The Way Forward:
Unmanned Aerial Systems for the
National Estuarine Research Reserves

Acknowledgements

Project funding was made available through the NOAA Operations Award for Wells NERR, Wells, Maine and Grand Bay NERR, Grand Bay, Mississippi
This project could not have been developed without the continued support from a variety of federal agency and university personnel.

Special appreciation goes to:

Nina Garfield	NOAA Office for Coastal Management
Robbie Hood	Director, NOAA UAS Program
John Coffey	NOAA UAS Program
Dr. Robert Moorhead	Northern Gulf Institute and Mississippi State University
Dr. James Gruber	Antioch University New England

Contact Information

Susan Bickford, GIS/Natural Resource Specialist
Wells National Estuarine Research Reserve
342 Laudholm Farm Road
Wells, Maine 04090
(207) 646-1555 x120
suebickford@wellsnerr.org

Lindsay Spurrier, GIS Specialist
Grand Bay National Estuarine Research Reserve
6005 Bayou Heron Road
Moss Point, MS 39562
(228) 475-7047
lindsay.spurrier@dmr.ms.gov

Cover photos courtesy of Grand Bay NERR and Northern Gulf Institute

Acronyms

AMA	Academy of Model Aeronautics
ATC	Air Traffic Controllers
COA	Certificate of Authorization
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
FAA	Federal Aviation Administration
GIS	Geographic Information System
GPS	Global Positioning System
IR	Infrared
KML	Keyhole Markup Language
LiDAR	Light Detection and Ranging
NAS	National Airspace System
NDVI	Normalized Difference Vegetation Index
NERRS	National Estuarine Research Reserve System
NERRA	National Estuarine Research Reserve Association
NIR	Near Infrared
NOTAM	NOtice To AirMen
OCM	Office for Coastal Management
NOS	National Ocean Services
RTK	Real-Time Kinematic
RFP	Request for Proposals
SAV	Submerged Aquatic Vegetation
SET	Surface Elevation Table
SOP	Standard Operating Procedure
SSAM-1	Sentinel Site Application Module-1
sUAS	Small Unmanned Aircraft System
SWMP	System Wide Monitoring Program
TRL	Training Readiness Level
UAS	Unmanned Aircraft System
USGS	United States Geological Survey

Table of Contents

Executive Summary

Drone, UAV, UAS. These terms are instantly confusing and that is only the beginning of the discussion. The use of unmanned aerial vehicles and the systems that support them have caused confusion at all levels, from the youngest recreational flyer to the halls of Congress. This confusion exists in part because it is a new use for a tool that has been in the military's toolbox since World War I and in part because of the outcry of the public over privacy concerns.[1]

Remotely sensed data is a valuable resource for natural resource science. It allows natural resource scientist and managers to visualize data at scales impossible to see from the grounds and to investigate relationships of objects in great detail. It also saves on the allocation of human resources being deployed on the ground. In some instances, it offers views of areas that are either too remote or too dangerous for ground crews to get to.

In addition to data collected by ground crews, remotely sensed data has traditionally been acquired using: satellites, manned aircraft, tethered blimps, and now Unmanned Aircraft Systems (UAS). UAS technology has become a popular tool for civilian use and is increasingly being applied to natural resource management, research, and education. This increase in use can be attributed to advantages that UAS offer over traditional technology such as: relative affordability, mission planning and flexibility, low altitude flights, customized sensors and imagery and high imagery resolution.

Because UAS are operated aloft along with manned aircraft in the National Airspace System (NAS), the regulatory environment governing UAS use is complex and hard to understand. The Federal Aviation Administration (FAA) is currently developing comprehensive regulations for UAS operators to ensure a continued safe environment in the NAS. The FAA has also recently released new rules for the operation of small UAS (sUAS) which has made it much easier to fly sUAS that weigh less than 55 pounds.

Ultimately, each organization must decide if the benefits of UAS technology outweigh the costs of navigating this complex system. This roadmap investigates whether that statement is true for the National Estuarine Research Reserve System (NERRS). It is imperative that the NERRS adopt a adopting a culture of safety and compliance. The UAS industry recognizes the need for this culture to be adopted by *all UAS users* and has created a "Code of Conduct" that is guiding the self-regulation of this emerging industry toward naturally and socially beneficial uses of unmanned aircraft systems.

This Roadmap is a snapshot in time. The rate of change for both UAS equipment and regulations is extraordinarily fast paced. The goal of this document is to fully inform the NERRS community about UAS operation, opportunities for applications, its regulatory environment, and UAS program development as it applies to the Reserves. It will enable all Reserves to discover the way forward in this complex new technological environment.

Section 1: National Estuarine Research Reserve System (NERRS)

The National Estuarine Research Reserve System is a network of 28 coastal Reserves designated to protect and study estuarine systems. Established through the Coastal Zone Management Act, the Reserves represent a partnership between NOAA and coastal states. The Reserves cover 1.3 million acres of estuaries and upland and focus their projects on stewardship, research, education, and training. [2]

Figure 1.1 NERR Locations [6]

1.1 Vision and Mission

The Reserve System envisions a nation with resilient estuaries and coastal watersheds where human and natural communities thrive. The goals of the Reserve System center on protected places, scientific enquiry, and educating people. [2]

UAS technology is an innovative remote sensing and monitoring method that can perform aerial missions to help answer critical questions that aid coastal decision makers. What is changing or not changing? If it is, how fast is it changing and where? How will it affect the surrounding habitats and my community? How can we resist, adapt, recover from this change?

Through a variety of partners and programs, the Reserve System has opportunities to make UAS technology locally operational to help answer these questions.

1.2 Data Needs Assessment/ Interviews

A system-wide data needs assessment was implemented in the fall of 2015 to better understand the remote sensing needs of the Reserves. Nineteen out of twenty-eight Reserves responded. The vast majority of respondents were not using UAS technology as yet, but a few had UAS-acquired data that had been collected by other partners.

Priority projects that were identified as having the greatest need for data were mapping invasive species and habitat change, wildlife surveys and emergency response.

Additional applications identified by respondents were:

- Marine debris tracking
- Sea otter forage areas
- Seagrass bed monitoring
- Digital surface modeling (DSM)
- Shoreline erosion
- Ice cover on marshes
- Shoreline armoring
- Water quality monitoring (algae, sediment…)
- Derelict crab pot monitoring
- Shellfish bed mapping
- Seabird nesting surveys

Common sensor types identified as being important were: Color Infra-red (IR), Light Detection and Ranging (LiDAR), and True-Color images

Other comments provided by the respondents included:

- Barriers to UAS adoption due to lack of staff understanding how UAS could support their projects
- Most reserves (90%) had ground control points to aid in improving accuracy of UAS acquired imagery
- Summer was the most ideal season for acquiring imagery and multiple season acquisition was ideal for many applications but ultimately, it would be project dependent.

One question about possible partner collaboration was intended to stimulate thinking about opportunities with other institutions, especially ones that Reserves already have a working relationship with. The full survey results can be found in Appendix A.

1.3 Reserve System Challenges

Each Reserve is staffed with a diverse team of experts assembled to achieve the stewardship, research, training, and educational missions. All Reserves have their own unique programs and projects tailored to local community and estuarine needs resulting in a diversity of resources and skills. This is both an opportunity and challenge for the Reserves.

Reserves with staff experienced in remote sensing and spatial analysis are more equipped to create in-house final products from UAS collected imagery compared to Reserves that do not. As such, Reserves will have varying skill sets and resources to apply to UAS projects and their derived products.

Similar to the diversity of skills and resources, Reserves have a diverse range of local and regional partners, whether it's a state agency or department, a non-governmental organization, or an academic institution. [3]

Figure 1.5: Reserve Partner Organizations by Type

There is no "one size fits all" approach to using UAS technology within the Reserve System. Each Reserve has different data gaps and data needs that could potentially be filled by UAS flights. Reserves have varying knowledge and experience working with UAS and the associated remote sensing software. Depending on the local partners, Reserves would potentially work with different academic institutions or private vendors to develop a UAS mission.

1.4 NERRS Resources

Nearly all reserves have sentinel site infrastructure and long-term monitoring to study the effects of changing sea/lake level and inundation patterns on marsh habitats. The protocols associated with this sentinel site monitoring include

- Vegetation transects of tidal marsh, mangrove, or submerged aquatic vegetation
- Wetland surface elevation change measurements (SETs and feldspar plots)
- A vertical control network from which elevation surveys and DEMs can be produced,

- Water quality/level data
- Meteorological data
- Habitat Maps
- Groundwater level/quality (optional)

All monitoring is tied spatially (horizontally and vertically), and temporally to provide a full picture of how marsh habitats are affected by changing water levels across the United States.

Sentinel sites make the Reserves an attractive test bed for UAS operations, specifically in terms of their application for vegetation, water, and elevation monitoring in coastal habitats. [4]

1.5 NOAA Resources

Being a part of NOAA facilitates access to resources beyond those that can be provided by local organizations. These include mapping skills, training programs, operational and communication support, and dedicated science project funding. Availability of these resources also make the Reserves valuable to local or regional partners as well. The following are NOAA offices and programs that routinely assist the Reserves with UAS project support.

Office for Coastal Management (OCM): OCM is part of NOAA's National Ocean Service. A major priority for OCM is habitat and community resilience. This includes all levels of government as well as non-profits and scientific communities. OCM administers the Reserve System and provides resources such as funding, tools and expertise.

UAS Program Office: The UAS Program is part of NOAA's Office of Oceanic and Atmospheric Research (OAR). The UAS Program Office explores and assesses UAS observations as an essential component of the NOAA observing system. UAS have advanced NOAA's ability to monitor and understand the global environment by complementing observations from satellites, ships, aircraft, balloons, and surface-based sensors. Better data and observations improve understanding and forecasts, save lives, property, and resources, advancing NOAA's mission goals. The UAS Program Office continues to examine how unmanned systems can safely, effectively and economically collect data in a more environmentally friendly manner. [5]

Cooperative Institutes: The NOAA Cooperative Institutes are partnerships of academic and non-profit research institutions. They support NOAA's Mission Goals and Strategic Plan by providing research support services outlined in their agreements. Cooperative Institutes are located throughout the U.S. Currently, NOAA supports 16 cooperative institutes consisting of 42 universities and research institutions across 23 states and the District of Columbia. [6] The Northern Gulf Institute is a Cooperative Institute who is involved in Gulf of Mexico activities and partnered with Grand Bay NERR to accomplish the proof-of- concept missions flown across that Reserve in 2015.

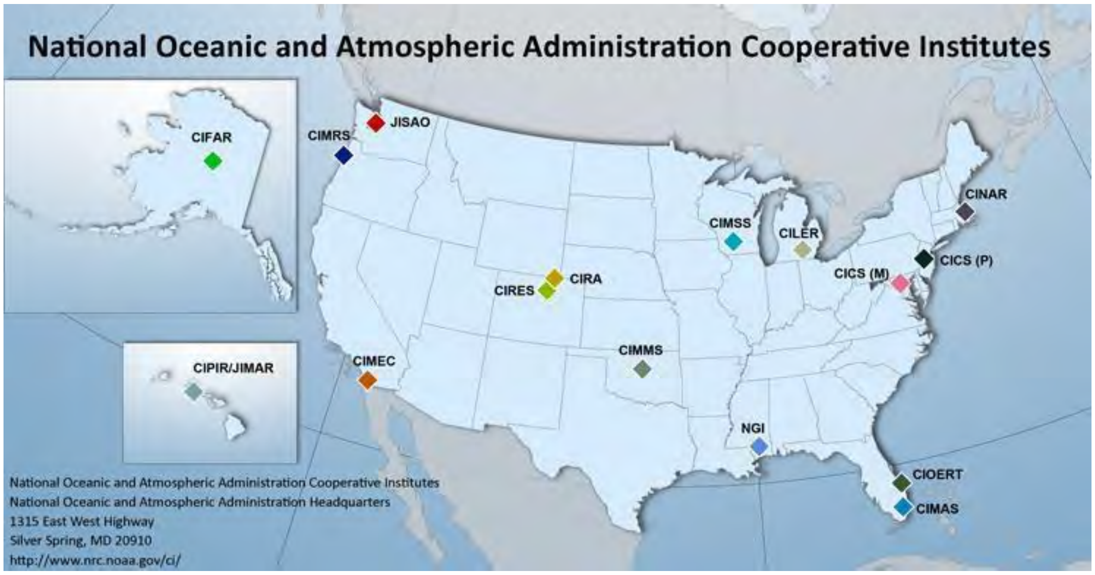


Figure 1.6 Location of NOAA Cooperative Institutes [6]

1.6 Current NOAA Projects

Consolidated Operations Center: NOAA's UAS Project Office is exploring the feasibility of developing Consolidated Operations Centers where Inter-Agency Agreements could be produced and resources pooled to maximize technology efficiency.[7]

This project could achieve several benefits for the Reserve System including establish a pool of assets for Federal (including NERRS) UAS use, including platforms, sensors, personnel, analytical assets, strategic operating plans, lessons learned and an established framework of consistent policies across organizations

This centralization model could be adapted for Reserve use by developing *regional* operations centers with their affiliated partners. Consistent policies would enable comparison of results across the Reserve System. Pooling assets and personnel resources lifts the infrastructure burden off of any one Reserve. Funding opportunities would be enhanced by showing cooperation between multiple types of organizations including federal, state, educational and nonprofit organizations. These strategies would help achieve a shared vision and realize the full potential of unmanned systems at an affordable cost with improved efficiency and assured safety of operations. [7]

More NERR resources can be found in Appendix A.

Section 2: UAS Elements, Mission Planning and Risk

Understanding the basic elements of a UAS is an important first step in integrating UAS technology into the Reserve System. Each element is integral to the total system and all must work in unison to ensure a successful flight.

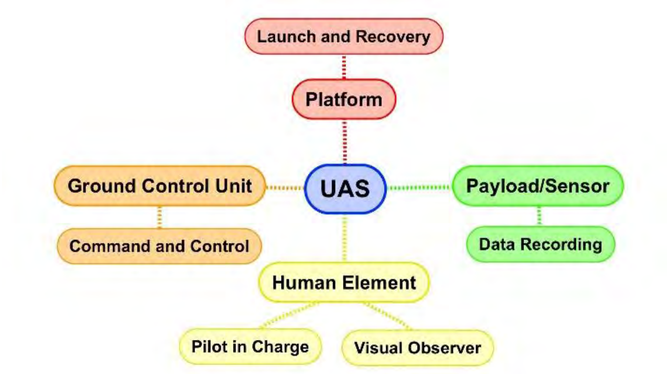
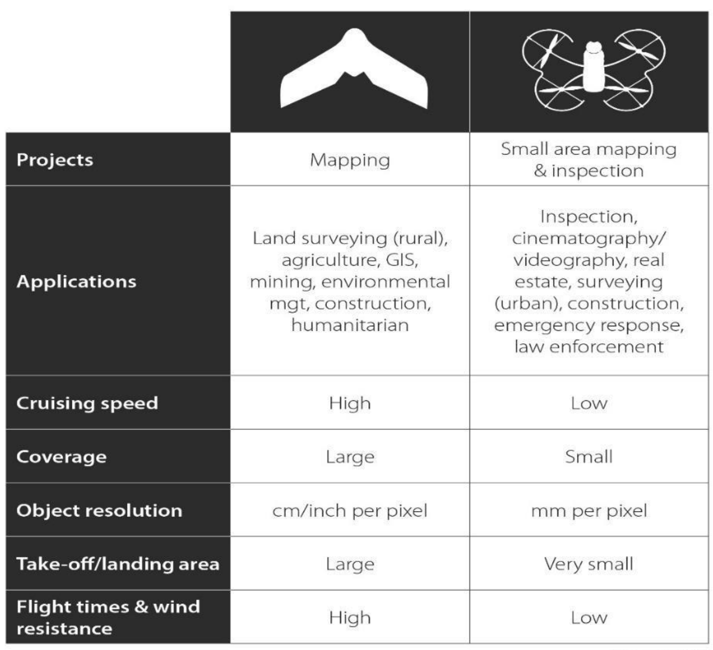


Figure 2.1: Elements of an Unmanned Aircraft System [8]

2.1 Platforms/Sensors

The aircraft that actually perform the flight are referred to as platforms and come in two basic types: fixed-wing platforms which are similar to traditional planes and rotary platforms which have multiple blades that rotate either above or below the platform. The platforms are powered by a single or multiple motor(s) which can be powered by either gasoline or electric batteries.



