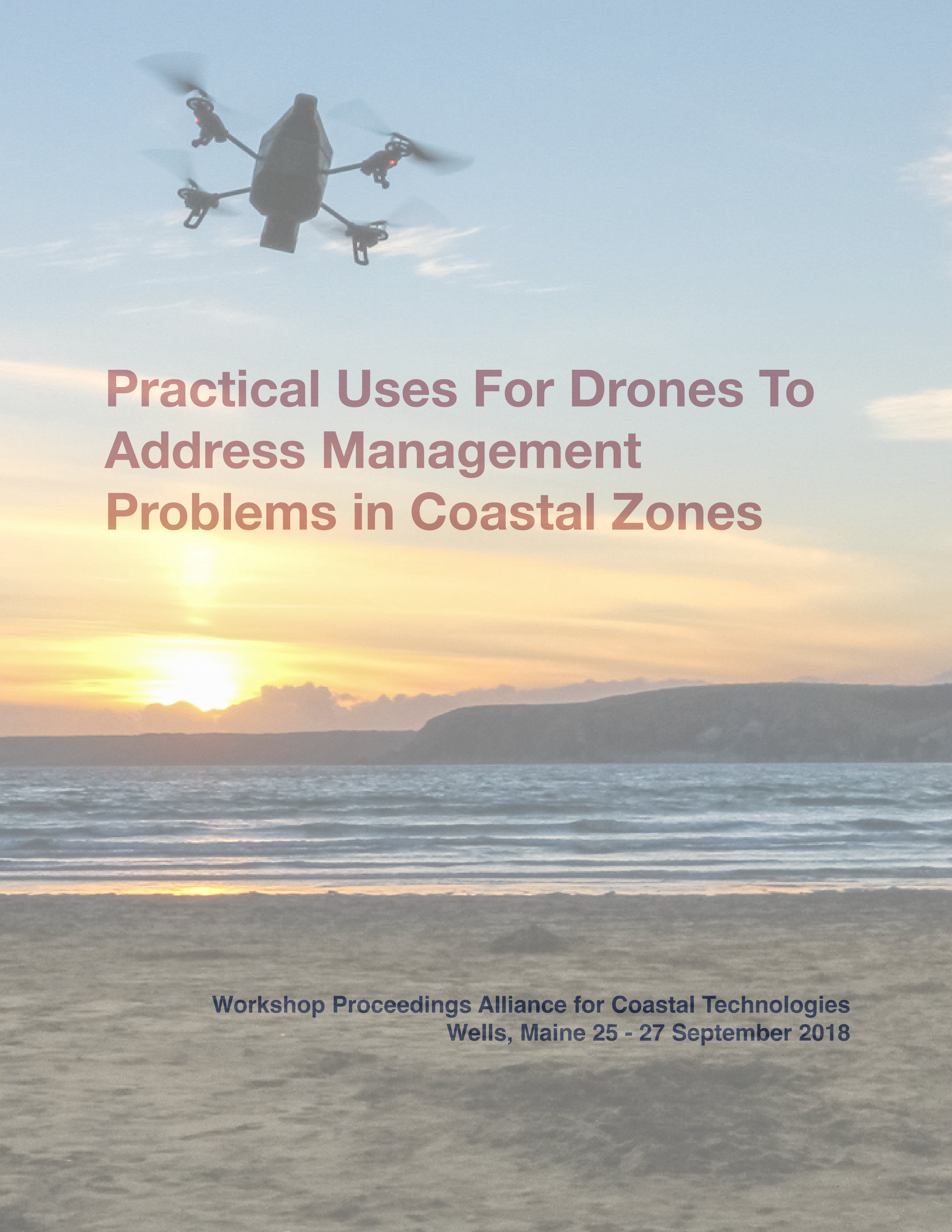

Practical Uses For Drones To Address Management Problems in Coastal Zones

Workshop Proceedings Alliance for Coastal Technologies
Wells, Maine 25 - 27 September 2018

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Alliance for Coastal Technologies

PRACTICAL USES FOR DRONES TO ADDRESS MANAGEMENT PROBLEMS IN COASTAL ZONES

Wells, Maine
September 25–27, 2018

This workshop was organized and hosted by the Alliance for Coastal Technologies (ACT) and sponsored by the National Oceanic and Atmospheric Administration (NOAA) / US Integrated Ocean Observing System (IOOS).

