Protocol for UAS Implementation for Oyster Monitoring and Assessment

About this resource:

This protocol was developed as part of a 2022-2025 Collaborative Research project titled *Collaborative Development of Novel Remote Sensing Workflows for Assessing Oyster Reef Structural and Demographic Characteristics to Inform Management and Restoration.* The protocol provides methodologies for the collection of field data, drone imagery, and lab processing.

About the project:

This protocol was developed as part of a 2022-2025 Collaborative Research project titled *Collaborative Development of Novel Remote Sensing Workflows for Assessing Oyster Reef Structural and Demographic Characteristics to Inform Management and Restoration.*

Oysters and the reefs that they form present unique management challenges as one of very few ecosystem engineers that are directly subjected to harvest. Harvest not only removes individuals from the population, but also removes shell and three-dimensional reef structure, thereby limiting settlement habitat for oyster larvae, reducing habitat value for reef-dwelling organisms, and often reducing the resilience of reefs to additional stressors (e.g., sedimentation, anoxia). Indeed, following more than a century of harvest, in combination with disease and poor water quality, oyster reefs have been labeled one of the most imperiled marine habitats on earth. To better manage and restore oyster reefs, resource managers and restoration practitioners have expressed a need for novel approaches to better monitor and assess the resource.

Oyster reefs are primarily managed by state agencies to sustain fisheries; however, the importance of regulating (e.g., nutrient remediation, shoreline stabilization) and supporting (e.g., nursery habitat) ecosystem services are increasingly gaining recognition. Along the south Atlantic bight of the United States (i.e., North Carolina to Florida), the focal geography of this project, Crassostrea virginica oyster reefs occur primarily in the intertidal. Oyster resource managers and restoration practitioners from NC to FL (primary end users of this project) often rely on the mapping (e.g., boat-based surveys or remote sensing) and monitoring (e.g., in situ quadrat sampling) of intertidal reefs to inform management decisions, such as fishery closures, and where to "plant" shell or other alternative materials to provide recruitment substrate for oyster reef restoration and habitat enhancement efforts. However, these methods can be time- consuming, labor intensive, destructive to the reef, and limited by spatial scale (e.g., m2 quadrats) or resolution (e.g., satellite pixel size).

Both resource managers, applied researchers, and National Estuarine Research Reserve (NERR) staff end users in the region have expressed a need for rapid, standardized, and quantitative measures to assess reef structural and demographic characteristics for monitoring, managing and restoring the resource in both habitat and fishery contexts. For our purposes, we are defining structural and demographic characteristics as two-dimensional (e.g., footprint) and three-dimensional (e.g., rugosity) physical metrics and metrics such as oyster density, all of which provide information on reef 'condition'.

In this project, we evaluated Uncrewed Aircraft Systems (UAS) as a tool for providing quantitative measures of intertidal eastern oyster reef structural and demographic metrics and changes to reefs in response to natural and anthropogenic factors. We developed and implemented an integrated collaborative and technical process with oyster resource manager end users from the Florida Fish and Wildlife Conservation Commission, Georgia Department of 7 Natural Resources, South Carolina Department of Natural Resources, and North Carolina Division of Marine Fisheries, as well as end users from all five NERRs in the southeastern U.S. (North Carolina, North Inlet-Winyah Bay, ACE Basin, Sapelo Island, and GTM Reserves). End users prioritized the following metrics: 1) reef height and elevation, 2) rugosity, 3) reef footprint and area, 4) shell substrate and oyster percent cover, 5) shell volumetric change, and 6) oyster density and size structure.

The project team developed a detailed protocol that included site selection, field survey preparation, and collecting *in situ* measurements of the prioritized metrics (listed above) as well as the mission planning for UAS-based image acquisition. Site selection procedures attempted to capture multiple reef types (e.g., fringe vs patch reefs) and management regimes (e.g., open vs closed to harvest). The *in situ* workflows were developed based on established field methods, and the drone image processing relied on protocols developed through the previous Catalyst Project. The drone surveys utilized aircraft equipped with stock red, green, blue (RGB) scale sensors flown at an altitude generating a ground sampling distance of ~1cm/pixel, and imagery was processed using structure from motion photogrammetry software.