	Fixed wing	Rotary
Projects	Mapping	Small area mapping & inspection
Applications	Land surveying (rural), agriculture, GIS, mining, environmental mgt, construction, humanitarian	Inspection, cinematography/ videography, real estate, surveying (urban), construction, emergency response, law enforcement
Cruising speed	High	Low
Coverage	Large	Small
Object resolution	cm/inch per pixel	mm per pixel
Take-off/landing area	Large	Very small
Flight times & wind resistance	High	Low

© senseFly 2015

Figure 2.2: Fixed Wing vs Rotary UAS [9]

The platforms carry a variety of components that enable the aircraft to stabilize itself in the air, establish its location on earth and communicate information to the pilot. Some platforms carry additional components that enable various degrees of automated flight. Platforms come in a variety of sizes from palm sized to the size of jumbo jets. [2] Besides traditional types of sensors (cameras, LiDAR,…), a vast array of other direct sensors are being developed and deployed such as thermal imaging, radiation detectors, and air sampling devices. [1]

2.2 Human Element/Ground Control Unit

The ground-based pilot is in charge of the flight of the platform and the operation of the sensor. The pilot is ultimately responsible for maintaining a safe flying environment and must be able to make quick decisions when potentially hazardous situations arise. [1]

Communication between the platform and the pilot on the ground is accomplished using a ground control unit. It is the communication link between the pilot and the on-board flight control unit of the aircraft which manages the altitude, direction and movement of the aircraft. Pilots must ensure that open channels of communication are maintained with the aircraft at all times. Loss of communication between the pilot and the aircraft is a major safety hazard and standard operating procedures (SOP) must be in place to deal with such emergencies if they should arise. [1]

Figure 2.3 Ground Control Unit of the quadcopter Yuneec Q500 [10]

Certain UAS models can fly pre-determined routes autonomously. According to current regulations, the pilot must always have the UAS in visual line of sight and be able to re-take command of the UAS if a potentially dangerous situation occurs. [1]

Maintaining situational awareness is the **number one priority of the pilot** along with any visual observers aiding the pilot. It is the primary means of ensuring a safe flight for everyone regardless if they are on the ground, in the air, involved in the flight or not. [5]

2.3 Cost Benefit Analysis

Determining cost comparisons between manned and unmanned aircraft flights is not as straightforward as it might seem because of two reasons. First, there are no standardized ways of calculating total costs for flights, and second, the cost-benefits vary based on a number of factors such as the scale of the operation and data requirements. [11]

Some of the benefits of using UAS as compared to manned flights include:

- Ease of access on short notice
- Ability to fly at lower altitudes
- Acquisition of higher resolution data
- Reduction of pilot risk in hazardous areas (e.g. wildfires)
- Ease of launch and retrieval
- Capability of real time data transmission
- Maneuverability [1]

The Bureau of Land Management (BLM) has used a variety of manned and unmanned data products to accomplish its Sandhill Crane population survey. Landsat was useful for regional surveys but its 30 m resolution was not adequate for local surveys. Manned aerial flights could bring the resolution to 1 m but could only afford to be flown every three years. Recently, BLM flew UAS missions and achieved centimeter accuracy for local surveys. [11]

Sandhill Crane Population Survey Costs	
Government Manned Aircraft (direct costs only)	$4,300
Contracted Manned Aircraft	$35,000
Unmanned Aircraft	$2,600

Table 2.1 Cost Benefit Analysis [5]

In this instance, the cost benefit of using UAS is quite significant [8]. But if the mission area is overly large, multiple small UAS flights would be needed to cover the same area that a manned flight could cover in a shorter amount of time. If a larger UAS platform was used, its costs may be comparable to manned flights. As more UAS missions are flown commercially, the price per hour or per acre is anticipated to decrease. [12]

When planning UAS projects, many factors should be considered to find the most cost effective way to achieve the project's objective. UAS are better suited to certain missions such as low altitude, high resolutions flights and small geographic areas. They are not meant to supplant all manned missions, but to compliment them when the benefit is greater. [12]

2.4 Mission Planning Overview

In order to assure the success of any UAS mission, operational planning is critical. It provides an opportunity to ask fundamental questions about the feasibility of a project.

- Can the required data be acquired with a UAS and operator available to your Reserve?
- Does the organization or partner have access to the necessary airspace, including the airspace required to *get* to the area of interest?
- Is that airspace regulated or restricted?
- What resource allocations (personnel, funding, support...) are needed and by when?
- Are skills available on-site to process the high-resolution data that will be acquired?

NOAA's UAS Program Office has developed a protocol for initiating UAS projects that involves a series of Key Technical Reviews. These reviews outline project proposal, flight execution and post-mission analysis. [13]

Parts of an initial proposal include the following sections:

1. Project Abstract - Describes the project plan (less than 500 words). The project abstract should include: objectives and benefits, an outline of the proposed work, the period of performance, Area of Interest (include a map).

2. Project Objective – Describes the project's statement of work that concisely defines tasks or milestones to be accomplished, the success criteria associated with each task, and possible partners for the project.

3. Expected Significance – Describes the expected significance of the project to the specific Reserve's Strategic Plan and/or the NERRS Strategic Plan. How will this project help achieve these organizations missions?

4. Deliverables **–** Describes the expected end products for the Reserves. The more details included the easier the initial mission planning will be. Details include type of data, area of interested, timing (season, tidal stage…), and accuracy of data.

The ability of a Reserve to write a basic UAS project proposal is a valuable asset. Reserves would benefit by developing a specific proposal for a variety of possible projects that could benefit from UAS-derived data. The Reserve would therefore be ready with a basic project proposal when partnership or funding opportunities arises.

2.5 Risk and Liability

Safety considerations are the number one hurdle facing UAS integration into the National Air Space System. Flight safety is determined at multiple levels, from the creation of standard operating systems, to ensuring the pilot has the appropriate knowledge, skill, and credentials.

If there is weakness in any one layer, the other layers help to mitigate it. But when there are multiple weaknesses in a program, these "holes" can ultimately line up to allow a potential hazard to progress into an unsafe situation. [1]

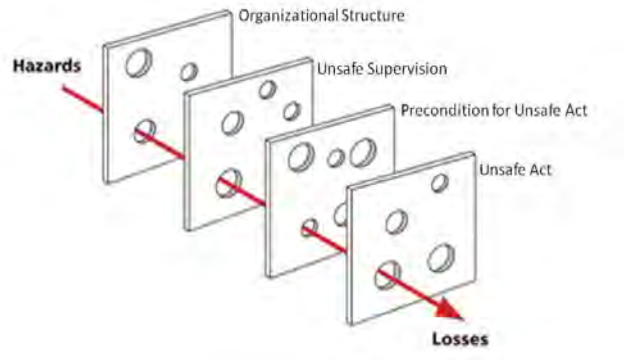


Figure 2.4: Swiss Cheese Model of Accident Causation [14]

Anytime objects leave the ground, their return is guaranteed. What is not guaranteed is the circumstances *surrounding* that object's return. Identifying possible hazards that would affect a UAS safe return to the ground is the first step to minimizing exposure to risk. This risk extends to other airspace users such as manned aircraft, as wells as the lives and property of people on the ground. The understanding of this risk cannot be overstated. [12]

Hazard assessment can be applied to each phase of a UAS mission: planning, staging, launch, flight and recovery .The goal is to mitigate any identified hazard which will then reduce or eliminate the exposure to that risk. [12]

Any accident involving damage to property or injury to a person from the use of a UAS needs to be reported to the appropriate authorities as soon as possible. Pre-knowledge of the contact information for this resource in each Reserve's local area is vital. Reserves should check with local FAA representative to find this contact information.

The need to get *all* UAS users moving toward the same safety standards is one of the major current challenges of the industry. The Reserve System could play a major role in this education effort by emphasizing the need to lead by example.

No discussion about risk can be complete without a discussion about liability which deals with who is the responsible party for a UAS flight. Ultimately, liability for any accident lies with the owner of the aircraft. [1] The responsible party needs to be identified before the first UAS is flown for any Reserve in the system.

One way to deal with liability issues is to carry UAS liability insurance. It is different than policies that only insure the cost of the UAS. Liability insurance is beginning to become available through a number of insurance carriers. Links to more resources are included in Appendix B.

Section 3: UAS Applications for the NERRS

In December of 2014 an ad hoc Reserve System UAS Working Group assembled on a conference call to discuss the possibility of deploying UAS technology at the Grand Bay Reserve in Moss Point, Mississippi. The group was made up of representatives from NOAA UAS Program Office, Northern Gulf Institute, Mississippi State University, NOAA Office for Coastal Management, Grand Bay Reserve, and Wells Reserve. The purpose was to demonstration natural resource applications of UAS technology and to enhance habitat mapping, long term monitoring, fire management and disaster response projects. Over the next three months, mission objectives were discussed, Key Technical Reviews were produced, necessary clearances from the FAA were obtained, and the appropriate UAS technology was identified. Below is a timeline of important team communication and missions performed to date.

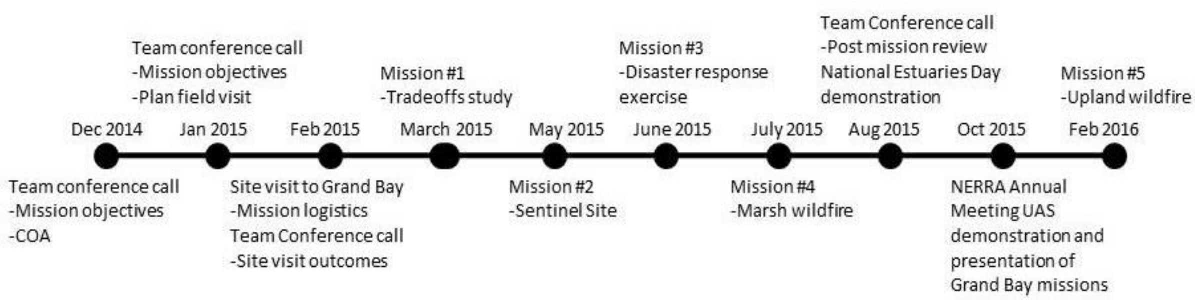


Figure 3.1: Timeline of Grand Bay NERR UAS Projects [15]

3.1 UAS Missions

Five separate UAS missions were accomplished spanning a variety of mission objectives and utilizing an assortment of platforms and sensors. These missions helped answer the following questions:

- What was the best platform to gather high resolution data for habitat mapping?
- What was the extent of a lightning-caused wildfire?
- How could baseline and future aerials be obtained to document best management practices using a controlled burn?
- What effect would a (simulated) chemical spill from an abutting phosphate plant have on the bay?

3.2 Lessons Learned

Planning: Planning for field visits to work through the logistics of the mission (launch/landing sites, land or water access, etc.) was essential. These included having a clear plan for the actual mission day (estimated time of each flight, travel time, weather, tides, etc.) Having a process in place for data management including where the final imagery will be stored and how it will be backed-up. Thinking through the entire process of deploying a UAS and making a plan will help make the mission a success. If you fail to plan, you plan to fail.

Flexibility: While planning is critical, remaining flexible is also necessary. With any field work, it is normal to run into problems. Equipment malfunctions, accessibility issues, weather, and unpredictable events are things that should be anticipated and contingency plans should be in place. Remaining flexible and anticipating (as much as possible) these hiccups can make the UAS mission a success. Suggestions include allowing for extra time out in the field, having alternative dates available for the mission, bringing back-up equipment, and maintaining a positive attitude.

Communication: Clear communication is a necessity for successful UAS missions. The ability to clearly communicate data needs and project objectives is vital to meeting the goals of the mission. Understanding what imagery specifications are required for analyses and clearly communicating requirements with the UAS team or vendor will ensure useful imagery is delivered. Communicating throughout the planning process, as well as after the mission will increase mission success and help identify improvements for future missions.

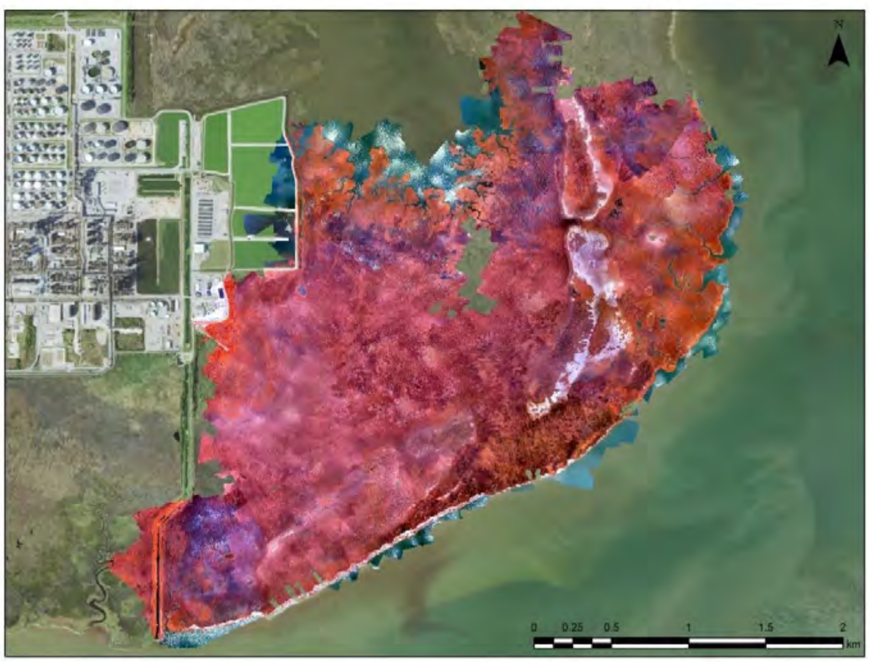


Figure 3.1 Post-Processed Image of the Grand Bay NERR Wildfire [15]

The diversity of partners associated with this case study and the resulting valuable lessons learned paved the way for a NOAA grant to have three more Reserves projects flown within the next two years. A complete description of the Grand Bay flights along with a bibliography of peer-reviewed journal articles focusing on other natural resource projects utilizing UAS technology can be found in Appendix C**.**

3.3 NERRS UAS Program Development

One of the major decisions about the use of UAS technology facing Reserves is whether to :

- Develop and operate their own UAS program and post-process their data in-house
- Contract these services from outside providers
- Partnering with state or regional organizations that have established UAS programs. and possibly use NOAA resources to assist in post-processing and analyzing the data

The table below is a concise view of the resources needed to fly UAS in the National Airspace System. Items are subject to change as new regulations emerge, but the basic sections will be required in some degree.

Table 1. Steps in order to fly in the National Airspace System Under FAA Regulations.
1. Qualifications, Exams, Training
• FAA Ground School (for external and internal pilots) • Special observer training • Second class or higher FAA airman's medical certificate • FAA Private Pilot's License (Pilot-in-Command) • Radio control training and experience (External Pilots)
2. Application for Certificate of Authorization (COA) • Ownership of UAS by public government entity • Manufacturer training on UAS operations and maintenance • Submit COA application with a 3-6 month waiting period (http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/uas/coa/)
3. Flying the UAS • Receive COA and fly according to all specifications in COA • Pre-flight planning to - establish home location coordinates for use after launch and in case of loss of link to UAS - establish flight pattern for travel to and from test site and for photography over test site with desired forward and sidelap - establish landing flight pattern - locate observer positions and road blacks during flight pattern - establish evasive maneuver protocol if air traffic approaches flight area • **Flight Mission** - issue Notice to Airman (NOTAM) 48 hours before flight - contact local designated FAA office to provide flight details - check for any frequency conflicts in area of the flight - provide radio broadcasts on day of flight to inform manned aircraft of UAS flight - conduct flight crew briefing before flight and de-briefing after flight - conduct airplane and control center checklists - launch UAS, upload flight plans, acquire photography, and land UAS
4. Documentation • File incident reports, if any, with FAA • Update log books and keep complete records

Table 3.1 Flying in the National Airspace System [21]

3.4 Local Use Protocol

One last issue concerning UAS flight over Reserves concerns local use protocols. For instance, can recreational or commercial operations launch flights within Reserve boundaries without permission? What is the protocol for researchers to fly over the Reserve? Who has management authority over different parts of the Reserve and do they have their own protocols already in place?

The National Park Service [15] and US Fish and Wildlife Service[17] already have nationwide protocol in place pertaining to flying UAS over their land. The same is true for many state park and recreation areas.

Figure 3.2: National Park No Drone Zones [18]

Knowing who has local protocols and what the procedure is to obtain flight permission will aid in mission planning. It will also help visitors understand what rules apply for both recreational and commercial flights. All UAS flights regardless of location require pilots to obtain landowner permission, but this is often overlooked on public lands.

The Aeronautical Modeling Association (AMA)[19] and UAS industry leaders [20] have developed codes of conduct that are steering all classes of UAS flyers toward responsible and ethical use of these aircraft. Self-regulation as an aviation community will enable this new industry to achieve its full potential to benefit both society and the natural world.

To aid Reserves in deciding whether or not to develop their own UAS program, a decision logic table as well as additional resources for this section are provided in Appendix D.

Section 4: Data

The central purpose for flying UAS missions is to collect remotely-sensed high resolution data over localized geographic areas. Identifying what data is most critical to Reserve programs is a necessary first step and was initiated through the data needs assessment discussed in the previous section. This section will goes into more detail about what data products are available, the workflow associated with data collections, and suggested procedures for long term large database management.

4.1 Data Cycle

There are several steps in planning for data acquisition that need to be considered for execution of a successful project:

1. The need data has to be clearly articulated and the data requirements and collection methods need to be defined. This part of the planning process addresses questions such as:
   - What accuracy of data is needed to meet the project objectives?
   - What seasons, time of day, or tidal cycle need to be captured by the data?
   - What is the optimal data collection strategy for acquiring the data?
   - What sensor or combination of sensors is best to use?
   - What height should the platform be flown at?

2. Processing the data – consideration needs to be given to the methods of collection as well as assessing the accuracy of the imagery. Very high resolution imagery presents challenges to the development of spectral signatures and classification methods since the distinctions between habitats are not as clear as in a lower resolution image.