ALLIANCE FOR COASTAL TECHNOLOGIES

About ACT

The Alliance for Coastal Technologies (ACT) is a partnership of research institutions, resource managers, and private-sector companies dedicated to fostering the development and adoption of effective and reliable sensors and platforms for use in coastal, freshwater, and ocean environments. ACT workshops are designed to aid these partners by identifying and discussing the current status, standardization, potential advancements, and obstacles in the development and use of sensors and sensor platforms for studying, monitoring, and predicting the state of coastal, fresh, and open-ocean waters. The workshop goals are to both build consensus on the steps needed to develop useful tools while also facilitating the critical communications between the various groups of technology developers, manufacturers, and users. Workshop reports provide a status report on current technologies and recommendations for both ACT and the broader community on steps forward. For more information, visit www.act-us.info.

About NERACOOS

The Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) is one of eleven Regional Associations that make up the US Integrated Ocean Observing System (IOOS). NERACOOS covers ocean and coastal waters from the New York Bight to the Canadian maritime provinces, including the New England states and the Gulf of Maine. For more information, visit www.neracoos.org.

Workshop Steering Committee

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Acronyms

ACT	Alliance for Coastal Technologies
NERACOOS	Northeastern Regional Association for Coastal and Ocean Observing Systems
NOAA	National Oceanic and Atmospheric Administration
CO-OPS	NOAA Center for Operational Oceanographic Products and Services
OCM	NOAA Office for Coastal Management
UAS	Unmanned Aircraft System (commonly known as a drone)
IOOS	Integrated Ocean Observing System
USGS	United States Geological Survey
WNERR	Wells National Estuarine Research Reserve

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Executive Summary

The Alliance for Coastal Technologies (ACT) and the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) convened a workshop on *Practical Uses for Drones to Address Management Problems in Coastal Zones* at the Wells National Estuarine Research Reserve (WNERR) in Wells, Maine, on September 25–27, 2018. The workshop was designed to facilitate sharing of information and best practices to support the rapidly expanding applications of unmanned aircraft systems (UASs), commonly called drones, in coastal management.

The goals of the workshop were to:

- Summarize the state of technology in research- and monitoring-grade UASs
- Compile examples of current use in this area
- Understand the limitations and logistical challenges associated with UASs
- Develop operational and data management/analyses best practices
- Describe future developments and applications for coastal ocean observing systems

The workshop also sought to explore the challenges of doing truly quantitative multispectral and hyperspectral remote sensing in coastal marine environments and the legal and privacy issues associated with using drones in public and private lands and ocean spaces.

To promote broad input and cross-sector information-sharing, workshop participants included private-sector UAS technology developers and service providers, academic researchers developing and/or using UASs, and government agency staff members with experience in using UASs or UAS data or working on management issues that could be addressed with UASs.

The first day of the workshop featured field demonstrations of three types of UASs: quadcopter, fixed wing, and hexacopter. On the second and third days were four panel sessions with a total of twelve presentations:

1. Use of drones to survey habitats (e.g., kelp, seagrass, intertidal) and marine life (e.g., sea otters, herring milt, jellies) in British Columbia
2. Research toward using drones for harmful algal bloom (HAB) detection and monitoring in Florida
3. Research applications of drones in Chesapeake Bay, including studies of HABs
4. Testing drones as a tool for surveying tidal marshes at three sites on the East Coast, Gulf Coast, and West Coast
5. Drone technology being developed in Hawaii for marine living resource protection, monitoring of coral reef bleaching, detection of marine debris, and other applications
6. Development of the first fixed-wing drone capable of transitioning between air and underwater flight
7. Use of drones by the US Geological Survey (e.g., surveys of coastal erosion and flood inundation)
8. Mapping estuarine and barrier beach habitats in Maine with LiDAR and orthophotography
9. Best practices for UAS missions
10. Development of a "flying submersible" product line
11. Using drones for coastal/offshore transects and other research in Monterey Bay
12. Development of a hybrid unmanned air/underwater multipropeller vehicle