This webpage provides more information about the project.

Data collection and processing procedures

An annotated protocol for the collection of field data, drone imagery, and lab processing for our National Estuarine Research Reserve System Science Collaborative project.

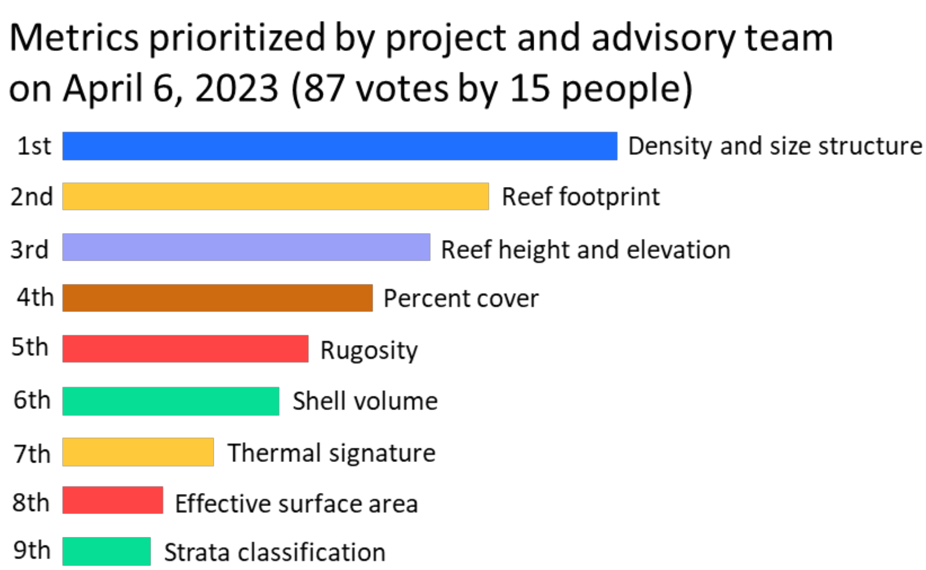
Workflow Overview

- Project Setup
- Field data
- Image acquisition
- Lab processing

Project Setup

Parameters

List of parameters/metrics prioritized by project team and advisory team. Metrics in **bold** are those we are SUGGESTING as Tier 1 (mandatory), while others are considered Tier 2 (optional).



1) **Oyster Demographics**
    a. **Density**: number of oysters per m^2 as enumerated from quadrat sample
    b. **Size**: shell length measurements of oysters from quadrat samples
2) **Reef Area/Footprint**: the 2D/areal extent of the reef
3) **Reef Structure**
    a. **Reef Height**: the vertical height of the reef crest to the nearby substrate
    b. **Percent cover of substrate**: quadrat-based percent cover of shell material
    c. **Rugosity**: structural complexity metric as measured through the chain method
    d. **Shell Volume (quadrat to reef scale)**: volume of shell material as it relates to quadrat excavation as well as the whole reef modeled from footprint and profiles
4) Other optional metrics
    a. Thermal signature/differential: thermal dynamics on the reef during exposure that could provide live oyster proxy

b. Effective surface area: the 3D surface area often estimated as a length x width relationship formula
c. Strata classification: A qualitative metric performed by SCDNR scoring reefs based on qualities such as amount of vertical shell and cluster substrate
d. Mission planning trade-offs: aspects of imagery collection that could influence the above metrics. Includes overlap (double grids), area coverage/altitude, uncertainty/repeatability, tides
e. Disturbance monitoring: assessing impact of reef sampling and tracking recovery

Site Selection/Experimental Design

- Sites
    - Three focus sites containing, as feasible, different management strategies (i.e., sites open and closed to harvest), multiple reefs, and an assortment of reef types (e.g., fringing and patch reefs)
    - Within each focus site, 3-4 discrete reefs at least 100 m^2 (as possible) in size will be selected for the follow-up in situ measurements
- Timing
    - UAS flights and in situ ground truth measurements will be conducted on intertidal oyster reefs within or proximal to the boundary of each participating Reserve during the summer of year 1

Planned Analyses

Space for Time

- Compare variability in all parameters within and among reefs. If differences are detected over space, then we can assume we will be able to detect differences over time.