3. Analysis and dissemination– this step is where a final map or derived product is produced and the imagery and/or derived products are made available. End-user feedback is an important step in this process. This process allows Reserves to be discerning end-users and improve the process for all future projects through Reserve feedback.[22]

4.2 Raw Data

Examples of raw data products include:
- Light Detection and Return (LiDAR)
- Aerial imagery including multispectral (3 band, 4 band, multiband) natural color, infrared (IR), color infrared (CIR), shortwave infrared (SWIR) and near infrared (NIR), Video
- Keyhole Markup Language (KML) (used in Google Earth)[1]

Examples of products derived from raw data include:
- Normalized Difference Vegetation Index (NDVI)
- Orthophotographs
- Digital Elevation/Surface/Terrain Models (DEM/DSM/DTM)
- 3D image models [1]

Along with downloading and storing the data, real-time data transmission offers the ability to use the data directly, such as in search and rescue missions, or post-disaster assessments. [1]

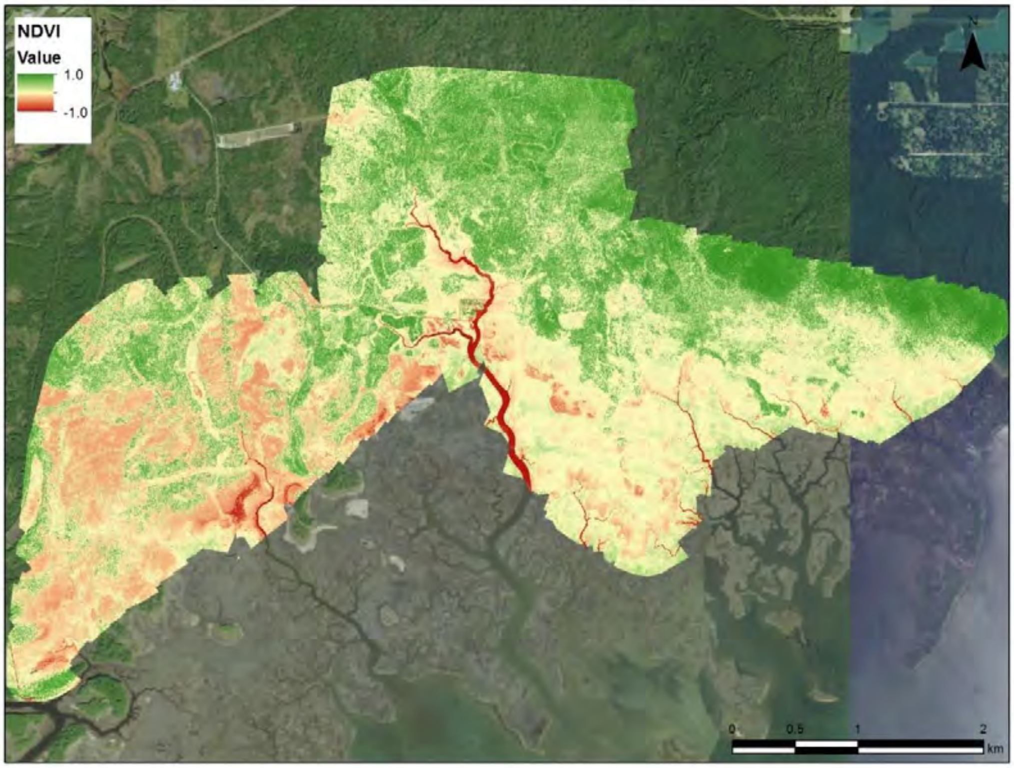


Figure 4.2: Normalized Difference Vegetation Index derived from wildfire imagery collected at Grand Bay NERR. [15]

4.3 Managing Large Data Sets

The United States Geological Survey (USGS) has been the forerunner in developing a UAS program that supports a variety of missions within the Department of the Interior. They have led the way in “safe efficient, cost-effective and leading-edge adoption of UAS technology.[21] USGS has also developed a protocol for managing the resulting large datasets produced from UAS missions.

Following the USGS best management practices for archiving and distributing information obtained through UAS missions ensures that data generated during the project and the associated documentation is safely stored, easily retrieved and able to be distributed. A standardized directory structure both within individual Reserves and across the Reserve System facilitates easy access to raw and derived data, metadata and project mission information. [22]

One of the advantages of using UAS is that multiple missions can be flown over a project area with ease. Having logical data management structures for imagery obtained by UAS is especially important for projects that involve several missions. A sample directory structure and reviews of processing software are included in Appendix D.

Section 5: UAS Regulatory Environment & Strategies

In the United States UAS regulations fall into two basic categories: those that regulate safe flying in National Airspace System and those that concern the safeguarding of privacy. Both of these regulation categories are in flux due to the rapidly changing technology as well as political, commercial and social pressures. It is important for Reserves to understand the drivers behind the regulations in order to assure compliance of UAS missions. Reading and understanding this section will help answer the common question: *"Why can't I just go buy a drone and fly it on my Reserve?"*

5.1 Understanding the National Airspace System

The basic regulations that allow thousands of manned aircraft to be in the air at any given moment revolve around aviation rules. These rules are meant to avoid collisions and maintain safe operations of all aircraft. [12]

For aviation purposes, there are two types of airspace controlled by the FAA: the National Airspace System, and another set of airspace known as Restricted, Prohibited or Warning Area Airspace. This last zone of airspace is specially designated areas such as the airspace over the Whitehouse or over US Fish and Wildlife Refuges.

The National Airspace System is divided into sections both vertically and horizontally. It is important to know the class airspace above a Reserve's area of interest because different rules and restrictions apply to each class (Class A-G). [23] There are several websites and apps that help UAS flight planners and pilots determine the airspace above their area of interest. These are listed in Appendix E.

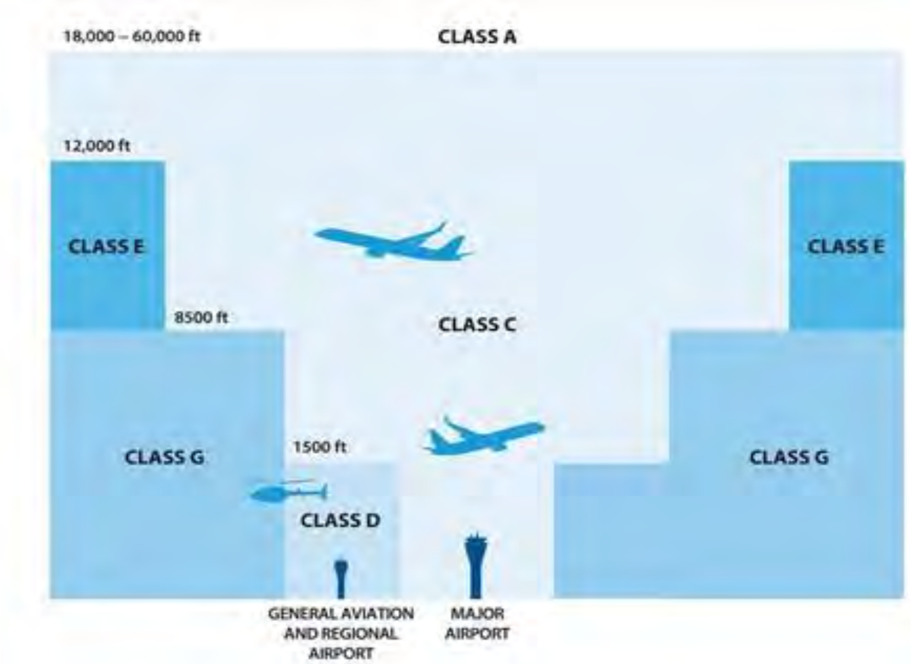


Figure 5.1: Examples of Airspace Classes [12]

Classes A-E are *controlled airspace* and rely on the ground-based coordination of Air Traffic Control personnel. Class F (not shown in diagram) is *restricted* (or *prohibited* or *warning* areas) and Class G is *unrestricted* which means it is not under the control of ATC personnel.

All of these classes have both a geographic component (distance away from the airport on the ground) and an altitude component (aircraft height above the ground) relative to some ground based object such as an airport.[4] When temporary events that affect airspace are happening in various geographic or altitudinal areas, pilots are required make other aviators aware by issuing a Notice to Airmen (NOTAM). Skyvector.com is a website that is used to find NOTAMS in an area of interest.

These FAA regulations address major safety concerns such as collision avoidance, aircraft safety, lost communication and pilot skills and experience.[1] In addition to regulating airspace, the FAA also has regulations for the pilot and aircraft, which include pilot certification and aircraft maintenance logs. [12]

5.2 Know Before You Fly/UAS Registration

To give UAS pilots a better understanding of current policies, the FAA has partnered with several industry leaders in developing a training program and a web application to promote safe and responsible use of unmanned aircraft. The *Know Before You Fly* educational campaign and web application will assist pilots and potential UAS users in getting acquainted with aircraft requirements, airworthiness, air space and pilot requirements. The website is based on three distinct classes of UAS operations: Recreational Model Aircraft users, Civilian Commercial users, and Public/Governmental users.[23]

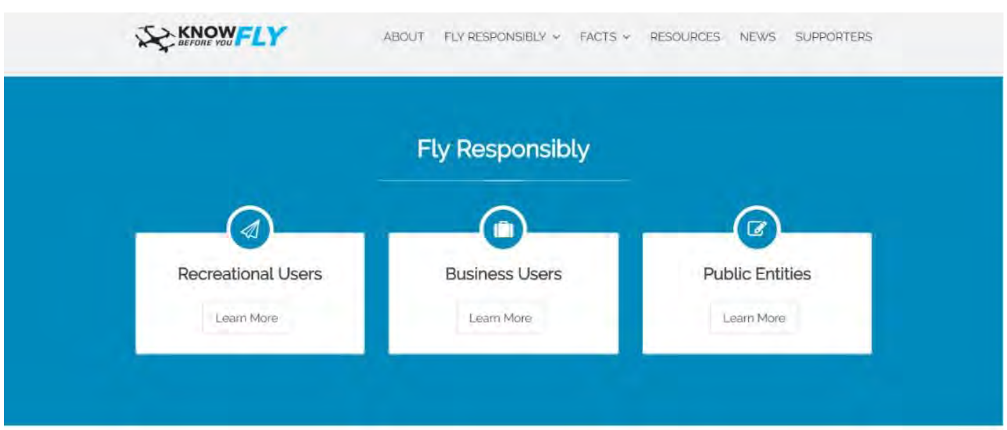


Figure 5.2: Know Before You Fly Campaign [30]

Recreational Model Aircraft Users: FAA does not have regulatory authority over recreational use of UAS. These aircraft are flown strictly for hobby/recreational purposes. This is an important and often debated distinction. The Academy of Model Aeronautics (AMA) is a long-standing nationwide organization that promotes community-based model aircraft use. The AMA has developed its own safety code and safety guidelines. [24] This organization is an effective advocate for the continued ability to self-regulate their own aviation community. Still, in 2015, the FAA issued an Advisory that outlines criteria to be considered in model aircraft use.[5] The full AMA safety code can be found in Appendix F.

Note on Recreational Flights and Imagery Use**:** Imagery acquired by a recreational flyer and donated to the Reserve for no cost is a very gray area. Further investigation is needed if the imagery is planned to be used in research publications or management plans.

<u>Civilian Commercial UAS Users</u>: June 21, 2016 was an historic day for the UAS industry. The FAA released a set of long-awaited small UAS rules (under 55 pounds). These rules are known as Part 107 rules, meaning that they can be found in the FAA Regulation 14 CFR in Part 107.

The major highlights of these new rules are that they streamline the process to use small UAS for commercial operations without the need to apply for a Certificate of Authorization (COA) or an exemption from a COA known as a 333 Exemption. These new rules also significantly modify the requirements for the UAS operators.

The new rules outline certification processes for UAS operators to obtain a "Remote Pilot Certification with a sUAS Rating". This means that the remote pilot has to pass a sUAS Airman Knowledge Test, be vetted by the TSA and pass a recurring test every two years. The pilot self-certifies that they are medically qualified to fly the sUAS without the requirement for an official medical certification. The rule also indicates that a non-certified person can actually operate the controls of the sUAS as long as they are under direct supervision of a certified sUAS pilot.[31]

Currently, the FAA is also considering the possibility of new rules for "micro-UAS" that would weigh under 4.4 pounds. These additional new rules also includes a discussion about flights over people not directly involved in the UAS mission.[31]

<u>Public/Governmental UAS Users</u>: This group of users are granted Certificates of Authorization (COA) to fly on a case by case basis. The COA application requires details about the UAS, where it will fly, what altitude, operations requirement and pilot and observer qualifications. The FAA currently requires the pilots to be licensed pilots.

Note on Public Entities and Part 107 Rules**:** The debate on whether Public/Government uses can fly UAS under the Part 107 rules is yet to be decided at the time of this writing. This is a critical part of the UAS puzzle for the Reserve System and more information will be distributed to the Reserves as it becomes available.

Links to more resources are included in Appendix E.

A final FAA requirement is to register each UAS that weighs from .55 pounds to 55 pounds. Registration can be accomplished through a website and costs a nominal amount. Once a registration number is received, that number is required to be displayed on the UAS in the largest way that is practical.

Figure 5.3 Registration process for UAS between .55 and 55 pounds registermyuas.faa.gov [18]

5.3 Privacy Regulations

Privacy, civil rights and civil liberty issues surrounding the use of UAS in national air space is fraught with emotional pitfalls. One reason that this issue is difficult to define is that it is entangled in a multitude of other privacy rights issues such as constant public surveillance (e.g. traffic cams, bank camera…). Meanwhile, state legislators haves been engaged in developing an assortment of bills relating to UAS integration and privacy issues. [34] Currently 35 states have bills pending dealing with UAS privacy issues. [25]

Figure 5.4: States with current bills concerning UAS (Blue= automated ground vehicles legislation Green=UAS legislations) [25]

It is important for Reserves to keep informed about state legislation for several reasons. It will facilitate mission planning efforts with potential partners from all levels. Also, a major part of the Reserve System's mission involves public outreach and stewardship. The Reserves can play a vital role in educating the public on the beneficial uses of this new technology.

Recommendations for the NERRS and OCM

- Adopt the ***Code of Conduct*** available in Appendix A and post to your website
- Establish on-site flight protocols for areas within the Reserve boundary, especially for visiting researchers.
- Ensure all pilots fly in accordance with applicable rules.
- Keep up to date with state legislation regulating UAS technology
- Establish effect data management protocols
- Investigate partnerships with NOAA Cooperative Institutes or university systems with UAS programs
- Initiate a relationship with the local Emergency Managers and First Responders
- Understand the National Airspace System classes over each Reserve (www.airmap.com)
- Help educate the next generation of resource managers about UAS technology for natural resources and the regulatory environment surrounding UAS use
- Consider using inexpensive training models of UAS before investing in costlier ones
- Develop draft mission planning proposals for potential projects in preparation of partnership and funding opportunities.
- Have local, regional and national conversations about societal benefits of UAS technology.
- Be part of the self-regulating movement in which organizations develop upfront privacy impact policies to address social and ethical issues of UAS use
- Establish/support a UAS working group and list serve so that new industry and research information can be assessed and distributed in a timely manner
- Ask the question- “What *should* UAS do?” Instead of what *can* UAS do?

Conclusion

The vision of the Reserve System is to have healthy coastal habitats and thriving coastal communities. All are under threat from a variety of forces and the rate of change continues to increase. Remote sensing images help answer critical questions about changing coastal environments.

Traditionally acquired remote sensing data provides reliable data that works well on a regional scale. But local questions need to be answered at smaller scales. These questions demand higher accuracy and more flexible timing than is traditionally available. Unmanned Aircraft Systems fit this bill perfectly. The National Estuarine Research Reserve System and their partners are strategically placed to deliver critical data to coastal decision makers.

The initial question posed at the beginning of this roadmap was: Does the benefits of using UAS technology outweigh the costs. This includes not only considering the upfront cost of unmanned aerial vehicles, but also considering the hidden infrastructure costs and the ability to accommodate the complex rules surrounding UAS technology use.

Using the resources presented in the roadmap, each Reserve now has the capability to make informed decisions about the benefits of UAS technology. Each Reserve is also situated to be a discerning, end-user of available data and also in requesting data. The key to optimizing the use of this resource will be in the collaboration of organizations. The Reserve System is uniquely position to do this well. As a starting point, these partnerships could include state or non-profit partners, commercial enterprises and NOAA Cooperative Institutes.

The next few years will see several more Reserves successfully partner with federal and state organizations to acquire UAS-gathered remotely sensed data.

- Jacque Cousteau NERR (NJ), Grand Bay NERR (MS), and San Francisco Bay NERR (CA) will all be flown in the next two years as part of a NOAA grant that will investigate using contracted UAS flights to deliver habitat and LiDAR data from a representative sample of each of those Reserves.
- Chesapeake Bay (MD) is being flown as part by a USGS mission that was slated to cover a nearby area.

Opportunities like these are going to be coming more rapidly and Reserves now have the knowledge and resources to be strategically placed to take advantage of them.

Like any emerging system, UAS technology is developing rapidly and chaotically. The benefit of using this technology for the NERRS is also unfolding at a similar pace. The sequence of system-wide progression over the past few years has been impressive, culminating in the production of this roadmap. Even though it is only a beginning, the National Estuarine Reserve System is well on its way and that way is forward.

Appendix A: NERRS Resources and Applications

<u>AUVSI "Code of Conduct":</u> [20]

Industry Code of Conduct

The emergence of unmanned aircraft systems (UAS) as a resource for a wide variety of public and private applications quite possibly represents one of the most significant advancements to aviation, the scientific community, and public service since the beginning of flight. Rapid advancements in the technology have presented unique challenges and opportunities to the growing UAS industry and to those who support it. The nature of UAS and the environments which they operate, when not managed properly, can and will create issues that need to be addressed. The future of UAS will be linked to the responsible and safe use of these systems. Our industry has an obligation to conduct our operations in a safe manner that minimizes risk and instills confidence in our systems.

For this reason, the Association for Unmanned Vehicle Systems International (AUVSI), offers this Code of Conduct on behalf of the UAS industry for UAS operation. This code is intended to provide our members, and those who design, test, and operate UAS for public and civil use, a set of guidelines and recommendations for safe, non-intrusive operations. Acceptance and adherence to this code will contribute to safety and professionalism and will accelerate public confidence in these systems.