Each panel session was followed by breakout group discussions. Plenary sessions included report-outs from the breakout groups and large-group discussions of the panel and breakout topics. Among the key takeaway messages from the presentations and discussions were the following:

- While UASs are a new tool for coastal management, their value has been demonstrated for a wide variety of applications such as habitat mapping, wildlife monitoring, detection of coral bleaching, shellfish management, marine debris detection, monitoring shoreline change, management of beaches and sand resources, mapping flood zones, and inspection of bridges and other structures.
- UASs could also be useful in many other management contexts such as harmful algal bloom (HAB) detection and tracking, monitoring of human/animal interactions, water quality monitoring, pollutant tracking, and monitoring tidal marsh stability.
- Managers are eager to use drones, but how to use them is not always well understood. It is important to begin by asking, "What is the management question or problem?" This will determine what data are needed and how they should be collected, which may be drones.
- As with any data, drone data need to be translated into information, which can then be used for management.
- Using drones to acquire accurate quantitative geospatial data is challenging and requires advanced technical skills and knowledge. Hiring experts in drone operations and data processing is typically necessary.
- Best practices for using drones to collect geospatial data are well established. Guidance on best practices is available in publications such as the PrecisionHawk e-book *Beyond the Edge* and the USGS *Unmanned Aircraft Systems Data Management Plan 2015*.
- Workshop attendees identified short flight times due to battery constraints as one of the biggest limitations in drone technology at present. Other desired technological improvements include expanded payload capabilities, modularity to allow drones to carry different payloads/sensors, all-weather capabilities, "smarter" drones with situational awareness, increased data storage capacity, standardization of data types, improvements in data management such as on-board data processing, and capabilities that go beyond imagery and remote sensing such as deploying water sampling devices.
- Laws and regulations constrain the use of drones for ocean and coastal research and management. For example, drones can be flown only below 400 feet and must remain within the pilot's line of sight at all times. Each drone must be flown by a dedicated, licensed pilot, meaning multiple drones cannot be controlled by a single pilot as in a swarm. Another important consideration is that uncertainty about potential changes in laws and regulations make it difficult to plan research.
- Testing and evaluation of UAS platforms and sensors by an independent entity such as ACT would be very useful to researchers, managers, and technicians.

Introduction

To support advancements in the use of unmanned aircraft systems (UASs), commonly called drones, for coastal management, the Alliance for Coastal Technologies (ACT) and the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) organized and hosted a workshop on *Practical Uses for Drones to Address Management Problems in Coastal Zones*. The workshop was funded by the National Oceanic and Atmospheric Administration (NOAA) through its US Integrated Ocean Observing System (IOOS) Program Office.

A Steering Committee with members from government, academia, and the private sector planned and executed the three-day workshop. Workshop planning was informed by previous events addressing similar issues, such as the NOAA Unmanned Aircraft Systems Symposium (2016), the Federal Unmanned Aircraft Systems Workshop (2017), and the New England Drone Conference (2018), and by publications such as the *NOAA Unmanned Aircraft Systems (UAS) Handbook* (2017) and the NOAA final report on *Unmanned Aircraft System LiDAR and Imagery in the National Estuarine Research Reserve System* (2018).

UAS technology is advancing rapidly, and the many types of UASs and sensors commercially available today offer much greater capabilities than those available even just five years ago. UAS payloads include RGB cameras (still and video), LiDAR, infrared sensors, and multispectral and hyperspectral sensors. In some cases, UASs can collect geospatial data faster, at higher resolution, and at lower cost than conventional platforms (aircraft, ships, satellites). UASs may also provide an alternative to on-the-ground data collection methods, such as marsh vegetation transects which may harm sensitive species and habitats. Operation of UASs and processing of UAS data for scientific data collection is a complex undertaking requiring specific skills, knowledge of best practices, and an understanding of the limitations of UAS platforms, sensors, and data.