Change Detection

Changes due to sampling, harvest, and restoration

Change causation: exploring the drivers of change we detect

- Pre- and post-sampling, same day (or soon after)
- Pre- and post-harvest season on reefs inside and outside of approved harvest areas (BACI)
- Shell Removal (Late Year 1/Early Year 2)
- Shell addition (Early summer Year 2)
- Could also track quadrat sites from Year 1 to Year 2

Field data

Coordinate Reference Systems

If possible, please use the following CRSs (acknowledging that drone imagery CRS may be limited)

- Horizontal: NAD 83 UTM
- Vertical: NAVD88 Geoid18
- Units: meters

Benchmark Survey

On each field day, each survey team will conduct an error check of their GNSS.

- Use the RTK-GNSS to survey a point of reference (preferably a NGS Benchmark or other permanently fixed object that can be established as your benchmark).
- *Alternatively*, pick or create a feature at your field site to survey once before, during (if possible), and after your fieldwork.

Metric 1: Oyster Demographics

Oyster density and size structure will be obtained through quadrat sampling and laboratory processing (outlined in the Lab Processing section).

- Number: 3-4 quadrat samples will be excavated per reef
    - scaled to fit the capacity of individual Reserves
- Size: 0.0625 m^2 (0.25 m x 0.25 m) quadrats
- Distribution: placed haphazardly on the reef to encompass variability across the vertical profile
    - reef crest down to near edge
    - high and low clustering
    - Note, be careful how low on the reef you place quadrats, because after excavation the void will fill with water and volumetric change (outlined further down) will likely not be measurable.
- RTK-GNSS quadrat location:
    - Corners of quadrat
    - Or center of quadrat and one corner
- Excavation
    - Hand-excavate material inside the quadrat to a depth of 10-15 cm (or until termination of the active, oxic shell layer)
    - If there is a cluster partially inside the quadrat be sure to collect only the portion of cluster that falls inside.
        - Use gloved hands, a hammer or shucking knife to separate clusters
    - Collect mussels to account for volume contributed (e.g., ribbed mussels, *Geukensia demissa*)
    - Material collected in a mesh-collecting bag or basket/bucket and tagged for later processing; 5-gallon buckets are a good option for sample storage if access to a walk-in cooler space
    - Rinse samples to remove mud while in the field or back at the lab before storing
- Sample storage until processing: Oyster samples will be frozen until ready for processing
    - Samples can be retained for a matter of months if kept cooled prior to processing

Metric 2: Reef Area or Footprint

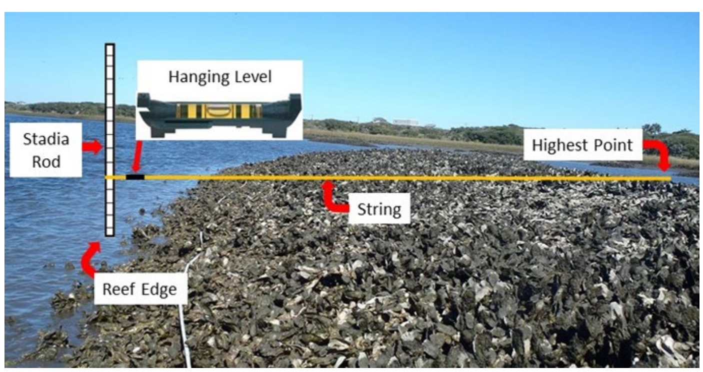
- For sites that can effectively walk the reef perimeter: RTK-GNSS points recorded at ~1 m intervals (or if not practical, at least 10-15 RTK points along each of the waterward and landward edges of the reef) around the reef where Reef Edge is defined as a continuous line where the **percent coverage of substrate, either living or non-living material remaining above the sediment, is equal to or greater than 25%** (Baggett et al. 2014)

- Alternatively, for sites where walking the reef perimeter is not an option: We obtain footprints from imagery and take "reef extent" endpoints on the axial profiles to compare to the digital footprint. Reef edge is still defined as above.