The code is built on three specific themes: <u>Safety</u>, <u>Professionalism</u>, and <u>Respect</u>. Each theme and its associated recommendations represent a "common sense" approach to UAS operations and address many of the concerns expressed by the public and regulators. This code is meant to provide UAS industry manufacturers and users a convenient checklist for operations and a means to demonstrate their obligation to supporting the growth of our industry in a safe and responsible manner. By adopting this Code, UAS industry manufacturers and users commit to the following:

Safety

- We will not operate UAS in a manner that presents undue risk to persons or property on the surface or in the air.
- We will ensure UAS will be piloted by individuals who are properly trained and competent to operate the vehicle or its systems.
- We will ensure UAS flights will be conducted only after a thorough assessment of risks associated with the activity. This risks assessment will include, but is not limited to:

- Weather conditions relative to the performance capability of the system
- Identification of normally anticipated failure modes (lost link, power plant failures, loss of control, etc.) and consequences of the failures
- Crew fitness for flight operations
- Overlying airspace, compliance with aviation regulations as appropriate to the operation, and off-nominal procedures
- Communication, command, control, and payload frequency spectrum requirements
- Reliability, performance, and airworthiness to established standards

Professionalism

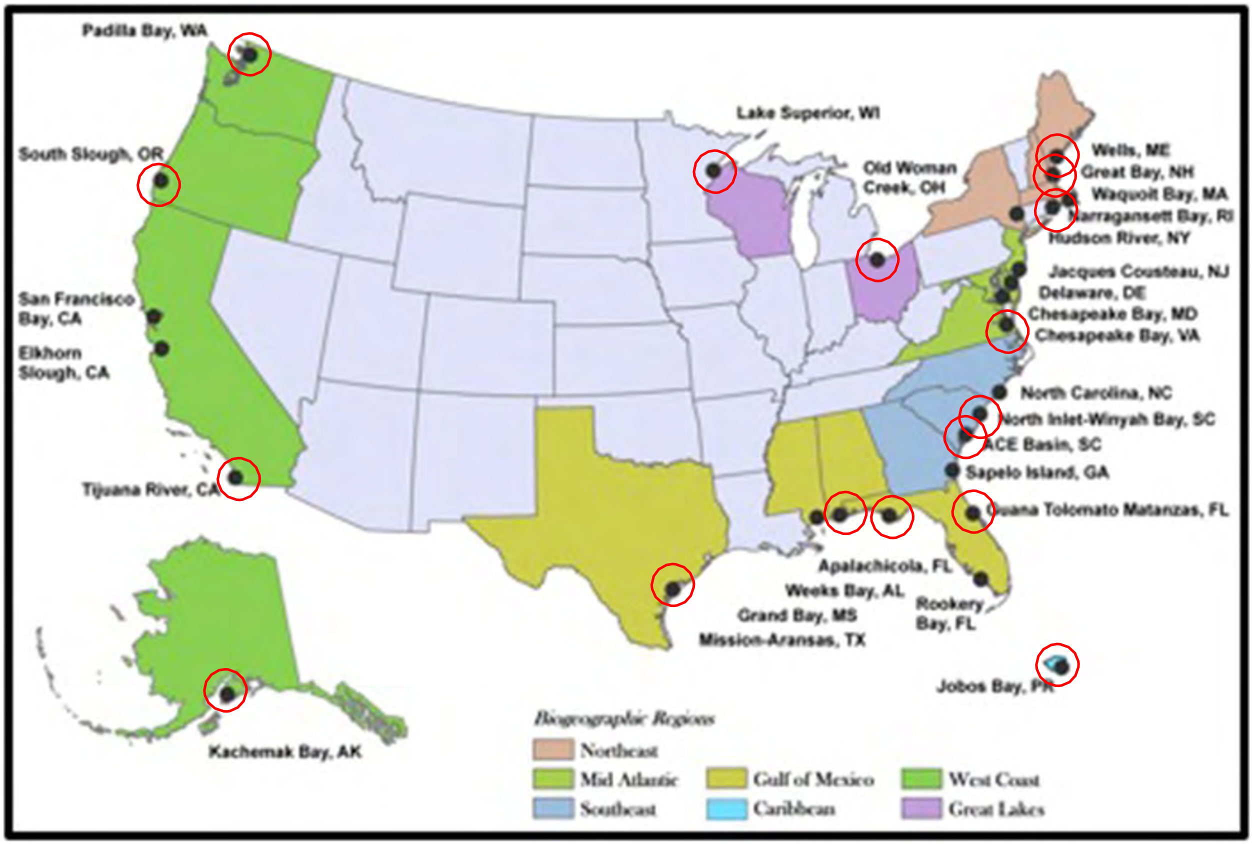
- We will comply with all federal, state, and local laws, ordinances, covenants, and restrictions as they relate to UAS operations.
- We will operate our systems as responsible members of the aviation community.
- We will be responsive to the needs of the public.
- We will cooperate fully with federal, state, and local authorities in response to emergency deployments, mishap investigations, and media relations.
- We will establish contingency plans for all anticipated off-nominal events and share them openly with all appropriate authorities.

Respect

- We will respect the rights of other users of the airspace.
- We will respect the privacy of individuals.
- We will respect the concerns of the public as they relate to unmanned aircraft operations.
- We will support improving public awareness and education on the operation of UAS.

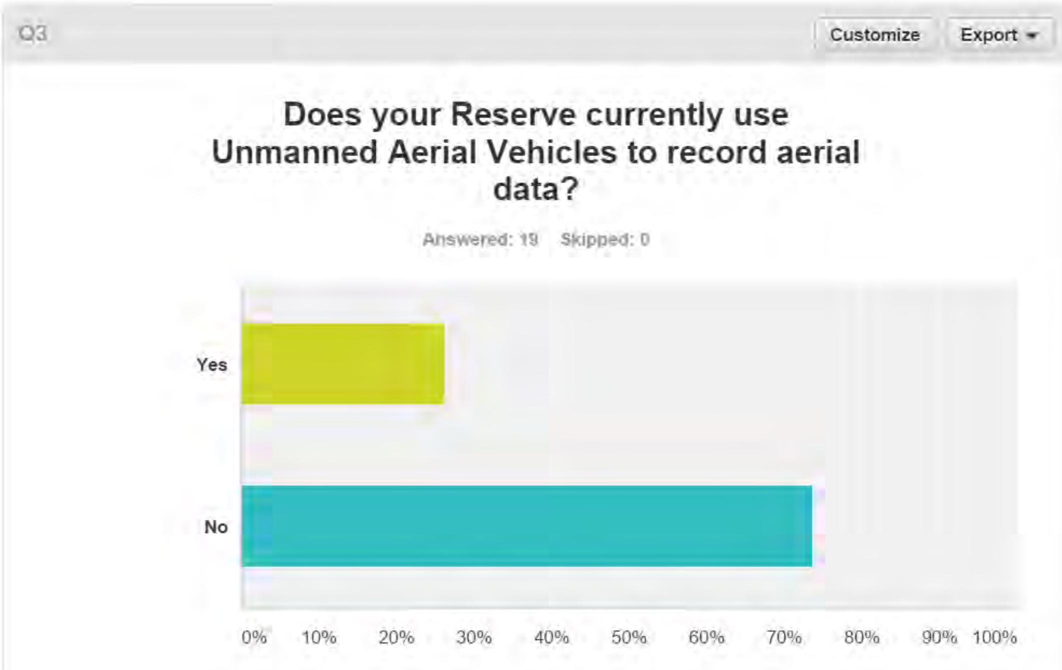
As an industry, it is incumbent upon us to hold ourselves and each other to a high professional and ethical standard. As with any revolutionary technology, there will be mishaps and abuses; however, in order to operate safely and gain public acceptance and trust, we should all act in accordance with these guiding themes and do so in an open and transparent manner. We hope the entire UAS industry will join AUVSI in adopting this industry Code of Conduct.

NERRS UAS Data Survey: This data needs survey was conducted through a Doodle Poll in the fall of 20015. Nineteen Reserves participated. The full report is included below. Another data needs survey is scheduled for FY 2017.



Respondents

Questions 1 and 2 were identifying questions asking for Reserve name and position. Screenshot of the Doodle Poll report are included for the rest of the questions along with additional comments provided by the respondents.

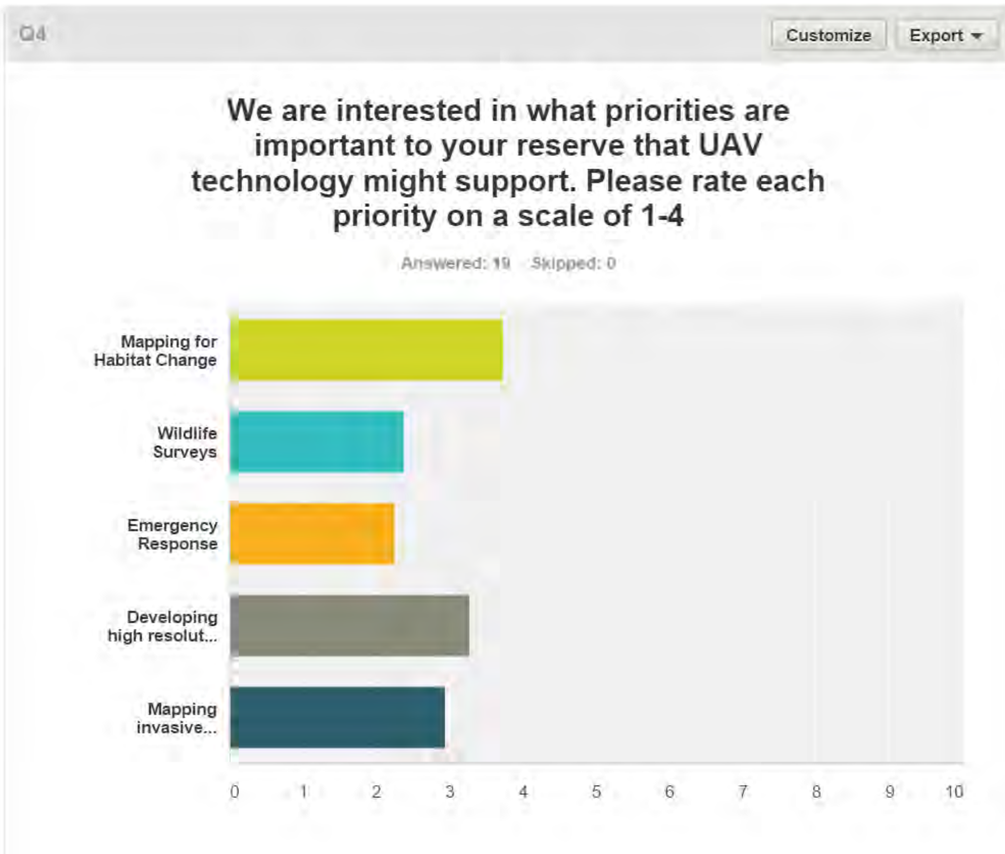


(NCNERR) But we are submitting a NOAA marine debris grant that incorporates UAVs in partnerships with Duke Marine lab's new UAV facility. There is still some hesitation by higher-ups to purchase UAVs for use in-house.

(CBNERR) However, there are groups we collaborate with at the Virginia Institute of Marine Science who have recently purchased UAVs. One group is actually doing a large watershed project (collecting multiple sources of information along with some data from UAVs) and another group has actually used our Goodwin Island component to field test their UAV and are currently working through challenges of getting a reliable DSM from the UAV (for which our on the ground vegetation data might be useful).

(WNERR) We fly recreationally and helped with a video for the Annual Meeting. I am seeking a 333 exemption so my pilot can fly missions for research and stewardship purposes.

(KBNERR) Only through collaborations with University of AK Fairbanks; sea otter forage observations (proof of concept) and our collaborators on a benthic long-term monitoring study have applied it to seagrass bed monitoring.



(OWC)We are planning to work with a university collaborator to use a UAV to map vegetation and shoreline erosion control structures along the Lake Erie shoreline.

(WBNERR) Would like to know how UAV can assist with high resolution DEMs (Digital Elevation Models).

(ANERR) UV's to map and monitor seagrass health and scarred restoration areas; erosion/elevation.

(WNERR) Ice coverage on marshes.

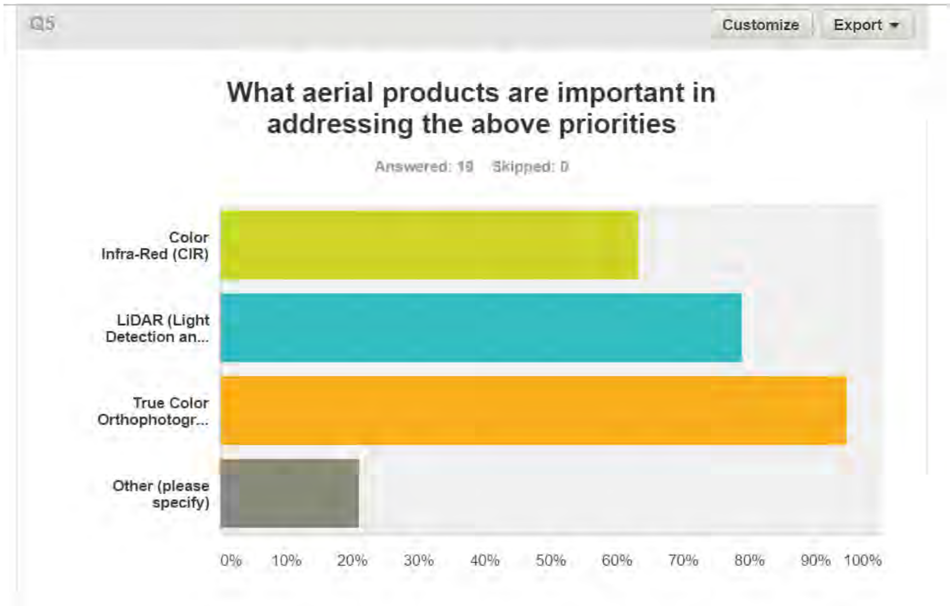
(WNERR)These could change if Rachel Carson Wildlife Refuge (owns most of our marsh) had other priorities.

(KBNERR) We are still working out the "bugs" for the best use of this technology at this point; wind, rain, personnel capable of operation, flight path restrictions and so forth for KBNERR.

(GBNERR) Assessing shoreline armoring/habitats and condition.

(JBNERR)Coral reef and sea grass beds mapping.

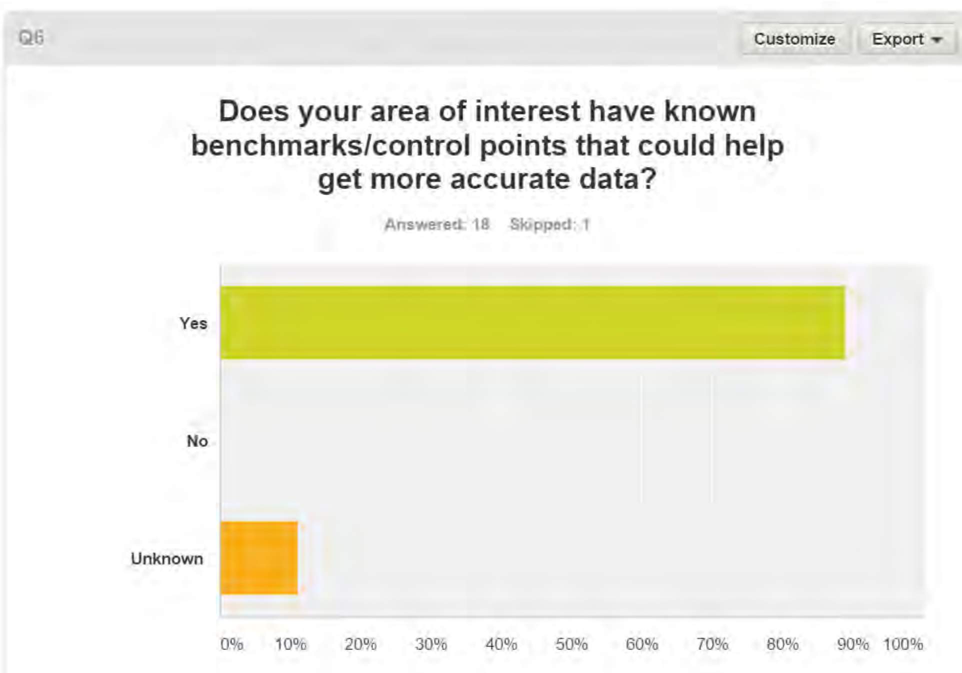
(LSNERR) Water quality: algae and sediment, also water temperature to identify groundwater upwelling areas.



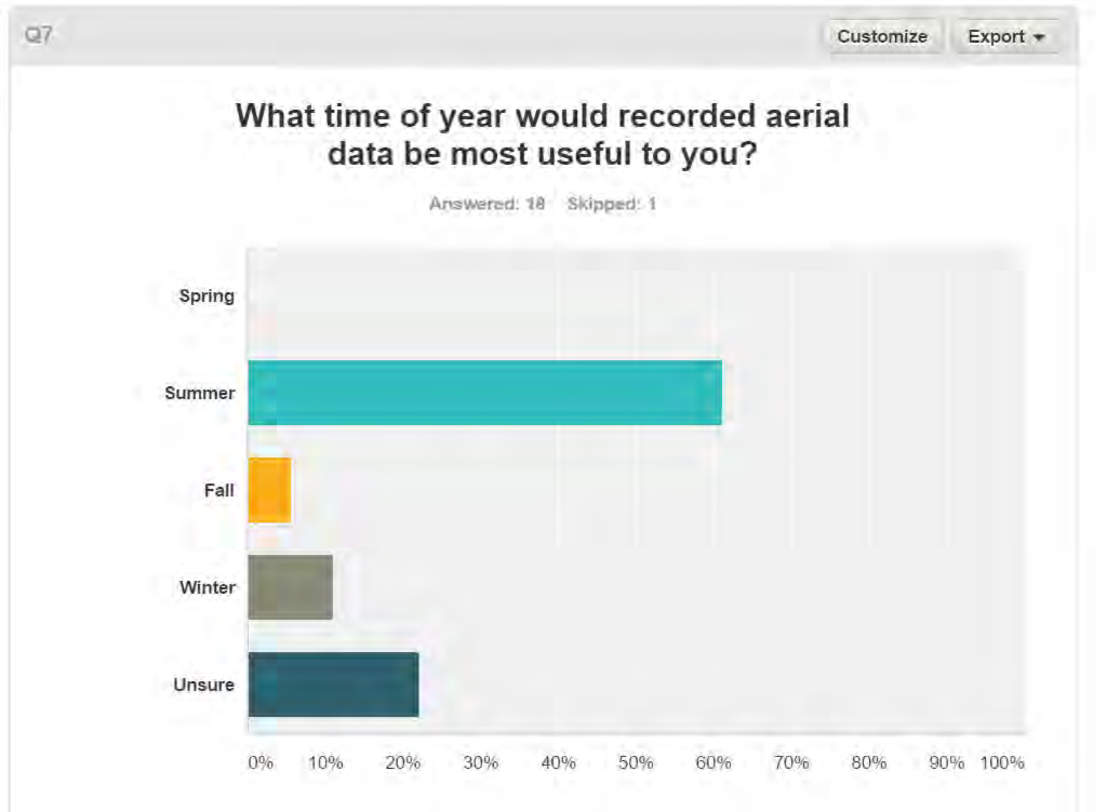
(WBNERR) Possibly other but I do not know the potential benefits of each product. (WNERR)

CIR especially for marsh zone delineation for HMC.