During workshop planning, the Steering Committee developed a draft list of Problem Areas in which UASs could be helpful. This list provided a starting point for discussions at the workshop:

- Changing coastal water quality, including storm runoff, turbidity, productivity, flow patterns, harmful algal blooms (HABs), and marine debris
- Coastal zone physical processes, including water depth measurement, land elevations, vegetation structure, coastal erosion rates, beach profiling, habitat changes, and effectiveness of living shorelines (e.g., marsh die offs, seagrass disturbance)
- Animal populations studies beyond stock assessments, including forage fish; individual animal health, including whale body condition, seabird and seal colony assessments; and mass estimation of invasive species

The goals of the workshop were to

- Summarize the state of technology in research- and monitoring-grade UASs
- Compile examples of current use in this area
- Understand the limitations and logistical challenges associated with UASs
- Develop operational and data management/analyses best practices
- Describe future developments and applications for coastal ocean observing systems

The workshop also sought to explore the challenges of doing truly quantitative multispectral and hyperspectral remote sensing in coastal marine environments and the legal and privacy issues associated with using drones in public and private lands and ocean spaces.

To promote broad input and cross-sector information-sharing, the workshop included participants (see Appendix A) from the following sectors:

- Private-sector UAS technology developers and vendors of UAS services
- Government agency staff members with experience in using UASs and/or UAS data for coastal management or working on management issues that could be addressed with UASs
- Academic researchers developing and/or using UASs

The workshop was held at the Wells National Estuarine Research Reserve in Wells, Maine, from September 25–27, 2018. The workshop agenda (see Appendix B) began with a morning of practical demonstrations of three types UASs. The next two days consisted of panel presentations on key themes followed by breakout group discussions. The breakout discussions were guided by questions (see Appendix B) developed by Steering Committee. Plenary sessions included report-outs from the breakout groups and large-group discussions of the topics.

The Wells Reserve is one of 29 National Estuarine Research Reserves established around the country to contribute to, and benefit from, nationwide initiatives that advance knowledge and stewardship of coasts and estuaries. National Estuarine Research Reserves operate as partnerships between NOAA and coastal states. Located on the southern Maine coast, the Wells Reserve encompasses 2,250 acres, including three watersheds, upland fields and forests, freshwater and estuarine wetlands, and a beach-and-dune system. The Reserve conducts programs in coastal research and monitoring, environmental learning and decision-maker training, and land and water resource management. Its coastal location, on-site meeting facilities, and focus on management-relevant coastal research made it an ideal location for the workshop.

The workshop was held at Wells National Estuarine Research Reserve in Wells, Maine.

Some of the workshop attendees gathered in the area of the Reserve where demonstration flights were conducted.

Demonstration Flights

The first day of the workshop featured three practical demonstrations by workshop participants who flew three different types of UASs: a small quadcopter, a fixed-wing UAS capable of vertical takeoff and landing (VTOL), and a large hexacopter. The demonstrations were originally planned to cover an area of salt marshes. However, a forecast of heavy rain caused them to be relocated to an upland area adjacent to the Reserve's meeting facility, where the UASs could be moved quickly indoors if necessary. Fortunately, the rain held off long enough for all three demonstrations.

The UAS demonstrators were workshop participants who had volunteered to bring and operate their drones. Each demonstration began with a brief introductory discussion of the UAS hardware and software, the ways in which the demonstrator typically uses the UAS, and the strengths and limitations of the system, as well as any special considerations for using it. Other workshop participants watched from a safe distance as the demonstrators launched their UASs and flew the predetermined survey area. The area included a field, a few trees and shrubs, and a variety of structures, including unrestored farm buildings. The UAS data will be useful to the Wells Reserve's staff, who are planning improvements and new uses for these buildings.