Metric 3: Reef Height

Reef height metric will be measured through axial profiles and vertical checkpoints (groundpoints)

- RTK-GNSS points will be obtained across the short and long axes of the reef at 0.5-1 m spacing as appropriate for size of reef ending at the Reef Edge (as defined above – shell material is 25%). <u>When entering the water to reach the Reef Edge</u>, add a designation in the labeling that the point was taken in water (elevation models perform terribly even in shallow water).
    - Optional **(<u>but strongly encouraged</u>)**: Additional ~20 vertical checkpoints collected on the reef haphazardly for more robust RMSE/accuracy analysis
- Alternative/Optional: Reef height can also be obtained without an RTK-GNSS using the following methods:
    - Locate the observed highest point on the reef (do not walk over potential sampling locations).
    - Locate the edge of reef closest to the highest point and mark location with a stadia rod
        - Note: The edge is defined as a continuous line where the **percent coverage of substrate, either living or non-living material remaining above the sediment, is equal to or greater than 25%** (Baggett et al. 2014)
    - Hold a string at the highest point and stretch tightly across the reef to the marked stadia rod at the edge point.
    - Attach a hanging level to the string.
    - Move the string on the rod up and down until the string reads level when held taught.
    - Record reef height on field data sheet (height on the stadia rod where the string hits).
    - Record distance on the field data sheet (length of the string from the highest point to the edge).
    - The ratio between reef height and distance are used to auto-calculate reef slope in the database.



Metric 4: Rugosity

Rugosity on the reef will be measured in situ using the chain method.

- Conduct 3-4 rugosity measurements on each reef trying to capture variability in clustering and 3D variability.
  - Chain size: ~ 3mm - decent balance between weight and ability to fill interstitial space
  - Chain length: 1-2 meters
- Chain is carefully laid along a straight path allowing (and helping) the links to settle into crevices then a measuring tape is used to collect the following measurements
  - RTK GNSS: The start and end location of the chain will be surveyed with RTK GNSS. Also survey several locations along the line.
- Measurement 1: Length of the chain from start to end as it rests on reef but with measuring tape mirroring the slope of the reef
- Measurement 2: Same as #1, but with measuring tape level (no reef slope) using a simple line level attached
- Measurement 3: The linear distance from start to end of the chain as chain is stretched (you may already have this measurement if you are using a defined length of chain)

-------------------End of Tier 1 Metrics------------------

Metric 5: Shell Volume

- Quadrat-scale
  - Follow Quadrat Excavation protocols above then for the quadrats, record 3-4 depths (from the top of the surrounding oysters to the sediment) using a ruler/meter stick.
  - A follow up flight will then be used to verify the volume change within the excavation areas.
- Reef-scale
  - The ground truth for reef-scale volume should be calculable/estimated using the axial profiles and the reef area/footprint

Metric 6: Percent Cover Substrate

Percent cover of reef substrate

- Using a handheld point-and-shoot camera or phone, take a photo looking down on the quadrat prior to excavation for density sampling. Surficial coverage of shell material will be analyzed in the picture.
- Or point-intercept: use a **1-m^2 quadrat with 100 intersections (or 50 intersections if you need to scale down)** and classify each point as live, dead, box, sediment, or other. [It would be hard to tell live from dead in pictures, so a comparison of photo-based and point-intercept could be a great student project.]
  - Place 1-m^2 quadrats
  - Survey four corners OR center and one corner with RTK-GNSS
  - Slide a flag pin directly down from the intersection of each grid
  - Examine area underneath each grid intersection and categorize as either: [live oyster, oyster shell, box (dead but valves still attached), mud/sediment, or ‘other’] or [oyster (live or box), cultch/shell hash, mud]
    - If category is ‘other’ then be sure to define what other is in the field notes (e.g., mussel, conch shell, etc.)