(PBNERR) Properly classified blue-green LiDAR.



(WNERR) But they are on Rachel Carson land and the USFWS system has a strict protocol in place for UAV flights over their land



(GTMNERR) Fall for marsh but tides are better for oysters in winter.

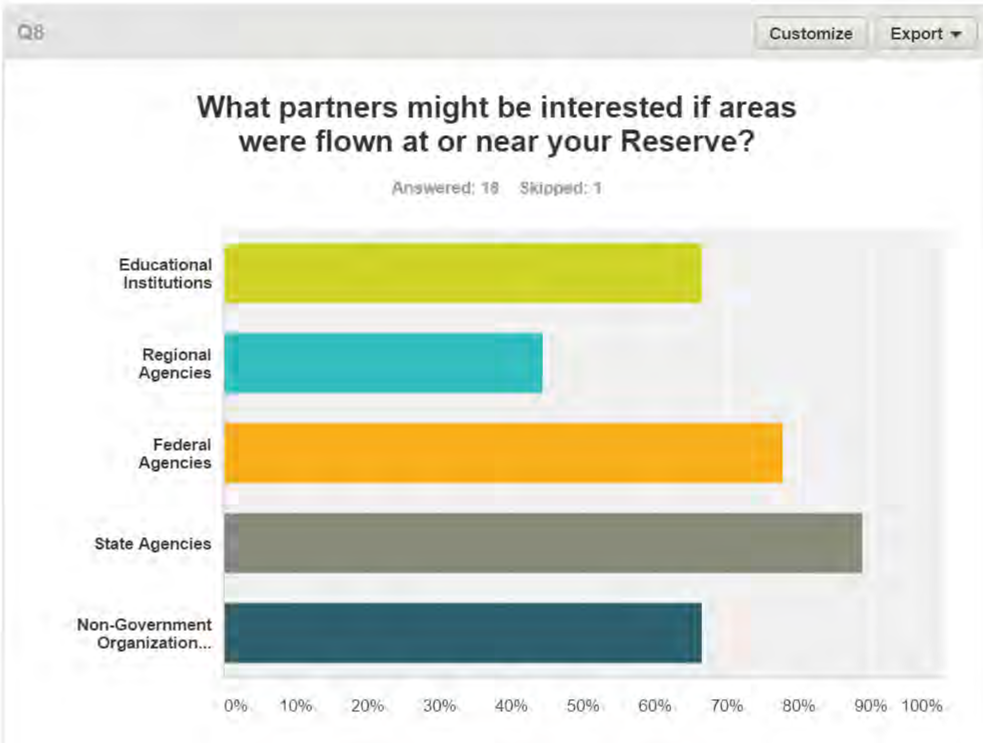
(CBNERR) For our site, collecting information in the summer/fall and winter might be useful (especially for sites like Sweet Hall which go from a lush, tidal freshwater/oligohaline system to a mudflat in the winter). Having the ability to collect elevation data from a UAV might be very useful during winter conditions.

(ANERR) Collecting data at other times of the year may also be beneficial; flying quarterly.

(WNERR) Depends on the project.

(GBNERR) Leaf off is important, but other uses might require leaf on.

(JBNERR)It depends of the survey objectives for example in summer there are a lot of boat activities in the Jobos Bay and would be interesting to see how mangrove, coral and sea grass beds can be impacted by human use and hazards to the Manatee population in the area. Surveys during any season of the year will be very interesting.



(MANERR) Nueces County, UT Austin, Coastal Bend Bays Estuaries Program, Texas Parks and Wildlife Department, City of Port Aransas, Fennessey Ranch, USFWS, TAMU-CC.

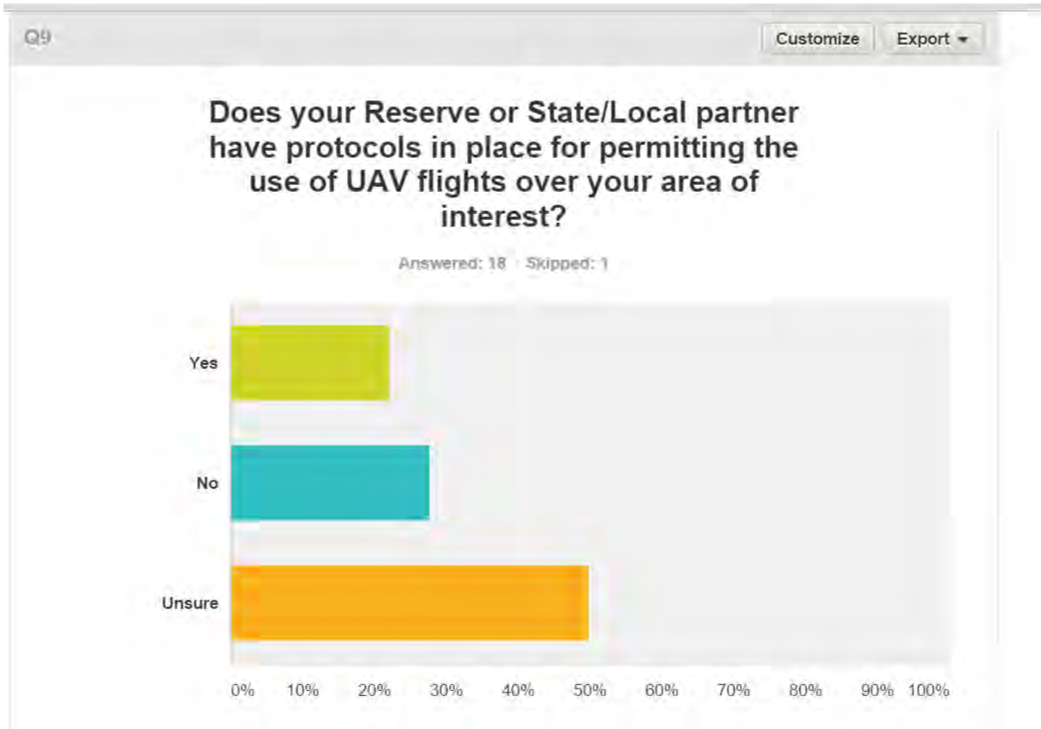
(CBNERR) Virginia Institute of Marine Science, Department of Conservation and Recreation - Natural Heritage Program, Department of Environmental Quality.

(WBNERR) University of South Alabama, Dauphin Island Sea Lab, and a plethora of other educational institutions. Alabama Department of Conservation, TNC, ADEM, Corps of Engineers, U.S. Fish and Wildlife, Geological Survey of Alabama, USGS.

(WNERR) Visiting researchers, Rachel Carson NWR, Jamie Carter/NOAA affiliate, Maine Warden Service, Land Trusts.

(JBNERR) DNER, NOAA, COE, University of Puerto Rico.

(ABNERR) College of Charleston, SC Department of Natural Resources, Open Trust organizations, etc.



(NCNERR) We have a working relationship with the local airport manager. We have not applied for COA's or anything like that through the FAA.

(MANERR) I would guess yes, we are located close to the UAV program at TAMU-CC.

(WBNERR) State is in process of determining rules.

(WNERR) These will be needed in the near future. We have already had researchers fly without landowner permission, and in most cases it was over Rachel Carson land.

(KBNERR) They are by permit for case by case applications at this point. No one here has an open permit for the use of this tool.

(GBNERR0 Probably not. This survey assumes that UAVs are essential to these data/information needs. They're not! I would put UAVs at a low priority compared to other research/monitoring needs, and if necessary to use a UAV, contracting would be a preferred option. It's senseless to invest in changing, high cost technologies, and build expertise for such limited use - contracting makes so much more sense!

(JBNERR) We need to follow the FAA regulations but we do not have to get permits to do the manatee survey. Anyway we checked with the USFWS and we have the authorization to do the aerial surveys.

(TRNERR) US FWS Refuge (very difficult).

Organizational Technology Change Resources:

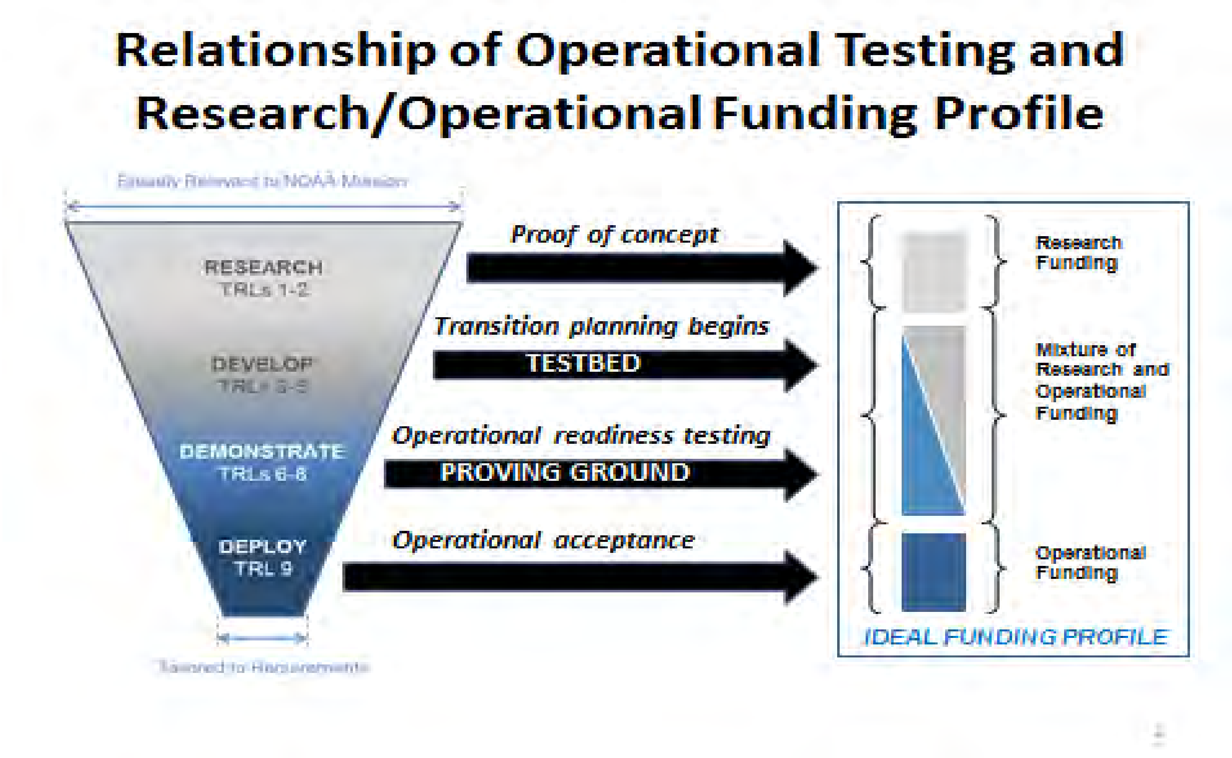
Technical Readiness Levels (TRL) this management tool rates a particular organization's ability to adopt certain technologies.[16] For example, a recent internal NOAA request for proposal (RFP) funded projects that advanced the TRL of a NOAA program office to implement UAS to meet their mission. TRLs include the capability of a program to conduct the following:

- Platform and payload selection
- Concept of operations
- Information management plan
- Staffing, safety, training and proficiency plans

Draft Technology Readiness Level (TRL) This TRL table has been adapted for Unmanned Aircraft Systems. [26]

Transition Index	Technology Readiness Level	Description
Research	TRL 1	Basic or Fundamental understanding of Unmanned Aerial Systems (UAS)
Research	TRL 2	Technology Concepts and applications to NERR missions understood
Development	TRL 3	Proof of Concept: flight and data post-processing/analysis accomplished by outside source
Development	TRL 4	Data Application: Analyzed data used to accomplish NERR mission
Development	TRL 5	In-house Data Analysis: UAS flight contracted, data is post-processed, analyzed, and applied in-house
Demonstration	TRL 6	COA/333 Exemption Applied For: Certified Pilot retained, mission procedures manual developed
Demonstration	TRL 7	COA/333 Exemption Granted: UAS purchased, registered and flown by certified pilot. Data processed in-house
Demonstration	TRL 8	UAS Program Developed: COA secured, staff certified, Mission procedures manual developed and used
Application	TRL 9	UAS Program Operational: COA reporting, UAS upgraded and maintained/documented, additional staff certified and trained

The diagram below shows the relationship between TRL level and possible NOAA funding opportunities. [26]



A Seven-Step Strategy for Managing Technology Change This article helps organizations manage technology changes from top level decision makers down to end users.

http://www.esri.com/esri-news/arcuser/fall-2015/a-seven-step-strategy-for-managing-technology-change

Appendix B: UAS Elements, Mission Planning and Risk

Platform/Sensor Resources:

AUVSI UAS Buyer Guide 2015, including Altavian Nova, Precision Hawk and DJI:
https://higherlogicdownload.s3.amazonaws.com/AUVSI/b657da80-1a58-4f8f-9971-7877b707e5c8/UploadedImages/2015_BuyersGuide_November_112015.pdf

Best Practices/Mission Planning

Humanitarian UAV Network: http://uaviators.org/docs

Risk Assessment Resource:

Arctic Monitoring and Assessment Program UAS Pilot Handbook:
http://www.amap.no/documents/download/2283

UAS Insurance Links (not vetted):

UAV Coach Insurance Guide: http://uavcoach.com/drone-insurance-guide/

Aviation Insurance: http://www.aviationi.com/DroneUAVHome.htm

Skyward Insurance Guide: https://skyward.io/getting-drone-insurance/

DroneGuard : http://www.willisprograms.com/view-insurance-program/35/DroneGuard#SubmissionRequirements

Incident/Accident Reporting:

Contact FAA: https://www.faa.gov/contact/

Appendix C:

Grand Bay Reserve UAS Missions (2015)

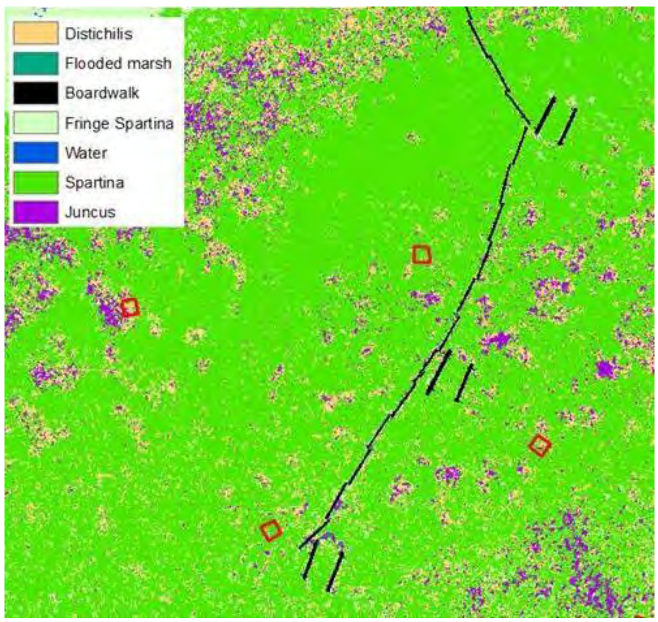
Tradeoff Study: The first mission flown at GNDNERR was a tradeoffs study to assess the performance of two UAVs, an Altavian Nova and a Precision Hawk. The objective of the flights were to collect imagery sufficient for single species vegetation mapping around the Sentinel Site areas of interest. These areas have intensive vegetation, elevation, and water-level monitoring for the purposes of determining what effect changes in water level and inundation have on marsh habitats. The Altavian Nova was deployed with a color-infrared camera at an altitude of 510 feet. The resulting imagery had a resolution of 1.3 inches and was evaluated for its effectiveness in creating a single species classification. Post mission conclusions were that the imagery was not sufficient for single species mapping, a higher resolution was needed, and the imagery needed to be collected at a lower altitude.