Demonstration 1: Small Quadcopter with RGB Camera

Sandy Brosnahan, USGS Aerial Imaging and Mapping (AIM) Group

Sandy Brosnahan of the U.S. Geological Survey's Aerial Imaging and Mapping (AIM) Group, based at the USGS Woods Hole Coastal and Marine Science Center in Woods Hole, Massachusetts, conducted the first demonstration flight. She flew a small, low-cost quadcopter (3DR Solo, approximately $1,200) carrying an RGB camera (Ricoh GR II, approximately $600). The AIM Group uses drones for beach erosion surveys, classification and biomass estimation of marsh vegetation, and other applications. They also have a GoPro4 and a MicaSense RedEdge multispectral sensor. On takeoff, Brosnahan brought the quadcopter directly to an altitude of 80 meters and then initiated a pre-specified, automatic flight path, which she had set up prior to launch in Mission Planner software. The software allowed her to specify, for example, the spacing of the drone's passes over the survey area and therefore the amount overlap of images. In a recent comparison of their data to LiDAR data collected by the U.S. Army Corps of Engineers, Brosnahan's team found that their data had a high level of accuracy, despite being from a low-cost, consumer-level UAS.

USGS demonstration flight.

Demonstration 2: Fixed Wing with RGB Camera

Erich Freymann, BirdsEyeView Aerobotics

The second demonstration mission was a fixed-wing drone (FireFLY6 PRO, approximately $6,000) flown by Erich Freymann of BirdsEyeView Aerobotics. While the FireFLY6 has a fixed wing, it can take off and land vertically like a quadcopter or hexacopter. For the demonstration, the drone carried an RGB camera (Sony a6000, approximately $500) with a 16 mm lens. Many other payloads are possible, such as multispectral and infrared sensors. A live video feed carried imagery from the aircraft to a computer; the feed can be displayed on multiple screens, if desired. After launching and ascending to 100 m, the FireFLY began automated flight along a pre-determined track. At the end of each leg, the drone flew a short distance beyond the survey area boundary, made a tight 180° turn, and returned to the survey area, flying parallel to the previous leg. The drone was guided by RTK GPS, providing very accurate geotagging of images during flight. Relative accuracy was approximately 1.4 cm. At the end of the flight, the drone descended vertically to land at the takeoff site. Two advantages of fixed-wing drones are speed and long battery life. The FireFLY6 completed the demonstration flight in approximately three minutes. With a battery life of one hour, it is capable of mapping 500 to 600 acres per flight. For surveys of small areas, the long battery life can be leveraged to acquire a large number of images.

BirdsEyeView Aerobotics demonstration flight.

Demonstration 3: Large Hexacopter with LiDAR

Sam Johnson and Ian Ray, AirShark

The third demonstration featured a large hexacopter (DJI M600, approximately $5,000) carrying a Phoenix LiDAR Systems miniRANGER sensor and an RGB camera (total cost for sensor and camera approximately $120,000). Other equipment such as ground station, RTK GPS, Pelican cases, laptops, and batteries added another $20,000 to $25,000 to the total cost of the setup. AirShark is a New Hampshire-based commercial vendor of UAS services including data collection, image analysis, and video production. AirShark's staff follow detailed protocols during missions, including a careful, detailed inspection of the aircraft and sensor prior to takeoff. One member of the AirShark team manually piloted the aircraft, while the other operated the LiDAR sensor and monitored data collection on a laptop computer. Both wore protective helmets with built-in microphones to talk to each other during the mission. The mission began and ended with the aircraft flying in a figure-eight pattern for a few minutes to calibrate its GPS with a known GPS base station on the ground. One reason AirShark pilots typically fly manually is that the GPS calibration takes a different length of time (1-3 minutes) each mission, making it impossible to automate the timing of the mission. In addition, AirShark frequently flies its drones over uneven terrain where automated flight is impractical. During the demonstration flight at 200-foot altitude, the LiDAR collected 40-50 points per square meter with 3-5 cm vertical accuracy.