- Record data on the 10x10 gridded section of the field data sheet.
- *__Note:__* Each intersection of the grid represents 1/100 points. The total number of points for each category is summed at the bottom of the field data sheet, yielding a percent cover of each category for each quadrat (*e.g.* # live = % live oysters; **OR** %shell vs %cultch/hash vs %mud if not determining live/dead).

Metric 7: Thermal signature/differential

This metric would primarily be collected using a UAS thermal sensor and would likely require a series of consecutive flights to establish the thermal differential across the variable substrate (different clustering on the reef vs. Mud/sand). On the ground sensors like temperature loggers could be dispersed throughout a study reef as a groundtruth measure.

Metric 8: Effective Surface Area

This metric would build on the quadrat sample processing, requiring additional steps during lab processing to obtain width measurements. This would likely be conducted on a subset of reefs and potentially a subsample of a quadrat. See section in lab processing.

Metric 9: Reef Elevation

See Reef Height.

Metric 10: Strata Classification

This is a qualitative metric to examine reefs using a visual assessment. Training from the SCDNR would be required to prepare everyone to determine reef aspects like amount of vertical shell, patchiness, substrate type (shell on other shell, shell on mud, horizontal shell). This creates a Strata score.

Metric 11: Mission Planning Trade-Offs

This would involve an exploration of factor(s) discussed in the image acquisition section and assessing how they impact metrics/products.

Metric 12: Disturbance Tracking

This metric would assess how much we are impacting the reef when surveying. Using pre- and post-excavation flights, a first pass of this metric could be analyzing any change detected around the axial profiles, checkpoints, rugosity measurements compared to the rest of the reef (excluding the excavations). Additional tracking could include ground crew surveying the reef tracking their movements across the reef using handheld GPS to add into the footprint of change detection.

Field Order of Operations

This field timeline captures only the Tier 1 Metrics with a few Tier 2 Metrics.

- Benchmark Survey
- Place and survey GCPs
- Conduct initial flight
- In Situ Sampling (with enough field support, the below can be conducted concurrently)
    - Axial Profiles RTK points
        - Additional vertical checkpoints
    - Density quadrats
        - RTK points (center/corner[s])
        - Photo/Percent Cover Quadrat (T2)
        - Excavation
        - Depth measurements (T2: shell volume)
    - Rugosity
        - RTK points
- Follow-up flight (if conducting; preferably within a week of initial flight)

Image acquisition

The following protocol items detail how UAS imagery should be acquired.

Timing

UAS flights conducted during the summer of year 1 at the time of in situ data collection (before and after) +/- 1 week

- Flights occurring at low tide around solar noon +/- 2 hours <u>as possible</u>
- Flights Pre and Post Quadrat Sampling (**Optional**)
    - Provides change detection on a fine scale
    - required for estimating shell volumetric change
- UAS flights during the summer of year 2

CRS for image acquisition

This may be dictated by drone. Each group will provide the CRS associated with their imagery.

Equipment

Drone

- Each group will be using a multirotor airframe with one or more sensors.

Sensors

- Required: RGB
- Optional: RGB + multispectral / thermal
- Optional: lidar

Mission planning

- GSD-driven altitude
    - 1 cm (for RGB); multispectral as can be accommodated
- Flight speed
    - 3-4 m/s or 6-9 mph (can be adjusted for faster if you are managing camera settings)
- Overlap
    - 75% Front, 75% Side
- Optional Mission Parameters (Pertaining to Metric 11)
    - Orientation of flight paths away and toward the sun AND/OR slight off-nadir camera angle (70-80 degrees)
        - If you use slight off-nadir imagery, increase your survey box size
    - Camera settings for RGB (fixed focal length, aperture settings, shutter speed)
        - Ability for people to adjust these may be limited by mission planning software
        - Ideally you will set the following:
            - Prioritize Shutter Speed: 1/1000 s or faster
            - ISO as low as you can – if sunny this should be 100-200, but may be more in cloudy conditions
            - You can let the aperture adjust to balance those other settings (priority on shutter speed)
        - Focus to infinity
    - Double Grids (perpendicular flight lines): most flights so far have been single grid, so potential for exploring benefit (if any) of double grid flights

