Drone the NERRS:
Assessing the Efficacy of a Drone-Based Coastal Wetland Monitoring Protocol Across Five Biogeographic Regions

Project Timeline: October 1st, 2023 - June 30, 2025

Participating Reserves: Apalachicola, Chesapeake Bay-Virginia, Great Bay, Rookery Bay, South Slough, Wells

Project Team Members and Other Participating NERRS Staff:
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Background: Visualizing changes in emergent vegetation due to stressors such as storm events, climate change, and/or anthropogenic impacts is integral to assessing the health of a wetland ecosystem. While ground-based monitoring is commonly used to assess habitat health, it is labor-intensive and can damage vegetation in sensitive habitats as well as miss key differences in small-scale heterogeneous habitats. Satellite imagery offers a solution to those pitfalls but comes with the sacrificial loss of detail. Uncrewed Aerial Systems (UAS, also known as drones) can provide a high-resolution imagery solution at a lower cost.

At the 2022 National Estuarine Research Reserve (NERR) Annual Meeting, a strong interest in implementing UAS-based monitoring was made evident by attendance at the Getting Creative session, which was a discussion following up on results from the “Drone the SWMP” science collaborative catalyst project. NERR staff were quick to follow up the Getting Creative session with the idea to take the information from the previous science collaborative work and create a proposal to transfer the information from that project to a more geographically-diverse set of ecosystems, different habitats, and associated end users. Representatives from six Reserves not associated with the original catalyst proposal expressed interest in testing the efficacy of the SOP generated from the Drone the SWMP project. Thus, the purpose of this transfer proposal was to evaluate the efficacy of this tool for the assessment and monitoring of emergent vegetation in six NERRs comprising a wider range of biogeographic regions, including Acadian (Great Bay, Wells), Columbian (South Slough), and Louisianian (Apalachicola), while expanding upon previous evaluation in the Virginian (Chesapeake Bay Virginia) and West Indian (Rookery Bay) biogeographic regions. Additional goals for this project, outlined below, included building a NERRS drone/UAS Community of Practice, identifying challenging areas, potential constraints, and logistical hurdles surrounding drone/UAS use, refining existing tools, and sharing results with the broader NERRs community.

Goals: The primary, overarching goals for this project were to evaluate the feasibility of using drones/UAS on a broader scale across the NERR system, building capacity across different NERRs to allow for more drone/UAS use, and to refine the existing NERRS drone protocol for future use by additional reserves. Specific goals have been outlined below:

1. Build a Community of Practice
    a. Reestablish the NERRS Drone Workgroup
    b. Compile a Community of Practice report
    c. Organize a Drone the NERRS Mini-Symposium to share results and lessons learned
    d. Survey the wider NERRS community on drone uses and needs
2. Assessment of the NERRS Drone Marsh Monitoring SOP
    a. Conduct UAS and ground-based monitoring surveys

    b. Process UAS imagery
    c. Post-processing analysis
    d. Qualitative assessment of the NERRS Drone Marsh Monitoring SOP over a range of biogeographic regions
    e. Store and share data
3. Refine existing tools and share with the broader NERRS community
    a. Identify areas of challenge and refine existing tools
    b. Disseminate information with the wider NERRS community and external partners
    c. Produce a whitepaper to share with the broader NERRS drone community

Methods and Results:

Goal 1: Build a Community of Practice (CoP)
At the start of the project the team members began this process by defining our CoP and goals for the CoP. Initial plans involved discussion of building an online workspace using open free software that could be used to house resources, documents, and a chat function to allow for the sharing of expertise and resources concerning UAS use and continue the momentum begun with Drone the SWMP and Drone the NERRs. However, the project team found that the appropriate free software does not exist, and this did not seem feasible given the one-year timeline of the project. The project team pivoted towards the following methods of ensuring that lessons learned from this project will continue to inform UAS work within the NERRS:

I. <u>Reestablish the NERRS Drone Workgroup</u>
The idea of creating a NERRS Drone Workgroup was proposed several years prior to the start of this project and several reserves expressed interest, but ultimately the workgroup was never fully established. The project team decided to move ahead with reestablishing the NERRS Drone Workgroup to continue the momentum begun with Drone the NERRs by promoting regular conversations among NERRS related to drone usage and by memorializing and sharing drone-related information.