AirShark uses an RGB camera with 8-10 cm resolution, which is fairly coarse but suitable for the main purpose of colorizing the LiDAR point cloud. The images from the camera can also be processed into an orthomosiac, and this is a good reference for identifying objects in the LiDAR data. During the flight, a subset of the data were encrypted and streamed down to the laptop over a publicly available wifi network. A flight like the demonstration typically produces 5-10 GB of data; the LiDAR files are large, but only approximately half the size of the photogrammetry files. After landing, the aircraft was left untouched and perfectly still for 5 minutes to allow it to exactly calibrate zero altitude using GPS. AirShark uses OPUS for base station corrections. From there, they use NovAtel Inertial Explorer to correct the trajectory of the aircraft with the OPUS. They then run the data through Phoenix Spatial Fuser to export into .LAS format. Within GlobalMapper, they bring in the .LAS file to process the following: Classified Point Cloud, 3D Contours (DXF / SHP), Raster Surface Model (DSM), Volume Calculations, Raster Terrain Model (DTM). The AirShark staff dedicates considerable time to maintaining drones, reflecting the cost and complexity of the systems.

Upper: Landing at end of the AirShark demonstration flight. Lower: LiDAR views from AirShark demonstration flight.

Panel 1: Examples of Current UAS Use in the Coastal Environment

Use of Drones for Coastal Research at the Hakai Institute

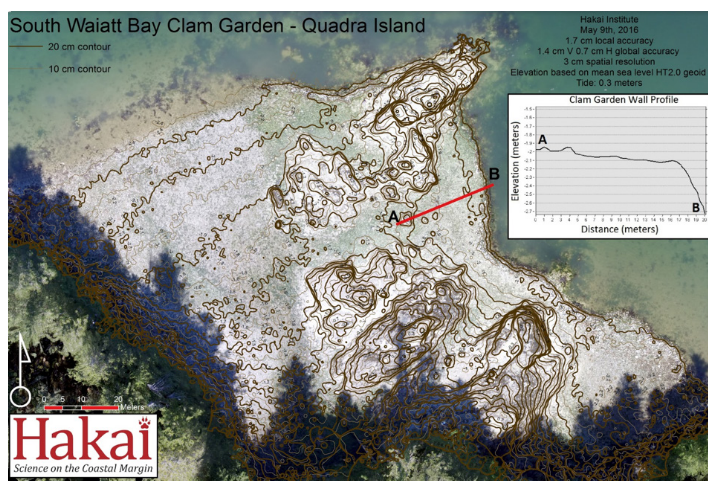
Will McInnes, Hakai Institute

The Hakai Institute is a non-profit scientific institution that conducts long-term research at remote locations on the coast of British Columbia, Canada, and seeks to inform sound policy and resource management. Their research extends from mountain ice fields to the ocean. Geospatial data collection is an important part of their research program. They use satellite data, small airplanes with aerial LiDAR, UASs, remotely operated underwater vehicles (ROVs), and acoustic sonar.


Composite of many missions flown on Calvert Island in 2018 to map kelp.

Hakai first used drones in 2014 for a study of sand dunes and beach dynamics. In 2018, they conducted more than 500 UAS flights. Hakai now use drones for a wide range of research programs:

- Surveys of kelp and seagrass: Unlike helicopters, which they used in the past, drones allow Hakai to conduct surveys even during foggy and cloudy periods by taking advantage of brief windows of good visibility. They are able to map large areas in high detail, and it is possible to distinguish between kelp species.
- 3D habitat modeling: Hakai researchers use drone data to build high-resolution 3D models of intertidal habitats.
- Archaeological features: Hakai uses drones to create detailed maps of ancient clam gardens created by First Nations, who constructed rock walls near the low tide line.



Mapping of intertidal archaeological features: clam garden.

- Snow depth: Hakai uses drones to map snow depth by comparing winter and summer surfaces. The data are used in models of snow depth in relation to weather and ecosystem conditions.
- Sea otter monitoring: For counting sea otters, the angle of view provided by a drone is better than the view from a boat.
- Herring milt: Hakai uses drones to map herring milt dispersal as it enters from streams into the ocean.

- Jellyfish bloom mapping: Hakai is comparing aerial data from drones with tow data from boats.

Herring spawning.

Hakai primarily uses the relatively inexpensive, consumer-level DJI Phantom because of the risk of loss in the rough environments where their research occurs. Recently, they also began using the DJI Matrice 210 because it can carry more sensors, and they use RTK GNSS (Real-Time Kinematic Global Navigation Satellite System). For classification, they use Pix4D and LAStools.

High-accuracy ground targets is the key to an accurate repeatable survey.