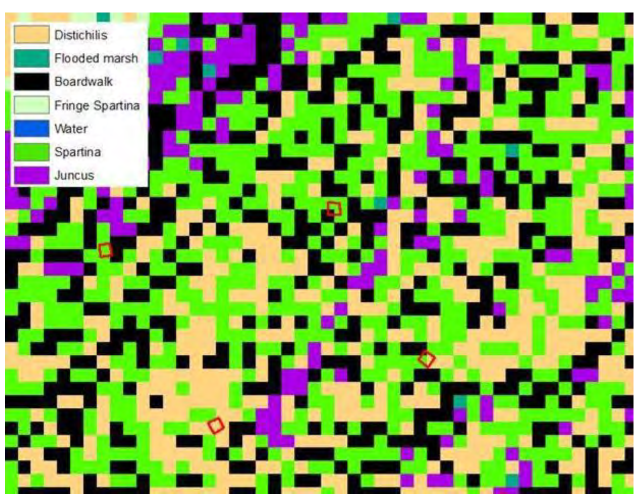
Altavian Nova [15]

Precision Hawk [15]

Single Species Classification: The second mission was flown using a Precision Hawk aircraft with a color infrared payload. The mission was performed at an altitude of 165 feet, and multiple flights were done focusing on the Sentinel Site monitoring areas. The resulting imagery had a resolution of 0.5 inches and was used in a single species classification.

A training dataset is made up of are ground-truthed data used to teach the computer as it classifies individual pixels. A training set of single species polygons was collected and used to classify the image. The same classification scheme and training dataset was applied to a World View 3 (WV3) satellite image collected 11 days before the UAV mission. The WV3 map has a pixel size of 1.2 *meters*, and the UAV map has a pixel size of 1.2 *centimeters* or 97 times the resolution when compared to the WV3 map.





Top map is UAV single species classification, bottom map is WorldView3 single species classification. The red squares in the images are the permanent vegetation plots associated with SSAM-1 at GNDNERR. The UAV imagery is capable of capturing variation within the plots while WorldView3 imagery captures very little or no variation within the plots. [26]

The red boxes on the maps are the permanent vegetation plots that are measured annually. Within the plots in the WV3 image very little or even no variation is detected, while in the UAS map a large amount of detail can be measured. Compared with the best satellite imagery available, the UAV imagery has much more utility for fine scale vegetation mapping. This kind of imagery and vegetation mapping would add value to Sentinel Site work being performed at any reserve.

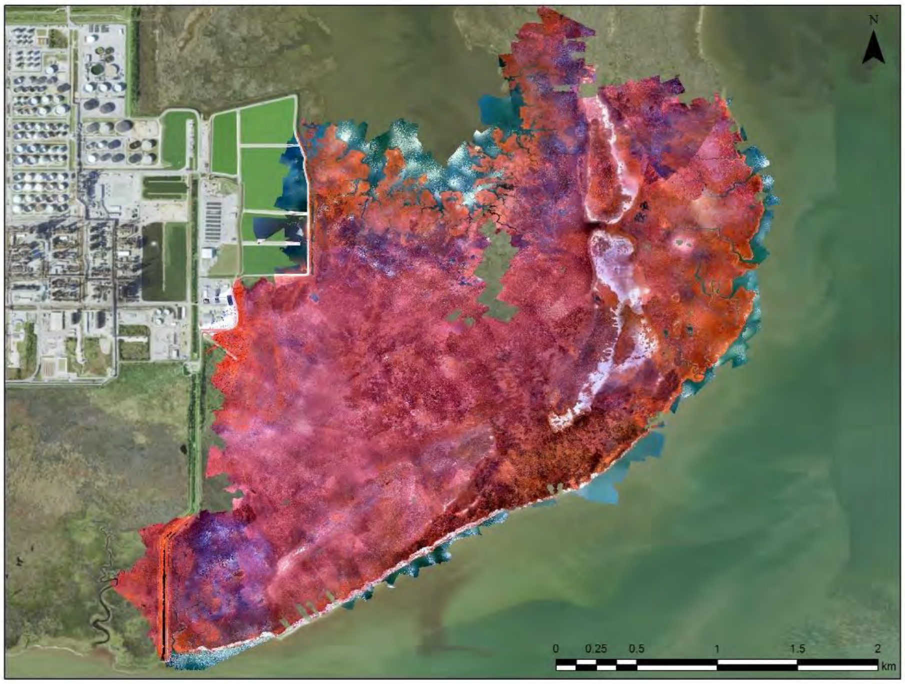
Disaster Response Exercise: The third mission was flown as a part of a disaster response exercise conducted in Bangs Lake at GNDNERR. The GNDNERR is adjacent to Mississippi Phosphates, a production facility that manufactures diammonium phosphate. MS Phosphates maintains a gypsum stack to contain wastewater from its operations, but during heavy storm events the stack has been breached and waste water has entered the GNDNERR boundary. These events have caused fish and oyster kills as well as damaged vegetation. Therefore, simulating a chemical spill in Bangs Lake is a very likely scenario.

The objective of the UAS flight during the exercise was to monitor the movement of non-toxic fluorescein dye. A DJI Phantom 2 Vision Plus quadcopter with a true color camera flew at various altitudes throughout the day. The quadcopter provided real-time video that directed water sampling efforts and documented the movement of dye throughout the estuary. This mission was a successful illustration of how UAS can be used in disaster response scenarios.

Still image of skimmer boat and fluorescein dye dump at Bangs Lake. [15]

Marsh Wildfire: The fourth mission flown at GNDNERR was in response to a wildfire that was ignited by a lightning strike out on the marsh. Reserve employees responded to the fire and determined that no structures were in danger; therefore, the fire was left to burn naturally.

The Precision Hawk was flown with a color-infrared camera at 590 feet to determine the extent of the marsh burn. The resulting imagery had a resolution of 2.0 inches and was used to map the spatial extent of the fire and to use for in a vegetation health analysis. It was determined that the burn covered approximately 1,700 acres. Re-flying the area at some future time will provide information about post-burn marsh plant regeneration.



Marsh Wildfire Extent Map [15]

Upland Fire: The final mission flown was in response to an upland wildfire that burned across approximately 4,200 acres of GNDNERR and Grand Bay National Wildlife Refuge lands. A UAS was deployed to document the extent and severity of the burn and investigate vegetation regeneration. The Nova aircraft was flown with a MicaSense 5-band sensor at an altitude of 1,000 feet.

The mission was done at a high altitude to cover the largest area possible and to collect imagery for the entire burn. Working in cooperation with U.S. Fish and Wildlife Service (USFWS) burn a severity analysis was performed. More imagery will be collected during the summer of 2016 to document plant regeneration.

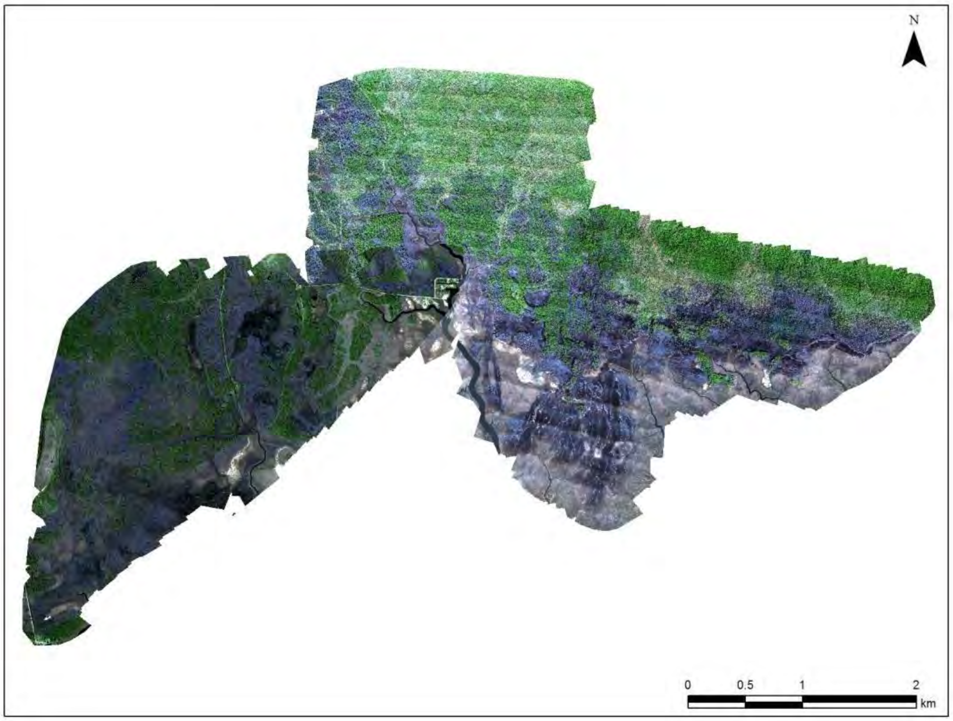


Figure C6: Upland wildfire true color imagery [15]

Outreach Applications

UAS have also been used at Grand Bay for outreach and educational demonstrations. Every year the staff host a National Estuaries Day event called "Seaside with a Scientist". For the 2015 event, GNDNERR had the UAS team from the Geosystems Research Institute (GRI) at Mississippi State University (MSU) perform a demonstration with the DJI Phantom 2 Vision Plus quadcopter. While the UAS team deployed the quadcopter, Grand Bay staff discussed with visitors the uses of UAS for research and response efforts.

Another demonstration was coordinated with the GRI team for the NERR Stewardship Coordinator meeting during the annual meeting in 2015. The DJI Phantom 2 Vision Plus was also flown for this demonstration. While the quadcopter was deployed Grand Bay staff elaborated on the multiple missions that had been performed and GRI staff discussed data collection, post-processing, and management. This demonstration was meant to inspire the Stewardship staff to think of potential UAS applications at their respective Reserves and allow for interaction with the GRI team.

Figure C7: Stewardship Coordinators at GNDNERR for NERRA Annual Meeting 2015, picture taken from DJI Phantom 2 Vision Plus [15]

Future Flights

A single snapshot from a UAS mission provides a wealth of information, but in order to perform change analysis and investigate marsh regeneration, missions need to be re-flown. The Sentinel Site areas would ideally be re-flown every growing season. This would enable documentation of vegetation changes over multiple years and allow comparison of changes in water levels and marsh elevation. The marsh and upland wildfires will hopefully be re-flown to analyze vegetation health and regeneration.

Appendix C cont.

Annotated Research Bibliography

Chabot, D., Carignan, V., & Bird, D. M. (2014). Measuring Habitat Quality for Least Bitterns in a Created Wetland with Use of a Small Unmanned Aircraft. *Wetlands, 34*(3), 527-533. doi:10.1007/s13157-014-0518-1

This article discusses the use of both ground-based and UAS for surveys of Least Bitterns and how UAS enables the production of accurate habitat mapping with significantly less disturbance. The resulting data contained 220 photographs that were stitched together using Pix4D software.

Cress, J. J., Hutt, M. E., Sloan, J. L., Bauer, M. A., Feller, M. R., & Goplen, S. E. (2015). U.S. Geological Survey Unmanned Aircraft Systems (UAS) Roadmap 2014. *Open-File Report*. doi:10.3133/ofr20151032

This roadmap describes a multiple applications of various organizations within the Department of the Interior. Full account of platforms, sensors and projects. The "Bible" of UAS projects in Natural Resource.

D'oleire-Oltmanns, S., Marzolff, I., Peter, K., & Ries, J. (2012). Unmanned Aerial Vehicle (UAV) for Monitoring Soil Erosion in Morocco. *Remote Sensing, 4*(12), 3390-3416. doi:10.3390/rs4113390

The authors describe a project that looked at filling the data gap between field research and satellite scaled research using UAS technology. The UAS images were mosaicked and post processed to produce a Digital Terrain Model (DTM). They quantified erosion using 2D and 3D products.

Jones, G. P., Pearlstine, L. G., & Percival, H. F. (2006). An Assessment of Small Unmanned Aerial Vehicles for Wildlife Research. *Wildlife Society Bulletin, 34*(3), 750-758. doi:10.2193/0091-7648(2006)34[750:aaosua]2.0.co;2

This article also describes the benefits of using UAS to fill a data void, especially in the ability to use UAS at a biologically distinguishable level. The evaluation of UAS was done in 2002 and 2003, and the difficulties they described with the UAS use were representative of the time. Significant improvements have been made in the ensuing decade and a half.

Klemas, V. (2013). Remote Sensing of Coastal Wetland Biomass: An Overview. *Journal of Coastal Research, 290*, 1016-1028. doi:10.2112/jcoastres-d-12-00237.1

This article does not include a discussion about UAS use, but discusses the use of LiDAR and mapping techniques for coastal research. The techniques described can easily be adapted from satellite imagery to UAS-obtained imagery.

Laliberte, A. (2009). Unmanned aerial vehicle-based remote sensing for rangeland assessment, monitoring, and management. *Journal of Applied Remote Sensing J. Appl. Remote Sens, 3*(1), 033542. doi:10.1117/1.3216822
The authors describe use of “off-the-shelf” UAS for use in rangeland monitoring. It focuses on the ability to use UAS on vast spatial areas. It showcases five different platforms used and their relative costs (from $2,000 to $35,000) and also includes a table of the platform specifications and compared satellite imagery with UAS imagery. In the conclusion, the author states that the UAS offer “simplicity, relative low coast, reliability and operational flexibility”.

Laliberte, A. S. (2010). Impact of flight regulations on effective use of unmanned aircraft systems for natural resources applications. *Journal of Applied Remote Sensing J. Appl. Remote Sens, 4*(1), 043539. doi:10.1117/1.3474649
This is an excellent resource about the process of flying UAS for natural resource use. Table 1 describes specific requirements and is included in Appendix E. Note: an external pilot is located away from the site the UAS is flying and an internal pilot is controlling the UAS onsite.

Lechner, A. M., Fletcher, A., Johansen, K., & Erskine, P. (2012). Characterizing Upland Swamps Using Object-Based Classification Methods And Hyper-Spatial Resolution Imagery Derived From An Unmanned Aerial Vehicle. *ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences, I-4*, 101-106. doi:10.5194/isprsannals-i-4-101-2012
Digital surface models were produced from the imagery and used to classify swamplands. The authors discuss the issue of classifying high definition imagery where one object can have a very fine digital signature (trunk, branches, base of tree…) Using Object Base Imagery Analysis (OBIA) resolves that problem.

Pereira, E., Bencatel, R., Correia, J., Goncalvas, G., Morgado, J., & Sousa, J. (2009). Unmanned Aircraft Vehicles for Coastal and Environmental Research. *Journal of Coastal Research,* 1557-1561. Retrieved December 29, 2015, from www.jstor.org/stable.25738051.
This article discusses not only fixed-wing and rotary UAS but also the use of blimps and kites.

Salamí, E., Barrado, C., & Pastor, E. (2014). UAV Flight Experiments Applied to the Remote Sensing of Vegetated Areas. *Remote Sensing, 6*(11), 11051-11081. doi:10.3390/rs61111051
This article discusses a literature search for vegetation research using UAS. Cites platforms, sensors, raw and derived products.

Schalles, J., Hladik, C., Lynes, A., & Pennings, S. (2013). Landscape Estimates of Habitat Types, Plant Biomass, and Invertebrate Densities in a Georgia Salt Marsh. *Oceanography Oceanog, 26*(3), 88-97. doi:10.5670/oceanog.2013.50
This article does not deal with UAS technology but is a good contrasting article that describes how labor intensive it was to do a project of that scope using field technicians.

Appendix D: Data Resources

Sample Data Directory Structure [21]

```
PROJECT (Name)
        PROJECT metadata
        PROJECT files  MISSION1
                MISSION1 metadata  MISSION1
                files  M1COLLECT1
                M1COLLECT1 metadata
                M1COLLECT1 files
                        SENSOR
                                RAW             PTCLOUD
                                ORTHO           DEM
                                VIDEO           SUPPORTFILES
                M1COLLECT2
                M1COLLECT2 metadata
                M1COLLECT2 files
                        SENSOR
                                RAW             PTCLOUD
                                ORTHO           DEM
                                VIDEO           SUPPORTFILES
              MISSION 2
                        MISSION2 metadata
                        MISSION2 files  M2COLLECT1
                        M2COLLECT1 metadata
                        M2COLLECT1 files
                                SENSOR
                                        RAW             PTCLOUD
                                          ORTHO           DEM
                                        VIDEO           SUPPORTFILES
                        M2COLLECT2
                        M2COLLECT2 files
                                SENSOR
                                        RAW             PTCLOUD
                                          ORTHO           DEM
                                        VIDEO           SUPPORTFILES
```

Post-processing Software

Desktop Software

Geographic Resources Analysis Support System (**GRASS GIS)**, is a free GIS software package which includes the ability to process UAS data. This contains over 350 modules including modules for point data analysis of LiDAR products and for aerial and UAV images. Post processing capabilities include shape detection, supervised/unsupervised classification. [27]

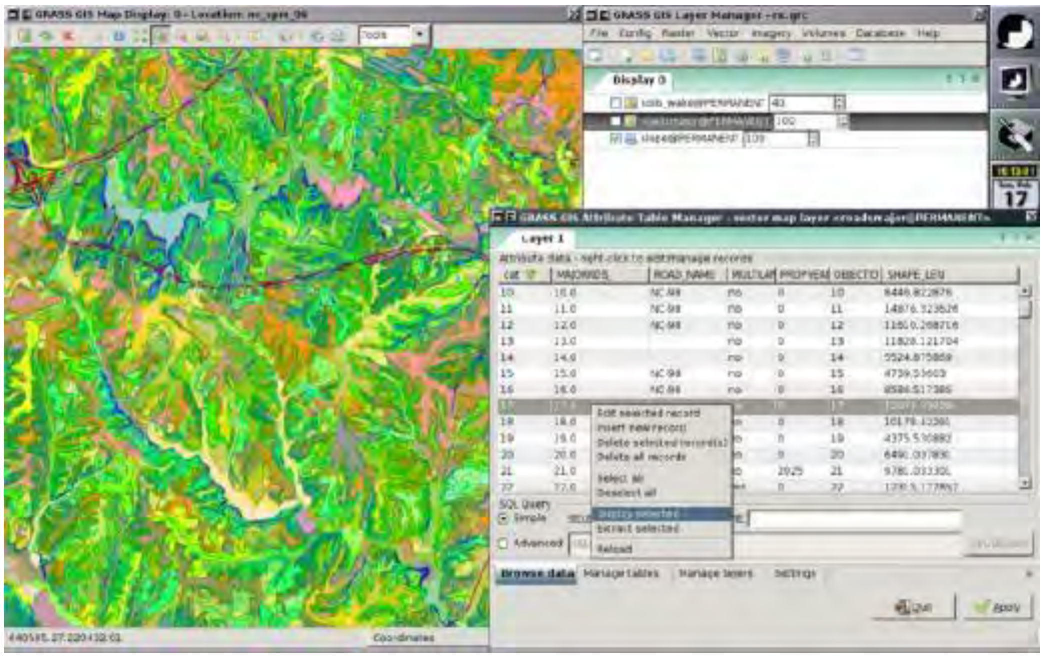


Figure D1: GRASS Interface [27]

ArcGIS: Although this software is routinely used for a variety of mapping needs within the Reserves, there are several extensions and add-ins that enable advanced processing capabilities. These include the ability to process LiDAR point clouds, rectify imagery and analyze resulting products. [28]

ERDAS IMAGINE: ERDAS IMAGINE is a raster-based software that supports collection, processing, analyzing, and delivery of geospatial products. It provides many services including: basic vector analysis, image analysis, LiDAR analysis, photogrammetry, consolidating remote sensing, spatial modeling with various data formats, and more. ERDAS IMAGINE supports multiple workflows that are important to the Reserves including: Land-cover mapping and terrain categorization, data conversion, spatial modeling and analysis, and feature capture and updating. [29]

ENVI: ENVI is a raster-based software that combines image processing and geospatial technology to extract information from multiple forms of data. It includes many image analysis tools such including spectral analysis, proven algorithms, and DEM extraction. ENVI provides many tools that are particularly relevant for the Reserves including change detection, classification, and feature extraction. [30]

Cloud-based services that are lower cost or free

Maps Made Easy: This cloud based service uses a pay-as-you-go credit purchasing system instead of a subscription service. It has an associated iOS app called Map Pilot (9.99) which provides an automated image capturing program that determines the best flight path for a quadcopter to fly. The data is then ingested into the online software and mosaicked into one image and orthorectified. [31]

Drone2Map: Environmental Systems Research Institute (ESRI) has developed a beta desktop version of post-processing software called Drone2Map. The requirements are an enterprise-level ArGIS 10.3 license and a graphics processing enabled computer. The NERRS have that enterprise level of licensing available through NOAA.