Justin Ridge (Research Coordinator, North Carolina NERR) worked with Elaine Vaudreuil (NOAA- National Ocean Service) to reestablish this workgroup. Justin distributed an email to NERRS staff who have previously expressed interest in being part of the drone workgroup; an initial meeting was set for February 25th, 2025, and the workgroup is working to establish a regular meeting schedule. The structure of the workgroup will include a small steering committee and a broader community of practice. Information shared within the workgroup, as expressed by a comprehensive needs assessment and further discussion within the group, will include successes and failures, mapping techniques, equipment troubleshooting, project ideas, and some of the results of the Drone the NERRs project.

II. Compile a Community of Practice report

The project team decided to memorialize their ideas and needs surrounding the drone CoP into a CoP report to serve as a future resource for interested parties and would include needs and goals for a wider NERRs UAS CoP. Megan Lamb (Apalachicola NERR) organized the ideas and needs generated through the brainstorming process into a report that is available on the NSC project website.

III. Organize a Drone the NERRS Mini-Symposium to share results and lessons learned

On March 7th, 2025, following the completion of fieldwork and the bulk of the data analysis (further described under Goal 2 below), team members met together virtually to share results, compare results across the different NERRs, discuss challenges and successes, and qualitatively analyze any differences in results between the NERRs. Team members found it useful to see the different types of equipment used by each reserve, the unique habitats that were mapped, and the successes and challenges of the entire process as experienced by each reserve. Important points taken from this mini-symposium are incorporated into this final whitepaper (see Appendix I), and key takeaways from the mini-symposium were also shared with the NERRS Drone Workgroup.

IV. Survey the wider NERRS community on drone uses and needs

To address the gap between drone-related needs across the NERRS and the necessary knowledge and skills to make these needs a reality, the project team decided to survey the wider NERRS community. Marissa Figueroa (Rookery Bay Training and Engagement Coordinator) and Jess Hedgpeth (Rookery Bay Training and Engagement Specialist) created a needs assessment via a google form survey that was sent out by Justin Ridge to the NERRS community in January of 2025. Forty people filled out this survey, representing 19 reserves. Respondents indicated how they were using drones or sharing how they would like to use drones, as well as providing perceptions of participating in a wider community of practice. A full summary of the survey results can be found on the NSC website, including an inventory of existing drone users, drones, and software, inventory of needs, uses, and potential uses for drones in their respective reserves (e.g., “matchmaking”).

Goal 2: Assessment of the NERRS Drone Marsh Monitoring SOP

I. Conduct UAS and ground-based monitoring surveys

Each participating reserve conducted both UAS-based and ground-based monitoring surveys at their chosen site(s). The UAS-based monitoring followed the NERRS Drone Marsh Monitoring SOP developed by the previous Drone the SWMP project. Ground-based monitoring was conducted using the vegetation monitoring protocols developed for the Wetlands and Water Levels program. Sites were monitored late summer-fall of 2024. Locations and equipment used by each reserve are as follows:

Equipment and Software Used:

Reserve	Drone	Sensor	Mission Planning Software
Apalachicola	Inspired Flight 800 Tomcat	MicaSense Red Edge-P	Google Earth, Inspired Ground Control (IGC) app
Chesapeake Bay-Virginia	eBee X	AgEagle Duet M	eMotion
Great Bay, Wells	DJI Mavic 2 Pro	Hasselblad L1D-20c, Sentera High Precision Single NDVI	Drone Deploy app
Rookery Bay	Inspired Flight 800 Tomcat	MicaSense Red Edge-P	Inspired Ground Control (IGC)
South Slough	DJI Matrice 300	MicaSense Altum PT multispectral	UgCS

Project Sites:

Reserve / *(Biogeographic Region)*	Site(s)	Habitat(s)	Dominant Species, if applicable
Apalachicola (*Louisianian*)	Pilot's Cove	Saltmarsh	*Juncus roemerianus, Spartina alterniflora*
	Unit 4	Saltmarsh	*Juncus roemerianus*
Chesapeake Bay-Virginia (*Virginian*)	Goodwin Island	Saltmarsh (Polyhaline)	*Spartina alterniflora, Distichlis spicata, Spartina patens, Juncus roemerianus*
	Sweet Hall Marsh	Tidal Freshwater Marsh	*Peltandra virginica, Spartina cyosuroides, Polygonum* spp., *Leersia oryzoides, Zizania aquatica, Carex* spp., *Sciurpus* spp., *Typha* spp., *Panicum virgatum*
Great Bay (*Acadian*)	Sandy Point*	Saltmarsh (Low Marsh and High Marsh)	*Spartina alterniflora, Spartina patens, Distichlis spicata, Juncus gerardii*
Rookery Bay (*West Indian*)	Shell Island Road	Coastal Scrub Pine Flatwoods Brackish Marsh	*Serenoa repens, Quercus geminata, Pinus elliottii, Morella cerifera, Cladium jamaicense, Conocarpus erectus, Acrostichum aureum*
South Slough (*Columbian*)	Wasson Creek	Tidal Marsh (oligohaline)	*Phalaris arundinacea,Scirpus microcarpus, Potentilla anserina*
	Tom's Creek	Tidal Marsh (mesohaline) and Freshwater Marsh	Tidal: *Carex lyngbyei, Agrostis stolonifera, Juncus balticus, Potentilla anserina;* Freshwater: *Carex obnupta, Juncus gerardi, Lysichiton americanus*
	Fredrickson South	Tidal Marsh (mesohaline)	*Juncus balticus, Potentilla anserina, Carex lyngbyei, Symphyotrichum subspicatum*
	Winchester Spruce Swamp	Tidal Forested Swamp (oligohaline)	*Picea sitchensis, Carex obnupta, Potentilla anserina, Juncus balticus*
Wells (*Acadian*)	Drakes Island Marsh	Saltmarsh (High Marsh)	*Spartina patens*

*Due to logistical challenges and staff turnover, Great Bay was not able to fly at this site. GRBNERR worked with staff from Wells NERR to conduct monitoring at Wells.

II. Process imagery

Using Pix4Dmapper or Drone2Map, each Reserve processed their UAS-acquired imagery to create outputs in the form of orthomosaics, digital surface models (DSM), digital terrain models (DTM), and/or Normalized Difference Vegetation Index (NDVI). The type of output each Reserve chose was dependent on the type of analysis that had been chosen to best meet individual Reserve needs.

III. Post-processing analysis

Each end user Reserve followed pages 30-46 of the NERRS Drone Marsh Monitoring SOP to analyze drone imagery outputs for the specific product(s) that met their individual needs.

Analyses Performed:

Reserve	Image Processing Software	Analyses Performed
Apalachicola	Drone2Map	Percent Cover, Ecotone Delineation
Chesapeake Bay-Virginia	Pix4Dmapper	Percent Cover, Ecotone Delineation
Great Bay, Wells	Pix4Dmapper	Percent Cover, Ecotone Delineation
Rookery Bay	Both Drone2Map and Pix4Dmapper; Pix4D was determined to be better and was used in analysis	Percent Cover, Ecotone Delineation
South Slough	Pix4Dmapper (began with Drone2Map)	Percent Cover, Ecotone Delineation, Plant Supervised Classification

In addition, UAS data was compared with ground-collected vegetation data to analyze differences between the two data collection methods.

IV. Qualitative assessment of the NERRS Drone Marsh Monitoring SOP over a range of biogeographic regions

A qualitative assessment of the NERRs Drone Marsh Monitoring SOP was conducted at the mini-symposium in March 2025 (see Goal 1.III above.) Team members found that this SOP was of great help in conducting their monitoring but also had several suggestions for improvements. Key takeaways from this symposium are included in Appendix I of this document.

In addition, project team members were asked to provide written feedback on each section of the NERRS Drone Marsh Monitoring SOP. This feedback is included in Appendix II of this document.

V. Store and share data

Following the conclusion of this project, data will be stored with the National Estuarine Research Reserve System Centralized Data Management Office (CDMO) to be made available for any interested parties.

Goal 3. Refine existing tools and share with the broader NERRS community

I. Identify areas of challenge and refine existing tools

Several areas of challenge were identified throughout the course of this project and have been addressed in the outputs listed below and the two appendices of this document. The primary challenges associated with the project included software issues, lack of file storage space, difficulty flying/processing imagery in areas with trees, and the learning curve associated with collecting, processing, and analyzing data, as well as with plant identification and RTK use.

II. Disseminate information with the wider NERRS community and external partners

Several outputs were generated from this project which will be shared with the NERRS Drone Workgroup, NERRS Science Collaborative, and other interested parties. Copies of all of these outputs can be found on the NERRS Science Collaborative website.