Ground control points

- White/black Checkerboard targets
    - RTK-GNSS survey center
- Concentration: (c. 5-10/ha for small survey areas or 1-2/ha for large areas)
    - If you are using an RTK/PPK equipped drone, you can reduce the number of GCPs in the study area, but should at least maintain 5
- Distribution: Quincunx or similar – think of the 5-side of dice, capture your corners and distribute some in the middle
- Additional 3-4 targets placed and surveyed to be used as **horizontal and vertical checkpoints** during processing

Preflight checks

- We will provide a template for checks to be completed and a mission form to be filled out
- Check this **Box Folder** for a:
    - Flight log template
    - Packing checklist example
    - Preflight checklist example
    - Combined Flight log/Packing/Preflight checklists

- Field monitoring equipment checklist
- README (metadata) example

Data management

- We will provide the template for how we will store and back up the data on the shared Box drive including the metadata documentation

Lab Processing

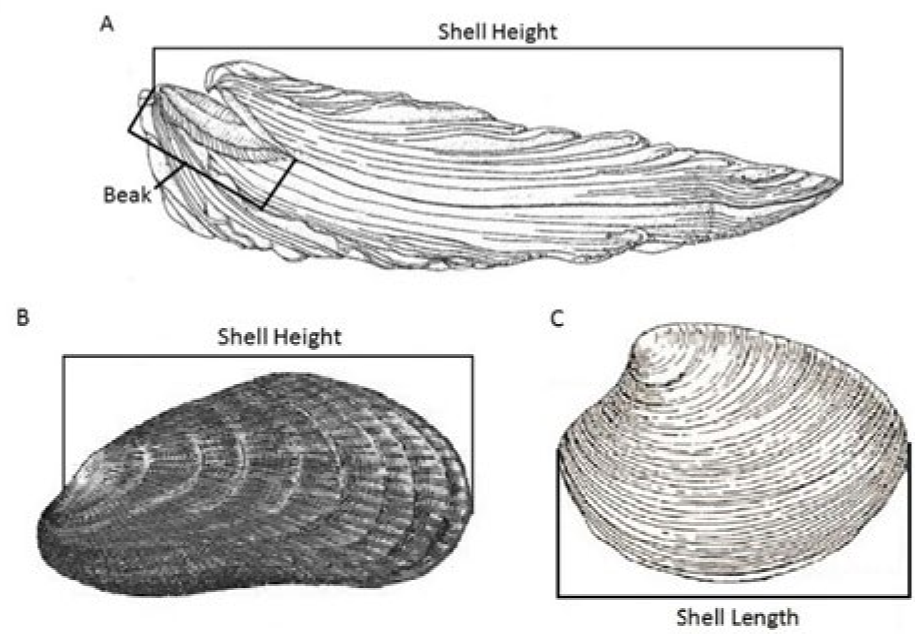
Dependent on parameters selected for measurement

Sort

- Samples sorted into two categories: (i) live oysters and boxes and (ii) reef substrate material (i.e., shell, shell hash).
  - In NC live oysters and boxes were sub-divided, and reef substrate material was sub-divided into oxic (brown shell) and anoxic (black shell) categories using shell coloration as qualifiers.
- Measurement of mussel volume during sample processing

Count and Measure

- Oysters and boxes (where both valves are present and together) counted and measured with calipers to the nearest millimeter using vertical shell height (VSH).



Weight

- Weight of each category is taken live oysters, oyster boxes, brown shell, and black shell with balance to nearest gram
- Also weigh mussels if present

Volume

- Volume obtained for each category through water displacement in graduated vessels (we created graduated buckets)
    - Graduated bucket: https://www.grainger.com/product/KRAFT-TOOL-Mixing-Bucket-1-Pieces-43Y530?findingMethod=orderHistory&opr=ODOH

Lab Processing Data Sheets

- We will provide a template for lab processing