Drone2Map uses Pix4D as the photogrammetry engine. It integrates seamlessly into ArcGIS, produces mosaicked orthophotographs, and 3D point cloud and meshed imagery. Drone2Map also enables sharing data through Enterprise Imagery Management and can produce automatic or semi-automatic classification of the data. The final cost of this software is unknown at this time. Free beta software and more information can be found at: [32] http://www.esri.com/products/drone2map.

Full Motion Video (FMV): This add-in enables ArcGIS users to see both the video and the location portrayed in the video on a map. The software reads a number of video formats and also the metadata associated with the video. FMV portrays it in two windows, a video window and a map window. As the video moves, the area in the video is outlined in yellow on the map and moves along with it. Frames can be captured from the video and that image is overlaid on the map. This add-in allows viewing and annotating live streaming video and enable searching video archives by geographic extent or time.

The add-in costs $19.99. Features seen on the video can be digitized and shows up on the map layer as features in a geodatabase. A free ArcGIS seminar entitled Getting Started with ArcGIS Full Motion Video is available at the ESRI training page. [33]

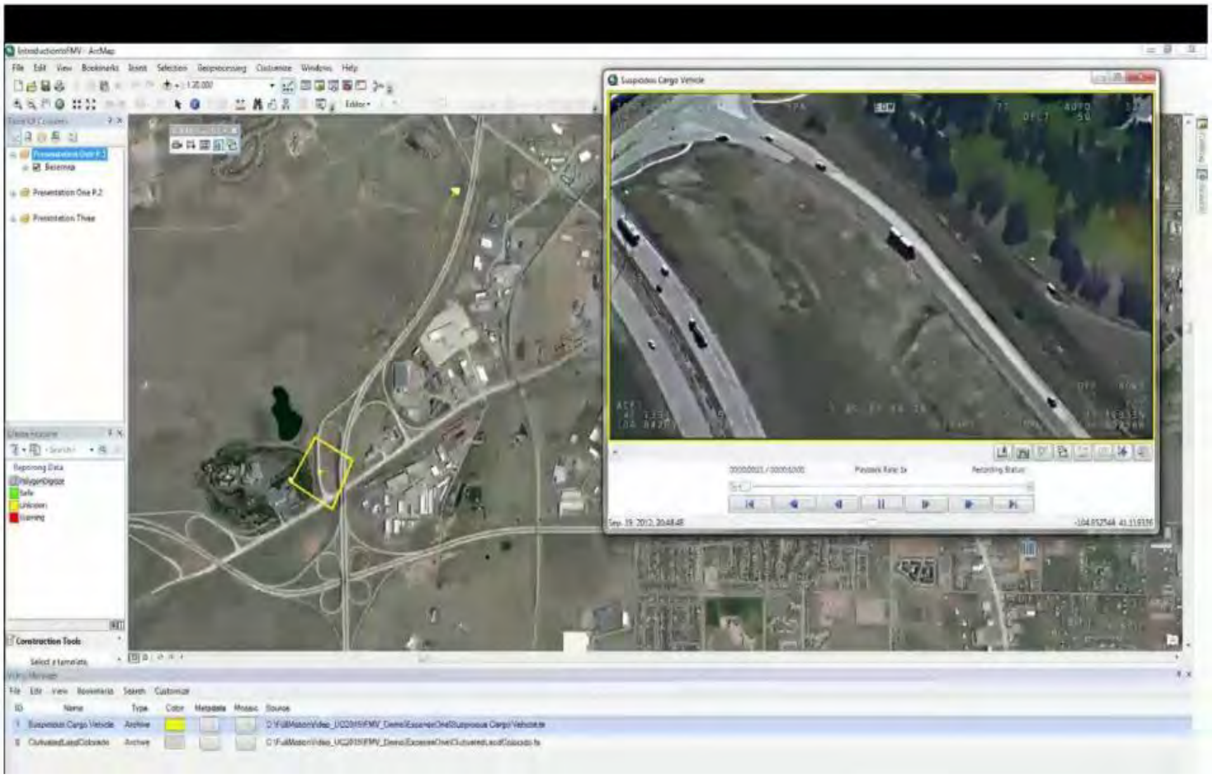


Figure: Full Motion Video [33]

The following report was created by *Lee Hathcock, Mississippi State University and NOAA's Northern Gulf Institute and Ryan MacNeille, Altavian, Inc.* [34]

Standalone mosaicking software

Agisoft Photoscan Pro

The primary advantage of Photoscan is its price. It is the cheapest option, and does a sufficient job in most situations. It can take advantage of multiple cores and certain graphics processors to improve performance. Distributed computing, though, requires particular versions of Linux to run correctly. This may cause issues if your particular resources are not configured to handle Photoscan specifically.

The latest version of Photoscan tends to have more problems with problematic imagery than the other two solutions. Whenever there are large stretches of featureless terrain (e.g. water, corn rows), there are no good tie points, and the generated mosaic will have gaps where images could not be correctly projected.

Photoscan is quite fast in producing mosaics, depending on the level of quality desired. It does, however, have a limit on how many images it can handle in a single run, particularly at higher quality settings. These settings will consume large amounts of computing resources, especially RAM. Projects may have to be separated into chunks to process completely, then merged at the end. Agisoft has excellent tools for merging datasets. . Photoscan can handle GeoTiffs larger than 4GB by specifying "Big Tiff" formatting when exporting.
The software also has a good color-correction algorithm, which helps the end mosaics look much more like a contiguous single image rather than many stitched-together images.

As far as accuracy is concerned, Agisoft makes no claims about how accurate mosaics are. Observed relative accuracy is quite good, but until recently, Photoscan did not utilize roll, pitch, and yaw for anything other than error estimates, so the absolute accuracy is rather poor. When absolute accuracy is required, it will require using software such as ESRI ArcMap or ERDAS Imagine to manually orthorectify the mosaic if ground control points are not used. Photoscan does do an excellent job mosaicking imagery that has no GPS information at all. This data can then be orthorectified later.

Photoscan has rather poor point cloud filtering, so some manual culling of points is required. There may also be other data manipulation necessary if the DSMs produced have too many polygons or odd shapes, or other issues arise.

Photoscan does not have a command-line interface, which is not ideal for automated processing. Batch jobs are possible, but all must be done through the graphical user interface (GUI). There is a Python scripting interface, but this too can only be used from inside the GUI. It does, however, boast a user-friendly interface.

Pix4D Pix4Dmapper

Pix4Dmapper is very solid. It seems to handle problematic imagery a bit better than Photoscan. It was able to mosaic some Tetracam ADC Lite imagery that Photoscan could not, although the mosaic produced was rather poor quality. It was recognizable, though, compared to Photoscan's output, which did not produce anything resembling a proper point cloud or orthophoto at all.

Pix4Dmapper is also very fast, like Photoscan, with a simple, easy-to-use interface. It has much better point cloud filtering than Photoscan, which allows for less data manipulation; the data manipulations tools present are excellent when it is needed, though. It also can import boundaries for data and automatically crop mosaics, which is useful should the user not have access to other geospatial software.

It will also perform automatic NDVI calculations, which is very useful for agricultural applications. Like Photoscan, it has very good color-correction algorithms, leading to very natural-looking mosaics.

There are a few drawbacks to the software, in that it requires a decent amount of experience and knowledge to determine the correct parameters for processing different datasets. It also makes very limited use of roll, pitch, and yaw values in mosaic production.
The "Pro" version appears to be a desktop-only application. It does take advantage of multiple cores and certain GPUs. If a scalable solution is required, the "Enterprise" version will be required. It is available for Windows, Mac, and Linux, and also provides a command-line interface for improving workflows. There is also an "Ag" version that can be bundled with a MicaSense Sequoia sensor, which can export NDVI maps and other relevant agricultural products.

SimActive Correlator3D

Correlator3D provides some of the best DSM/DTM algorithms on the market. If precision surveying is a necessity, it is the software to use. The accuracy of Correlator3D, according to the website and in conjunction with their other add-ins, is under a pixel. It gives comprehensive calibration and processing reports for each mosaicking step.

Related to accuracy, Correlator3D fully utilizes roll, pitch, and yaw. This enables one to deal with image sets that give other mosaicking programs issues, such as time-varying scenes (water or wind-blown fields) or scenes lacking detectable, unique tie points. Other programs have difficulty finding tie points within these images, since they do not utilize roll, pitch, and yaw data to project each image onto a surface, leaving large gaps in the mosaic where tie points cannot be found. Correlator3D uses roll, pitch, and yaw values and projects the individual images onto a flat surface, giving a contiguous mosaic even when there are areas for which tie points between images cannot be found. However, Correlator3D doesn't have a very good color-correction algorithm.

Since Correlator3D uses roll, pitch, and yaw information, it can also produce individual orthophotos from each input image. It also will automatically generate overviews for orthomosaics, which is very useful for quicker viewing of the data in other programs like ArcMap or Imagine. In contrast, after Photoscan is finished, overviews of large mosaics must be generated using other programs, such as ArcMap, Imagine, or the freely-available Geospatial Data Abstraction Layer (GDAL) suite of tools.

Correlator3D will take advantage of multiple cores, and can also be configured to utilize certain graphics cards for processing of data. There is also a command-line interface. Parallel computing is done through use of scripting and batch processing, but the ability to use explicit multi-computer/node processing is unknown and may be version or product level dependent. Unfortunately, Correlator3D can be a bit slow with larger datasets. It also generates a large amount of data, so significant storage may be required for efficient workflows. The interface is not user-friendly, and the software requires some familiarity with scripting and configuration file editing for proper usage.

Trimble Business Center (TBC)

Trimble Business Center is another mosaicking software that works with data obtained from Trimble's UAS platforms. We have not evaluated the accuracy and effectiveness of the software and the software may only ingest imagery from Trimble's UAVs. Modifications can likely be made to get other aircraft data into the proper format for processing, however, if TBC is already available.

<u>Cloud-based solutions</u>

MicaSense ATLAS Service

MicaSense Atlas Service is used for their lines of multispectral cameras, like the RedEdge and Sequoia. There are very specific procedures that need to be followed to obtain optimal quality from the mosaics. There are some artifacts in the imagery, though, when bright objects are present. We have some speculations as to why this is, based on a response from MicaSense and knowledge of one of our image processing experts. The advantage to their service is that it does the band alignments on the multispectral cameras, and puts together a mosaic and DSM, along with other common products such as NDVI, with very little user input.

This also means that any particular settings when mosaicking, color balancing, reference panel adjustment, and other issues that might need to be controlled for in a research environment are out of the researcher's hands. This can make it more difficult to ensure the data has been prepared as needed, and can also make it more difficult to publish results based on the cloud-based products.

Precision Hawk DataMapper

Precision Hawk also has a cloud-based service called DataMapper. It seems to perform an adequate job in mosaicking imagery, but also gives very little control to the user in what is produced, and very little transparency in how the final products are generated. This is the primary drawback of all the cloud-based systems; there may be quality control on all the imagery, but the end user has no idea what that quality control is.

DroneDeploy

DroneDeploy has a cloud-based mosaicking software. It is generic in nature, but pricing for the highest tier is $4999/yr., which makes it more feasible to buy a stand-alone software. Of course, this is an option if an institution doesn't have someone that can perform the mosaicking process, and may not have the computing resources and infrastructure necessary. Resolution in their mosaics at this level is claimed to be 1cm/pixel.

Advantages and disadvantages of desktop vs. cloud approach

As alluded to earlier, there are advantages and disadvantages to each approach. For the ordinary user, the cloud-based services are simpler to use, and will provide the necessary information to make timely decisions. It frees them from having to devote computing and storage resources, as often they just want an answer. For example, a farmer might only want a prescription map for fertilizer, or how much to irrigate a particular area of a field.

For research institutions, this may not be sufficient. As there is a significant pressure to publish results, and maintain control over the way mosaics are produced, it is often better to own the software in question and produce mosaics in-house. Most mosaic software isn't very difficult to use when good data is supplied, but it may take a bit more expertise if the data lacks quality. It is much easier to publish when the data is well-known all the way from the raw imagery to the final output.

Pricing

Agisoft Photoscan Pro

Full license for commercial use is $3499, academic use is $549.

Pix4DMapper

Full license for Pix4DMapper is $8700, academic license is $5220.

Correlator3D

Cost of Correlator3D depends on the product level. The full version is $45000. The UAV version is available for organizations that are collecting data with UAS, and has a 40 megapixel limitation for each source image. This version is $5900, and for academic use is $2950.

Precision Hawk DataMapper

PLAN	STORAGE	PRICE (PER MONTH)
FREE	2GB	$0
BRONZE	60GB	$25
SILVER	200GB	$45
GOLD	500GB	$70
PLATINUM	750GB	$95

MicaSense ATLAS

PLAN	AREA (ACRES/MONTH)	PRICE (PER MONTH)
PER USE	N/A	$0.60/acre ($5 minimum job)
BASIC	150	$50
PLUS	350	$100
PRO	1000	$250

Custom / enterprise plans are also available.

DroneMapper

AREA (KM^2)	GSD > 5 CM	3-5 CM GSD	1-3 CM GSD
< 1	$20	$60	$100
< 2	$40	$120	$200
< 3	$60	$180	$300

DroneDeploy

PLAN	PRICE (MO/YR)	RESOLUTION	PROCESSING TIME	SUPPORT
EXPLORER	Free	20 cm/pixel	Standard	Community-based
PRO	$99/$999	5 cm/pixel	Expedited	Email + Chat
PRECISION	$499/$4999	1 cm/pixel	Immediate	Dedicated ENG support

Custom / enterprise plans are also available.

<u>Summary of Desktop Software</u>

Agisoft

Pros:
- Fast
- Relatively simple interface

- Easy dataset merging
- Good color-correction algorithm
- Impressive results when processing images without GPS data

Cons:

- Poor point cloud filtering
- Usually requires manual data manipulation
- Only recently has begun to implement roll, pitch, and yaw in camera alignment
- Inefficient hardware utilization

Pix4DMapper

Pros:

- Fast
- Very simple interface
- Extensive documentation and support
- Accurate point cloud filtering
- Excellent data manipulation tools
- Boundary importing and automatic cropping
- Automatic NDVI calculations
- Very good color-correction algorithm

Cons:

- Requires some experience and knowledge to determine proper parameters for different types of data
- Limited use of roll, pitch, and yaw values

Correlator3D

Pros:

- Best DSM/DTM algorithms on the market
- Fully utilizes roll, pitch, and yaw
- Can directly generate georeferenced orthophoto for each image
- Easily processes data over water
- Excellent calibration and processing reports from each processing step
- Automatically builds GeoTIFF overviews

Cons:

- Tends to be slow with large datasets
- Generates large amounts of data, Interface is not user-friendly
- Poor color-correction algorithm
- Requires familiarity with scripting and configuration file editing

Appendix E:

24 Hour Accident-Incident Reporting: See FAA Regional Operations Center

https://www.faa.gov/about/office_org/headquarters_offices/arc/

National Airspace System

FAA TV: How Does the National Airspace System (NAS) Work: http://www.faa.gov/tv/?mediaId=370

FAA Unmanned Aircraft Systems website: https://www.faa.gov/uas/

Aircraft Owners and Pilots Association (AOPA) "Airspace for Everyone" document: http://flighttraining.aopa.org/students/solo/topics/SA02_Airspace_for_Everyone.pdf

Appendix I: Memory Devices

Type	Mnemonics	Charted Using
Class A	Above 18,000 feet; Altitude; Approval (IFR clearance)	N/A
Class B	Biggest and Busiest Boundary(ATC clearance)	Solid Blue Line
Class C	Communication within 20 miles (with approach)	Solid Magenta Line
Class D	Dialogue (with tower)	Dashed Blue Line
Class E	Everywhere Else	Dashed Magenta Line or Vignette
Class F	Forget it (not in U.S.)	N/A
Class G	Government Free	Blue/Magenta Vignette

From AOPA "Airspace for Everyone" [24]

UAS Program Development

Know Before You Fly: http://knowbeforeyoufly.org/

Summary of Small Unmanned Aircraft Rule (Part 107): https://www.faa.gov/news/press_releases/news_story.cfm?newsId=20515/

FAA Unmanned Aircraft System: https://www.faa.gov/uas

FAA Public Operations website: https://www.faa.gov/uas/public_operations/

Sample COA:

http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/uas/media/COA%20Sample%20Application%20v%201-1.pdf

Part 107 Links:

FAA Unmanned Aircraft System webpage: https://www.faa.gov/uas/

FAA Advisory Circular 107.2: https://www.faa.gov/search/?omni=MainSearch&q=AC+107.2
This circular is an excellent resource that helps understand the new rules.