- A **whitepaper** (this document; Goal 3.III) giving an overview of this project, lessons learned, successes, failures, and recommendations for future UAS research.
- A **Community of Practice Report** (Goal 1.III) summarizing project team discussion regarding setting up a UAS community of practice. Although it was determined not to be feasible to create a community of practice through this project, the team hopes that the memorialization of these efforts will be of use to future UAS-related work in the National Estuarine Research Reserve System.
- A **summary of the NERRs Drone Needs Assessment** (Goal 1.IV) highlighting key takeaways from the survey and needs assessment sent out to current and potential UAS users across the NERR System.

III. Produce a whitepaper to share with the broader NERRS drone community

A summary of the information gathered from this project was organized into a final whitepaper (this document) to be shared with the new NERR Drone

Workgroup (Goal 1.I) and respondents to the NERRS Drone Survey (Goal 1.IV) This whitepaper includes suggestions and recommendations to the NERRS Drone Marsh Monitoring SOP (Goal 2.IV; Appendix II) and points brought up from the mini-symposium (Goal 1.III; Appendix I) on lessons learned, successes, failures, and recommendations for future drone work.

Conclusion:

Despite the challenges associated with UAS use, the project team found that UAS-based habitat monitoring is feasible on a broader scale across the National Estuarine Research Reserve System, particularly when integrated with ground-based vegetation monitoring. While UAS-based monitoring lacks the fine scale of ground-based vegetation monitoring, it can be done on a larger scale with less damage to the ecosystem, and when the two methods are integrated their strengths complement one another. By combining ground and UAS data, NERRS staff can get a geographically extensive but detailed picture of changes in coastal habitats.

The project team found that the NERRS Drone Marsh Monitoring SOP was an invaluable resource for conducting UAS-based habitat monitoring. By implementing this SOP on a wider scale across multiple biogeographic regions, the team developed some additional suggestions for this protocol for further refinement and increased ability to implement this protocol within other NERRs.

Sharing of expertise, time, and resources across the National Estuarine Research Reserve System will be integral to the process of continuing to build UAS capacity. The establishment of the NERRS Drone Workgroup will facilitate this continued exchange between reserves moving forward.

While some barriers to wider UAS usage remain, it is our hope that this project, the connections created, and the identification of possible solutions will facilitate further development of UAS-based mapping within the National Estuarine Research Reserve System to monitor the critical coastal ecosystems we all study and protect.

APPENDIX I
Key Takeaways from the Drone the NERRS In-House Symposium

Successes

- Partnerships and collaboration are key- don't be afraid to reach out for help.
    - Within reserves
    - Among different reserves
    - With the local partnering organizations (state, university, etc.)
    - AI/ChatGPT can make things easier! (particularly if it's trained on ESRI and Pix4D documentation.)
- The NERRS Drone Marsh Monitoring SOP is very helpful.

Challenges

- The SOP is written for a quadcopter; there were challenges implementing the SOP for fixed-wing drones.
- There is a learning curve to learning how to use drones.
- Learning plant identification skills and RTK operation are a challenge.
- Flying drones and using RTK is challenging in forested habitats and ecotones.
- Analysis and processing is very time-consuming.
- Software crashes and problems connecting to the network were a significant problem.
- Multispectral imagery requires large storage space.

Lessons Learned

- Everything takes longer than expected; budget extra time!
- Run test flights with small datasets.
- Reach out for help if needed.
- Be prepared and flexible.
- GPS or RTK ground control points so they can be found again later.
- AI can be a big help, particularly if it is trained on ESRI and Pix4D documentation (i.e., ChatGPT.)
- Fly before ground vegetation sampling to minimize the disturbance the drone picks up on.
- It's faster and more accurate to digitize ecotones in the office. Field RTK surveys are time-consuming, challenging, less accurate, and potentially damaging to the marsh. However, field RTK surveys do help ground-truth the digitizing done in the office.
- Store data locally (it cuts down on processing time), then upload it to the network once finished.
- Species-level mapping may not be feasible.
- Have fun!

