimate of surficial tires in the 2019 dataset and the 2019 estimate of total tire quantity in the 2019 survey area were used to compute a representative ratio of the average number of tire layers within the 2019 survey area.
- The total estimated number of tires in the 2019 survey 684,461 and the AI tool estimate of surficial tires represented in the 2019 survey was 84,250.
- From this, a ratio of 8.124166 is computed (684,461/84,250). There is no further linear model to weight the ratio against observed tire abundance.
- The ratio was applied to the AI-derived number of tires per pixel (after the 19% offset correction) universally, including low tire abundance pixels.

We have no further data to clarify whether stacking at the 2019 area was an over or underestimate nor whether observed tires in low abundance areas harbor any stacking. Hence the ratio was applied universally.

To compute the total number of tires, with consideration of layering, the assumed relationship between spatial abundance and tire layers was applied across the entire 2024 AI tool output matrix on a 5 x 5-meter grid cell by grid cell basis. At each grid, the spatial abundance within that grid was assessed by the model and the associated layering ratio was applied to compute the total volume of tires within that grid cell. The total estimate of tires within the entire 2024 survey area was then computed as the sum of the tire quantity estimate for all the grid cells. Applying these assumption and methods resulted in an estimated total tire quantity within the 2024 survey area of 769,418.

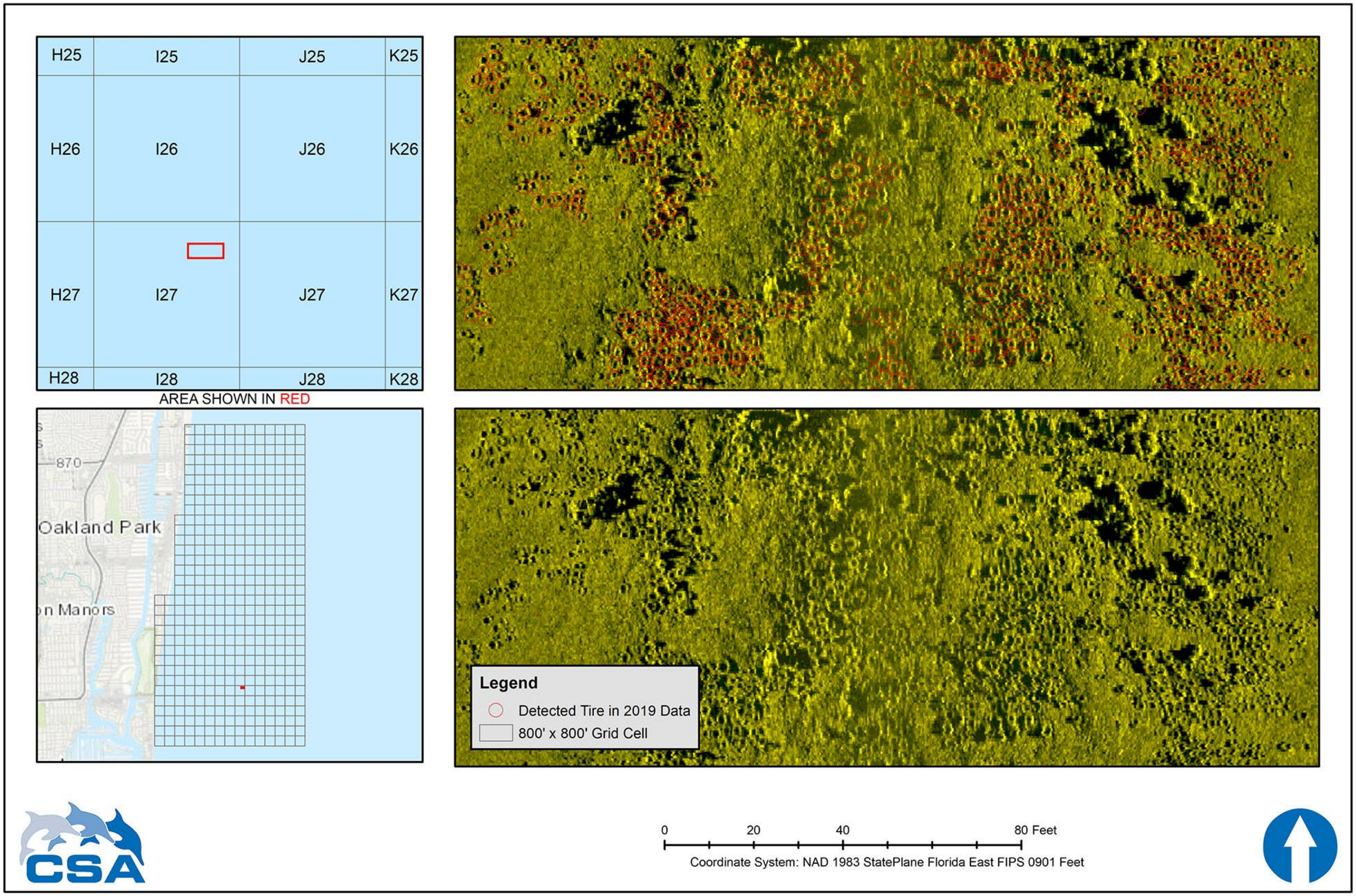


Figure 17. Osborne Tire Reef 2019 Survey data showing tires detected (top image) by the RCNN Model in an area of grid cell I27.