FAA sUAS Airman Knowledge Test:
https://www.faa.gov/training_testing/testing/acs/media/uas_acs.pdf
This document describes in detail exactly what is on the Airman Knowledge Test and what resource the item can be found at.

FAA sUAS AKT Introduction Course:
https://www.faasafety.gov/gslac/ALC/course_content.aspx?enroll=true&cID=451

FAA Sample Exam:
https://www.faa.gov/training_testing/testing/test_questions/media/uag_sample_exam.pdf

Air Space Links:

National Airspace Overview:

https://www.faa.gov/air_traffic/nas/nynjphl_redesign/documentation/feis/media/Appendix_A-National_Airspace_System_Overview.pdf

Temporary Flight Restriction Notice (TFRN):

Federal Aviation Administration TFRN: http://tfr.faa.gov/tfr2/list.html

Notice to Airmen (NOTAM):

Skyvector: https://skyvector.com/

USGS Skyvector.com Guide: http://uas.usgs.gov/pdf/UAS%20NOTAM.pdf

Pilot Training and Certification:

FAA Pilot Portal: https://www.faa.gov/pilots/become/

Remote Pilot Small Unmanned Aircraft System Airman Certification Standards: *This document details every item that makes up the bank of questions on the Airman Knowledge Test*. https://www.faa.gov/training_testing/testing/acs/media/uas_acs.pdf

Gleim Airman Knowledge Test Training: https://www.gleim.com/aviation/#avTab%3DId

Drone Knowledge Test Prep: http://www.droneknowledgetestprep.com/test-prep.html

Embry-Riddle Aeronautical University Online Course – Aviation 101(free)

https://www.canvas.net/browse/erau/courses/aviation-101

AMA UAS Course (free): http://www.fly-robotics.com/amaflightschool/course/view.php?id=6

FAA Safety UAS Course (Free): https://www.faasafety.gov/login/Default.aspx?dest=gslac/ALC/course_content&enroll=true&cID=451

Integrated Airman Certification and Rating (IACR) website (to apply for Airman Certification after passing the Airman Knowledge Test) https://iacra.faa.gov/IACRA/Default.aspx

UAS Online Courses:

Udemy: https://www.udemy.com/courses/search/?ref=home&src=ukw&q=drone&lang=en

Pre-Mission Planning Apps:

Airmap: https://www.airmap.com/

Hover: http://www.hoverapp.io/

Google Earth: http://www.google.com/earth/explore/products/mobile.html

Operations Manual:

Arctic Monitoring and Assessment Program UAS Pilot Handbook:

http://www.amap.no/documents/download/2283

Skyview Aerials Solutions Template:

http://skyviewaerialsolutions.com/wp-content/uploads/2016/01/UAS-Operations-Manual-

Template.docx

UAS Professional Organizations

Association of Unmanned Vehicle Systems International (AUVSI) http://auvsi.org/

Academy of Model Aeronautics (AMA) http://www.modelaircraft.org/

Aircraft Owners and Pilots Association (AOPA) http://aopa.org/

sUAS News http://www.suasnews.com/

Small UAV Coalition: http://www.smalluavcoalition.org/

Data Buy or End User Services: [35]

The following is adapted from the NOAA UAS Program requirements for purchasing data collected by and/or post-processed by a private vendor. It is meant to be used as an example of what to specify when writing up a Request for Proposal (RFP). [36]

Refer to the site's specific policy regarding procurement. In either case, some or all of the following will apply:

1. Supervisory approval must be obtained.
2. An authorized Government credit card holder with purchase authority must make the purchase. Note: the vendor must invoice for the supply or product, not "services provided."
3. Verify the vendor meets all FAA requirements.
4. A written agreement with the vendor must be signed by both parties and will include, at a minimum:
    a. A detailed description of the product desired, the date of delivery, and note all products are the property of Government.
    b. Windows of opportunity to achieve best results for obtaining the product(s).
    c. Vendor's responsibility for complying with all local, state, and federal regulations, such as minimum altitudes above area commensurate with Federal Aviation Regulations and including FAA certification and Section 333 Exemptions.
    d. Areas to be avoided; measures to avoid impacts on natural resources and personnel.
    e. A vendor-provided operational safety plan.
    f. Procedures for data management and processing.
    g. Procedures and responsibility for recovering a downed aircraft and any associated damage to resources.
    h. Representations that the operator is properly insured and adequately indemnifies the Government (as applicable).
5. The written agreement shall not include:
    a. Specified aircraft type
    b. Pilot requirements
    c. Point(s) of departure
    d. Any authorization for take-off, landing, or operation

AMA Safety Code: [19]

Academy of Model Aeronautics National Model Aircraft Safety Code Effective January 1, 2014

A. GENERAL: A model aircraft is a non-human-carrying aircraft capable of sustained flight in the atmosphere. It may not exceed limitations of this code and is intended exclusively for sport, recreation, education and/or competition. All model flights must be conducted in accordance with this safety code and any additional rules specific to the flying site.

1. Model aircraft will not be flown:
(a) In a careless or reckless manner.
(b) At a location where model aircraft activities are prohibited.

2. Model aircraft pilots will:
(a) Yield the right of way to all human-carrying aircraft.
(b) See and avoid all aircraft and a spotter must be used when appropriate. (AMA Document #540-D.)
(c) Not fly higher than approximately 400 feet above ground level within three (3) miles of an airport without notifying the airport operator.
(d) Not interfere with operations and traffic patterns at any airport, heliport or seaplane base except where there is a mixed use agreement.
(e) Not exceed a takeoff weight, including fuel, of 55 pounds unless in compliance with the AMA Large Model Airplane program. (AMA Document 520-A.)
(f) Ensure the aircraft is identified with the name and address or AMA number of the owner on the inside or affixed to the outside of the model aircraft. (This does not apply to model aircraft flown indoors.)
(g) Not operate aircraft with metal-blade propellers or with gaseous boosts except for helicopters operated under the provisions of AMA Document #555.
(h) Not operate model aircraft while under the influence of alcohol or while using any drug that could adversely affect the pilot's ability to safely control the model.
(i) Not operate model aircraft carrying pyrotechnic devices that explode or burn, or any device which propels a projectile or drops any object that creates a hazard to persons or property. Exceptions: Free Flight fuses or devices that burn producing smoke and are securely attached to the model aircraft during flight. Rocket motors (using solid propellant) up to a G-series size may be used provided they remain attached to the model during flight. Model rockets may be flown in accordance with the National Model Rocketry Safety Code but may not be launched from model aircraft. Officially designated AMA Air Show Teams (AST) are authorized to use devices and practices as defined within the Team AMA Program Document. (AMA Document #718.)
(j) Not operate a turbine-powered aircraft, unless in compliance with the AMA turbine regulations. (AMA Document #510-A.)

3. Model aircraft will not be flown in AMA sanctioned events, air shows or model demonstrations unless:
(a) The aircraft, control system and pilot skills have successfully demonstrated all maneuvers intended or anticipated prior to the specific event.

(b) An inexperienced pilot is assisted by an experienced pilot.

4. When and where required by rule, helmets must be properly worn and fastened. They must be OSHA, DOT, ANSI, SNELL or NOCSAE approved or comply with comparable standards.

B. RADIO CONTROL (RC):

1. All pilots shall avoid flying directly over unprotected people, vessels, vehicles or structures and shall avoid endangerment of life and property of others.

2. A successful radio equipment ground-range check in accordance with manufacturer's recommendations will be completed before the first flight of a new or repaired model aircraft.

3. At all flying sites a safety line(s) must be established in front of which all flying takes place. (AMA Document #706.) (a) Only personnel associated with flying the model aircraft are allowed at or in front of the safety line. (b) At air shows or demonstrations, a straight safety line must be established. (c) An area away from the safety line must be maintained for spectators. (d) Intentional flying behind the safety line is prohibited.

4. RC model aircraft must use the radio-control frequencies currently allowed by the Federal Communications Commission (FCC). Only individuals properly licensed by the FCC are authorized to operate equipment on Amateur Band frequencies.

5. RC model aircraft will not knowingly operate within three (3) miles of any pre-existing flying site without a frequency-management agreement. (AMA Documents #922 and #923.)

6. With the exception of events flown under official AMA Competition Regulations, excluding takeoff and landing, no powered model may be flown outdoors closer than 25 feet to any individual, except for the pilot and the pilot's helper(s) located at the flight line.

7. Under no circumstances may a pilot or other person touch an outdoor model aircraft in flight while it is still under power, except to divert it from striking an individual.

8. RC night flying requires a lighting system providing the pilot with a clear view of the model's attitude and orientation at all times. Hand-held illumination systems are inadequate for night flying operations.

9. The pilot of an RC model aircraft shall:
(a) Maintain control during the entire flight, maintaining visual contact without enhancement other than by corrective lenses prescribed for the pilot.

(b) Fly using the assistance of a camera or First-Person View (FPV) only in accordance with the procedures outlined in AMA Document #550.
(c) Fly using the assistance of autopilot or stabilization system only in accordance with the procedures outlined in AMA Document #560.

C. FREE FLIGHT:

1. Free flight must be at least 100 feet downwind of spectators and automobile parking when the model aircraft is launched.

2. Launch area must be clear of all individuals except mechanics, officials, and other fliers.

3. An effective device will be used to extinguish any fuse on the model aircraft after the fuse has completed its function.

D. CONTROL LINE:

1. The complete control system (including the safety thong where applicable) must have an inspection and pull test prior to flying.

2. The pull test will be in accordance with the current Competition Regulations for the applicable model aircraft category.

3. Model aircraft not fitting a specific category shall use those pull-test requirements as indicated for Control Line Precision Aerobatics.

4. The flying area must be clear of all utility wires or poles and a model aircraft will not be flown closer than 50 feet to any above-ground electric utility lines.

5. The flying area must be clear of all nonessential participants and spectators before the engine is started.

Endnotes

[1] Barnhart, R. K. (2012). Introduction to unmanned aircraft systems. Boca Raton, FL: CRC Press.
[2] NERRS Overview (n.d.) Retrieved January 21, 2016, from http://nerrs.noaa.gov/about/
[3] National Estuarine Research Reserve Strategic Plan 2011-2016 (n.d.) Retrieved January 21, 2016, from https://coast.noaa.gov/data/docs/nerrs/StrategicPlan2011.pdf
[4] L. Spurrier (personal communication March 21, 2016)
[5] Welcome: National Unmanned Aircraft System (UAS) Project Office (n.d.). Retrieved March 26, 2016 from http://rmgsc.cr.usgs.gov/uas/
[6] Labs and Cooperative Institutes Cooperative Institutes. (n.d.). Retrieved March 27, 2016, from http://www.ci.noaa.gov/
[7] FEDERAL UNMANNED SYSTEMS - nopp.org. (2013, April 01). Retrieved March 5, 2016, from http://www.nopp.org/wp-content/uploads/2010/03/SUS_Recommendations_V20_17Apr13.pdf Written by the Subcommittee on Unmanned Systems
[8] Wells National Estuarine Research Reserve. (2016). [Graphic Illustration Elements of an Unmanned Aircraft System. Created using Simple Mind app.} The Way Forward: Unmanned Aerial Systems for the National Estuarine Research Reserves.
Internal document, request from S. Bickford suebickford@wellsnerr.org.
[8] Bickford, S (2015). NERRS UAV Survey. Internal National Estuarine Research Reserve report
[9] Should you buy a fixed wing or rotary drone? (n.d.) Retrieved April 6, 2016, from http://waypoint.sensefly.com/buy- fixed-wing-drone-or-rotary/
[10] Wells National Estuarine Research Reserve. (2016). [Ground control unit of the quadcopter Yuneec Q 500. Photo taken May 1, 2016] The Way Forward: Unmanned Aerial Systems for the National Estuarine Research Reserves.
Internal document, request from S. Bickford suebickford@wellsnerr.org.
[11] Mailey, C. (2013, October 24). Are UAS More Cost Effective than Manned Flights? Retrieved March 19, 2016, from http://www.auvsi.org/browse/blogs/blogviewer?BlogKey=47ec1760-d31e-4f6a-9c8d-78ad8643ae54
[12] AMAP, 2015. Arctic Science Remotely Piloted Aircraft Systems (RPAS) Operator's Handbook. By: R. Storvod, C. Sweatte, P. Ruel, M. Wuennenerg, K. Tarr, M Rausteine, T. Hillesoy, T. Lundgren, M. Sumich, Arctic Monitoring and Assessment Programme, Oslo. 25 pp.
[13] Hood, Robbie. (2011). NOAA UAS Program Project Management Requirements. NOAA Unmanned Aircraft Systems Program, National Oceanic and Atmospheric Administration.
[14] Swiss Cheese Model. (n.d.) Retrieved March 30, 2016 from https://en.wikipedia.org/wiki/Swiss_cheese_model
[15] Grand Bay National Estuarine Research Reserve. (2016). [Remote sensing maps and photographs developed and taken 2015] UAS Flights over Grand Bay National Estuarine Research Reserve. Internal document, request from L. Spurrier lindsay.spurrier@dmr.ms.gov.
[16] DOI OPERATIONAL PROCEDURES MEMORANDUM (OPM) – 11 (January 1, 2016) Retrieved March 21, 2016
from https://www.doi.gov/sites/doi.opengov.ibmcloud.com/files/uploads/OPM-11.pdf
[17] Reynolds, C. (2016, January 11). The latest buzz on flying drones in state and national parks: Rules can still be vague. Retrieved May 01, 2016, from http://www.latimes.com/travel/la-tr-d-spot-20160110-story.html
[18] McNeal, Bill. (n.d.). No Fly Maps Now Available to UAV Pilots. Retrieved 10 April, 2016 from http://www.directionsmag.com/entry/no-fly-maps-now-available-to-uav-pilots/454101
[19] AMA: SUAS Flight Safety Guide - Academy of Model Aeronautics. (2014). Retrieved March 19, 2016, from http://suas.modelaircraft.org/ama/images/sUAS_Safety_Program_web.pdf
[20] HOME - Association for Unmanned Vehicle Systems International. (n.d.). Retrieved March 2, 2016, from http://www.auvsi.org/home
[21] USGS Unmanned Aircraft Systems Data Management Plan. (2015, October 23). Retrieved March 19, 2016, from http://rmgsc.cr.usgs.gov/UAS/publications.shtml
[22] Miller, J. O., Pawling, Carl R., Chambal, Stephen P. (2004). Modeling the U. S. Military Intelligence Process. Air Force Institute of Technology, Department of Operational Sciences, Wright Patterson AFB, OH.

[23] Know Before You Fly (n.d.). Retrieved April 21, 2016, from http://knowbeforeyoufly.org/
[24] Airspace Advisor, Safety Regulations No. 1, Airspace for Everyone (n.d.) Retrieved May 1, 2016 from https://www.aopa.org/-/media/Files/AOPA/Home/Pilot-Resources/ASI/Safety-Advisors/sa02.pdf
[25] Jansen, B. (2016). State drone laws could clash with federal drone policy. Retrieved April 09, 2016, from http://www.usatoday.com/story/news/2016/03/13/state-drone-laws-could-clash-federal-drone-policy/81604344/
[26] J. Coffey (personal communication March 14, 2016)
[27] GRASS GIS. (n.d.). Retrieved March 24, 2016, from http://grass.osgeo.org/
[28] ArcGIS. (n.d.). Retrieved March 18, 2016, from http://www.esri.com/software/arcgis/
[29] ERDAS IMAGINE. (n.d.). Retrieved February 1, 2016, from http://hexagongeospatial.com/products/remote-sensing/erdasimagine/overview
[30] ENVI Software Platform - Image Analysis Software | Harris Geospatial. (n.d.). Retrieved April 5, 2016, from http://www.harrisgeospatial.com/ProductsServices/ENVIProducts.aspx
[31] Maps Made Easy - Home. (n.d.). Retrieved April 21, 2016, from https://www.mapsmadeeasy.com/
[32] Drone2Map. (n.d.). Retrieved March 7, 2016, from http://www.esri.com/products/drone2map [48] ArcGIS Full Motion Video. (n.d.). Retrieved April 20, 2016, from http://www.esri.com/products/arcgis-capabilities/imagery/full-motion-video
[33] ArcGIS Full Motion Video. (n.d.) Retrieved April 20, 2016, from http://www.esri.com/products/arcgis-capabilities/imagery/full-motion-video
[34] R. Moorhead (personal communication March 24, 2016)

Notes