<u>Recommendations for Future Drone Work</u>

- Continue to share knowledge within and among reserves.
- More RTK training would be helpful.
- Plant identification training would be helpful- perhaps include some recommended apps to use in the field.
- Spend more time on percent cover analysis in the Northeast, and see if it can be improved by including higher-resolution habitat classes (high marsh, low marsh, mixed/transitional, forbs, etc.)
- Consider making permanent ground control points, although these do take quite a bit of effort to make.
- Find something without multispec that can approximate NDVI
- Further evaluation of office vs. field/RTK ecotone digitization. Multiple reserves reported greater accuracy, greater ease, and faster speed to conduct ecotone delineation in the office rather than in the field with an RTK unit.
- Use drones as a compliment to, rather than a replacement of, on-the-ground vegetation surveys.
- Use AI to assist with processing and analysis, create a template of instructions that can be fed to the AI before getting started, and create instructions for users on how to be efficient and minimize AI errors.
- Determine if we should force percent cover to equal 100% in vegetation plots.
    - Yes- better to compare to drone mapping
    - No- better to approximate biomass; can try to normalize data.
    - Yes and no- we can add columns on the datasheets for % vegetated and % unvegetated.
- Clarify **<u>why</u>** certain things need to be done in the NERRS Drone Marsh Monitoring SOP.

APPENDIX II
Summary of Project Team Feedback on the NERRS Drone Marsh Monitoring SOP

Each participating reserve was asked to give feedback on the efficacy of the NERRS Drone Marsh Monitoring Standard Operating Procedure which was used throughout the course of this project. It is our hope that this feedback will be helpful to other reserves as they explore using UAS to conduct mapping and monitoring. This summary has been organized to follow each main section of the SOP.

I. **<u>Operational Protocol</u>**

A. Ease of following protocol
  - Generally the participating reserves had no issues following this section of the protocol, although having extra time and room for error in familiarizing personnel with the equipment would have made it easier.
  - The mission planning parameters table was very helpful.

B. Issues or difficulties following protocol
  - The hyperlinks in the PDF SOP don't seem to work.
  - Funding delays, challenges with ground vegetation surveys, hurricanes, and challenges with RTK complicated the data-gathering process.
  - The SOP recommended that flights be conducted at 15 mph, but this was not always possible given equipment limitations (i.e., the minimum speed for the eBee fixed wing drone is 25 mph.)
  - Flight altitude had to be modified at South Slough due to the presence of tall trees. After testing several methods it was determined that flying higher and adjusting GSD (ground sample distance) was an adequate workaround. Flight altitude also had to be modified to approximately 400 feet at Chesapeake Bay- Virginia to allow imagery from their fixed-wing drone to be processed in Pix4Dmapper.
  - The SOP did not have any recommendations or guidance for automated flight planning software that will provide adequate control of mission settings (i.e., flight speed) specified in the SOP.
  - Different reserves measured percent vegetated cover differently during the ground surveys. Some reserves measured percent cover by species at multiple canopy levels (i.e., percent cover could exceed 100%), while others forced all percent cover, including unvegetated cover, to total 100%. This latter method allowed for better comparison with the drone data.
  - The recommended timing of the mission (between 7:00 and 10:00 AM) resulted in some shadows on the western side of tree lines and creek banks. It is unclear if this creates fewer issues for analysis than any reflected sunlight from the marsh surface later in the day.
  - Collecting accurate RTK points for the ecotones was challenging for one of the reserves. The creek edges were steep and can be convoluted, making precision of walking the boundaries challenging. Also, the upland-wetland ecotone was difficult to survey due to tree cover interfering with the satellite signal. This reserve ended up resurveying this ecotone boundary in late fall after most trees had dropped their

leaves. This resulted in better precision and more points were taken, though there were still some gaps. The reserves participating in this project found that ecotone delineation was much more efficient and accurate when done in the office with drone imagery rather than in the field with RTK.

C. Recommended changes to the protocol
  - Have the full url to links spelled out in the SOP rather than using hyperlinks.
  - Add an additional parameter to vegetation plot datasheets to estimate overall percent vegetated and unvegetated cover (i.e., force all percent cover to equal 100%.) This will allow easier comparison between the ground-based veg plot data and the aerial drone mapping.
  - Include a reference to the manufacturer's operating recommendations if available, as specific drones and sensors may have different recommended settings than the SOP.
  - Some guidance on automated flight software would be helpful, although that information could become outdated quickly.
  - Consider allowing ecotone delineation to be done in the office rather than in the field.

II. Image Processing

A. Ease of following protocol
  - The protocol was clearly laid out, easy to follow, and very helpful.
  - It was helpful working with a member of the project's technical advisory committee who had more expertise.
  - The troubleshooting tips helped.