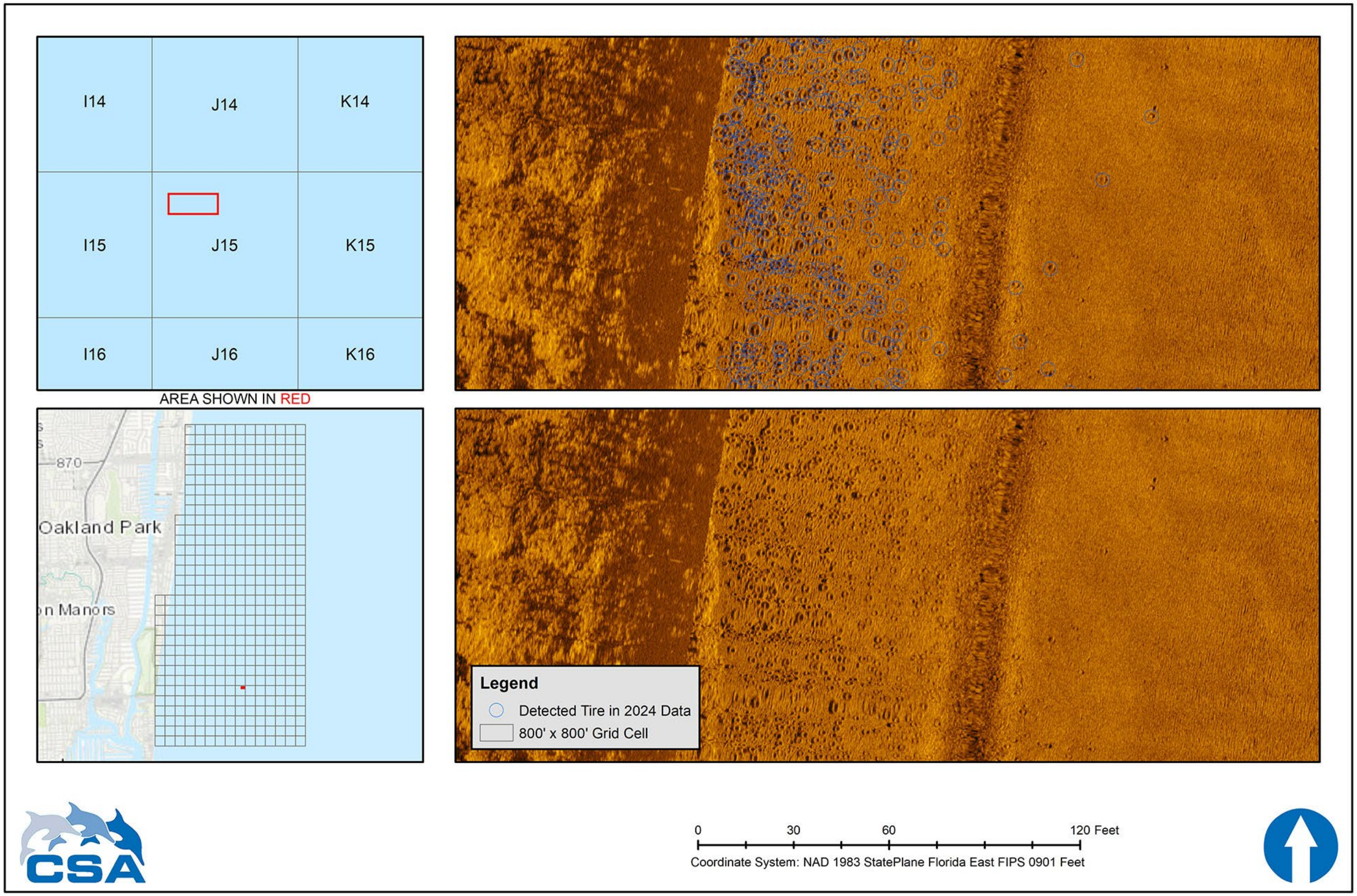


Figure 18. Osborne Tire Reef 2024 Survey data showing tires detected (top image) by the RCNN Model in an area of grid cell J15.

5 Conclusions

Overall, tire distribution occurs throughout the entire OTR area. **Figure 10** shows the combined data sets for both the 2019 and 2024 Surveys and where the RCNN Model identified tires from the post-processed data. The Artificial Intelligence-based algorithm identified a combined total of nearly 80,000 tires using geophysical survey methods. As previously discussed, tires that were buried (i.e., not observed), largely submerged in sand or piled atop one another were not visibly discernible and could not be counted.

The accuracy assessment showed a consistent under-counting of surface tires by the algorithm (19%). This is not surprising given the variation in the geometry of partially exposed tires. Significant additional training of the model would be required to reduce this discrepancy. Application of the accuracy assessment to the AI counts produced an adjusted AI count (AI_a) of 94,707 visibly discernible tires.

To provide a reasonable estimate of the total tire abundance a multiplier was developed from the ratio of previously enumerated tires in the 2019 survey area subset of the total 2024 survey area to those enumerated with AI_a in the 2019 area. That multiplier (8.124166) was then used to established the maximum tire layering for area of highest spatial abundance with the minimum spatial abundance represented by one layer. A linear relationship between spatial abundance from the AI output and the layering range, was applied to AI_a counts across the entire survey area, resulting in an estimated total tires present in the survey area of 769,418 tires. This assumption of constant proportionality was used as a convenient proxy given the lack of detailed information of tire layering. As more information is gathered about the condition of tire layering across the survey area, updates of this relationship between spatial abundance and tire layering can be considered to improve the estimate to total remaining tires across the survey area.

Previous work in this area indicates many more tires either underneath those visible or simply buried and it is important to recognize that the number of tires observed here during this survey is a snapshot of visible tire abundance. Personal observations of divers conducting ground truthing of the side-scan sonar data reveal that tremendous amounts of sand movement occur in this environment, resulting in rapid (days) burial or exposure of tires at different locations in the landscape. Sediment movement could result in fewer or more tires detected at a subsequent survey. Lastly, the number of tires removed from the tire abatement permit area by DEP’s tire removal project is not reflected in these estimates. The tire counts provided in this report serve as a conservative estimate of tires present at the time that SSS imagery was collected.

6 Literature Cited

CSA Ocean Sciences Inc. 2019. Osborne Tire Reef Benthic Survey Diver Verification Surveys Report. Prepared for the Florida Department of Environmental Protection. Miami, FL. 32 pp.