McInnes identified the following keys to their successful use of drones:
- Their team has a strong geodesy and GNSS background.
- They use high-accuracy ground targets for an accurate, repeatable survey.
- They also collect data on the ground or underwater (e.g., kelp) to understand what is being mapped.
- They use various sensors to obtain the best possible data for the application, such as near-infrared (NIR) to visualize submerged kelp.

Among the biggest challenges and limitations that they have encountered are the following:
- Spectral calibration is extremely difficult because of changes in light due to clouds and other variables. Drone data are more difficult to process than satellite data in this regard.
- Ground control is challenging when flying over water. They tend to fly higher and get control points from rocks and other features.
- In surveys of kelp coverage, correcting for tide height is necessary but challenging. To model how kelp coverage changes with tide height, they did 100 flights to collect data at different tide heights.
- Structure from Motion drone data from beach surveys tend to be noisy because the beach surface is fairly homogeneous. The point clouds often need to be cleaned up.

UAS Technology for Remote Sensing of Florida Harmful Algal Blooms (HABs)

Vincent Lovko, Mote Marine Laboratory

The marine dinoflagellate *Karenia brevis* causes near-annual blooms of red tide along the Gulf Coast of Florida. It produces a potent neurotoxin called brevetoxin. Early detection and accurate tracking of red tide is critical to protect human health. Currently, field detection via boat-based sampling can take days, is expensive, and lacks spatial and temporal resolution. Lovko is working with colleagues from City College of New York (CCNY) on using VIIRS (Visible Infrared Imaging Radiometer Suite) satellite data and a neural network model to detect changes in ocean color considered indicative of a *K. brevis* bloom. However, satellite data have important limitations: Typically, only one satellite image is available per day, often no images are available for multiple days in a row due to cloud cover, and spatial resolution is insufficient to relate satellite-based data to cell concentrations.

Red tide in Florida.

Lovko is in the early stages of exploring the use of UAVs as a platform for sensors for detecting red tide. UAVs have several perceived advantages for this work:

- low cost
- low altitude flight: improved spatial resolution and temporal coverage
- different sensors available: multi- vs. hyperspectral
- data can be used with existing algorithms used for satellite data (VIRRS; normalized fluorescence line height [nFLH])
- improved data resolution: less than 1 m^2 compared to approximately 1 km^2 for nFLH data
- potential for improved taxon discrimination

UAVs could complement other autonomous monitoring that is already being done with gliders. In an ideal scenario, Lovko envisions that UAVs would deploy periodically, perhaps weekly or monthly, to scan for blooms, which are thought to originate approximately 10–40 miles offshore. If a bloom were detected, researchers would conduct sampling from boats to verify it. Lovko's group does not yet have a plan to address the challenge of maintaining calibration of the hyperspectral sensor, which can be thrown off by clouds and other changes in lighting. In addition to imagery, Lovko sees potential for drones to deploy in-water sensors and water samplers to collect additional data for *K. brevis* detection. Other potential applications include the use of drones to sample for aerosols produced by HABs.

Drone Applications at Virginia Institute of Marine Science

Donglai Gong, Virginia Institute of Marine Science

Bloom streaks in the York River in July 2017. Read more at: https://phys.org/news/2017-09-aerial-drones-sweet-hab-vims.html#jCp

Scientists at the Virginia Institute of Marine Science (VIMS) have used drones since 2013 for several areas of research. The Center for Coastal Resource Management first acquired a drone in 2013 for shoreline surveys. The Coastal and Polar Physical Oceanography Lab started marine drone operations in 2014. The Coastal Geomorphology and Ecology Lab started using drones to study marsh evolution in 2015. VIMS offered its first graduate-level course in drone operations and applications in spring 2017. The Eastern Shore Lab started using drones to study marsh grass die-off in 2017.

Multiple VIMS labs began collaborating in summer 2017 to study harmful algal blooms (HABs) using drones and vessel-based surveys. In the past decade, HABs have worsened in the Chesapeake Bay, and yet the drivers of HAB events are largely unknown. The blooms can vary on an hourly timescale with fine-scale features of one meter or less. Gong is interested in whether HAB structure and variability are biologically or physically driven. His research group is using the York River as a testbed for developing HAB monitoring tools, including drone technology, which will be applicable to other parts of Chesapeake Bay.