B. Issues or difficulties following protocol
  - One of the reserves found the naming convention to be too long for Pix4D, causing errors.
  - Pix4D repeatedly crashed and failed for Chesapeake Bay- Virginia. They were able to process the Goodwin Island imagery using Pix4Dmapper; however, trying to process the multispectral and RGB imagery together from Sweet Hall caused Pix4Dmapper to repeatedly crash. Pix4Dmapper continued to crash despite switching from multispectral to orthophoto processing, opening a support ticket with Pix4D, upgrading the graphics card and BIOS, processing smaller project areas, and reprocessing Goodwin Island. Working with Justin Ridge, they were able to process the imagery by separating multispectral and RGB imagery into individual Pix4D projects and disabling a sunlight correction setting.
  - Both Rookery Bay and South Slough found Pix4Dmapper worked much better than Drone2Map.
  - The software had some issues calibrating the images in areas where trees were present near the edge of the marsh.
  - One of the reserves had a multispectral sensor that wasn't documented in the SOP (Hasselblad L1D-20c.)
  - The guidance on the vertical coordinate system was a bit confusing (what

is its purpose, and how should it be done?)
- The template for the Sentera sensor didn't seem to work (the Sentera specific index failed to process.) Sentera or Pix4D may have made some updates that eliminated the need for the template.

C. Recommended changes to the protocol
- List what files don't need to be saved once processing is done.
- Include a reference to the manufacturer's processing directions if available, as specific sensors may have extra settings needed.
- Perhaps have the vendors/manufacturers review the SOP to see if it is current with the associated software.
- Elaborate the purposes and methods for setting the vertical coordinate system of the GCPs.
- Provide some better tips on how to predict the vertical adjustment that may be needed to bring the GCPs close enough to the point cloud to be able to register enough images.
- Recommend that all processing be done in a site-specific naming convention and a secondary copy be made with SOP naming post processing. The reason behind the secondary copy is that if Pix4D ever needs to be reprocessed, changing names and moving projects has produced errors in the software and made it more difficult to rerun old projects.

III. Post Processing and Analysis

A. Ease of following protocol
- This section was thorough and easy to follow.
- The links to ESRI websites were helpful to read more about a given tool.
- The Quality Notes were appreciated.
- The flow charts helped to understand the process.
- The step-by-step guide was very helpful.

B. Issues or difficulties following protocol
- When identifying the correct class for each accuracy point, it was unclear from the instructions which layer would be the most appropriate to look at - the flight orthomosaic, the segmented raster, or something else.
- While in the field, Apalachicola did not take the center point of each 1x1 m plot. Instead they had small PVC poles in offset corners of the plots so they took those with the RTK. However, the instructions for creating a shapefile for the plots were "follow at first." This created square plots that were not oriented in the same way their plots were oriented in the field. Had they not taken the offset poles, they might not have recognized the rotation of these plots and the incorrect orientation.
- The digitization of ecotones and marsh boundaries were especially time-consuming.
- It would have been helpful to have had practice with selecting training polygons to improve results.
- There was some unexpected behavior from ArcGIS, but this was overcome by using ChatGPT to troubleshoot.

- In ArcGIS Pro 3.4.0, the rasters must be saved to the geodatabase because otherwise the tool defaults to a .crf file and won't run.

C. Recommended changes to the protocol
   - Clarify which layer would be most appropriate to look at while identifying the correct class for each accuracy point.
   - Would recommend adding a section with instructions on how to compare field-collected data with drone-collected data, whether through statistical analysis or another method.
   - Include the directions for creating the RGB image in the main part of the protocol rather than the appendix.
   - List which files don't need to be saved when processing is finished.
   - It is unclear from the SOP that the random trees classification tool needs to be run to generate an .ecd file.
   - The SOP could be more clear that the Train _______ Classifier does not produce a raster file.
   - Suggested update to the SOP:
     - When running the **Classify Raster** tool in ArcGIS Pro, attempting to save the output as a **.tif** or other file-based format may result in the error: *"No raster store is configured."* This occurs because ArcGIS defaults to the **Cloud Raster Format (.crf)**, which requires a raster store that is not configured in most local workflows. To avoid this error, always save the classified raster inside a **geodatabase (.gdb)** first, using a path such as C:\Users\[YourUsername]\Documents\ArcGIS\Projects\[ProjectName]\[ProjectName].gdb\ClassifiedRaster. If a **.tif** output is required, export it after classification using the **Copy Raster** tool, specifying the **input raster from the geodatabase** and an output location such as C:\Users\[YourUsername]\Documents\ArcGIS\Projects\Drone the NERRS\ClassifiedRasters\ClassifiedRaster.tif. This ensures successful classification without errors while allowing flexibility in output formats.

IV. Overall

A. Do you think you will continue to follow this SOP at your Reserve?
   - Yes (all participating reserves)
   - Some amendments or notations may need to be added to the SOPs to address particular issues (i.e., use of a fixed-wing drone, monitoring freshwater tidal marshes, etc.)
   - It is helpful to have an SOP simply for image acquisition, with steps for improving the products with recommended flight parameters, though these might be improved on for individual sites (for example, eliminating shading with time of day.)
   - One reserve intends to use the image classification for estimating percent cover so they can calculate changes over time. While they don't anticipate being able to classify individual species, the basic vegetated vs. unvegetated metric is still useful.

B. Do you think using drones to monitor emergent vegetation is something you will continue at your Reserve?
    - Yes (all participating reserves)
        - One reserve noted that they will continue to use drones to monitor habitat change along with on the ground field data collection because the two methodologies complement each other and are useful when used together.
    - Several reserves noted that they are currently or plan to use drones to monitor restoration sites

C. Do you intend to adopt additional drone monitoring programs following participation in this project at your Reserve?
    - Yes (all participating reserves)
    - One reserve has already started LiDAR mapping by drone.
    - Another reserve noted that they are still growing their drone program and in the process of figuring out when to collect multispectral imagery vs. RBG imagery.

D. Can you discuss any other barriers or limitations to your Reserve's adoption of using drones for biological monitoring that you have identified through the course of this project?
    - Staff time and workload is a big limiting factor, including time to run test flights, time to deal with maintenance and repair, time to build knowledge with data processing, and time to build general proficiency with the whole process.
    - Redundancy of staff skills would be necessary to prepare for possible staff turnover.
    - Storage capacity and processing speeds are significant barriers to multiple reserves.
    - Licensing of software is also an issue- one reserve noted that they would be disappointed to lose access to Pix4Dmapper once this project is complete; although a Drone2Map license is shared among the Florida reserves, it did not perform as well as Pix4D and an additional Drone2Map license would be necessary to handle additional future projects.
    - Specific habitat characteristics and access are issues for several reserves, including difficulties accessing the site, difficulties flying/mapping around tall trees, and uncertainty about how the protocol would translate to a diverse fresh-brackish marsh system compared to a more typical saltwater site.
    - Monitoring canopy height and biomass would involve taking a lot of additional metrics, which would involve extra staff time and resources.
    - Restrictions and policies related to drone usage and drone models limit what types of drones can be used and where they can be flown.
    - Issues in finding support for data processing with the Duet M Camera (lack of support from AgEagle and using the camera outside of agricultural applications and more towards our coastal applications.)
    - Over time the technology is going to age, and support for the firmware/hardware may be discontinued. In order to keep using UAS for

this monitoring it would be helpful to have some guidance on how to plan for continued use as equipment changes and how to update the SOP while maintaining consistency with the data to enable long term comparisons.

E. Any other feedback you'd like to provide?
   - Overall the SOP was fairly easy to follow.
   - More still images of the process would have been helpful.
   - While it will eventually become outdated, having a general how-to video on each step could be useful for a first-time user.
   - Processing software and images cannot work through a network connection; it is necessary to have the data stored on a local drive or external hard drive and upload the final products to the network once processing is complete.
   - One reserve waited to process data weeks after the field work, and would not suggest doing this.
   - Don't leave GCPs out! Place them out the day before or day of flying and then retrieve the same day or the day after. One reserve had a lot of issues with lost or flipped over GCPs.
   - If you can't RTK GCPs on the same day or have multiple people measuring the GCPs, mark them in the field with Fieldmaps or another mobile app.
   - Training on RTK, PPK, benchmarks, and Ntrip would have been helpful.
   - How should we share and present data once we do all the work- should it just be a map, or would other formats be helpful?
   - Overall, the SOP is a great resource, but the learning curve may be pretty steep, and having a community of practice that can help would be essential for more widespread adoption in the system. It may be that a better model going forward would be to have a few dedicated people that can do the image processing and analysis for the Reserves, and that all Reserves need to focus on is data collection. It might be more efficient than trying to have every Reserve be able to do all of the steps, particularly as the software and technology advances.