Drone imagery enables the research team to analyze structures and patterns in HABs that cannot be visualized easily otherwise. The images reveal that HAB distribution is very dependent on tidal circulation and mixing. HAB hotspots are often found in shallow embayments, and blooms can occur in a matter of days after a mixing event. The next step is to develop methods for drones to identify the types of HAB organisms in the water, which will require new multispectral sensors. The researchers are currently trying to determine the most useful type of hyperspectral sensor. As an example, a typical field of view for a sensor is 18 degrees and they range up to 40 degrees, but the wider field of view can lead to more issues with glare.

Gong and his collaborators have found that drone technology enables effective monitoring of small tributaries and other neighborhood-scale water bodies. Drones excel in providing high-resolution data and event-scale rapid response. Challenges remain in data georeferencing, processing, calibration, and sharing. Gong believes that precision georeferencing and advanced sensors such as multispectral and hyperspectral sensors will drive future quantitative applications in coastal research and monitoring.

Plenary Discussion

After the Panel 1 presentations, a plenary discussion took place. Main topics of discussion included the following:

- There is a whole remote sensing literature and field of practice that often biologists are not aware of when they begin to fly drones with an eye toward using them in research. Familiarity with well-established remote sensing practices and considerations is important so that biologists can make informed decisions about how to operationalize drones as a research tool. For example, for satellites there are whole teams of specialists who do calibration and ground control. Individual drone operators do not have all of that expertise and capacity. Deploying drones to collect good data usually requires a team of people with specific expertise in drone operations. This is important for biologists and others to consider.
- One practical problem that researchers often encounter in trying to use drones in the context of coastal research and management is that the metal hull and components of a ship can throw off the drone's compass, causing the drone to fly missions incorrectly. Having a way to avoid this issue would be very useful. One workaround is to use fixed-wing drones, which can be launched with a catapult from a boat, avoiding the compass issues.
- It would be extremely helpful if there were a standardized system of connectors for drone hardware. This would make it easier to use multiple types of sensors, allowing integration of different types of data.
- The consensus was that relatively short flight times are currently the biggest limitation in drone technology.

Breakout Group Discussion 1: Current Uses of UASs

Following the Panel 1 presentations, the workshop participants split into three breakout groups to discuss uses of UASs in the coastal zone. The discussions were guided by questions listed on the agenda (see Appendix B). Notetakers assigned to each group wrote notes in a shared Google Doc.

Q1-1: Are the Problem Areas [see list on the workshop agenda] correct? What else?

The breakout groups agreed with the Problem Areas listed in the agenda. They also identified three categories that should be added, as well as a number of subcategories that should be added to the original categories.

Categories:

- Ports and coastal infrastructure, including physical condition of piers, jetties, bridges; ocean traffic for port authorities and harbor pilots; navigation channels/charting; ship collisions with whales
- Public safety, including search and rescue, oil spills and other emergency response situations, natural disasters and storm damage, environmental hazard mitigation, beach closures
- Historical sites, such as shipwrecks, water burial grounds, and historic structure assessments

Subcategories:

- The category "Changing coastal water quality and air quality" should also include changes in air quality associated with HABs.
- The category "Coastal zone physical and habitat processes" should also include erosion of polar coastlines, monitoring river plumes and internal waves with complementary surface and underwater measurements, wave run-up, sea level height, shallow-water bathymetry, and groundwater seeping into waterways.
- The category "Animal populations" should also include human/animal interaction (e.g., ships and whales), presence of animals (e.g., white shark), managing/closing beaches, anti-poaching, telemetry, estimating populations (e.g., turtles, seals, manatees), animal strandings and mortality events, and invasive species removal.

Q1-2: How and where are UASs used to survey the coastal zone? Please give specific examples.

The breakout groups felt that the Panel 1 presentations discussed many of the most important ways that UASs are used in the coastal zone at present. Other applications include:

- Monitoring of shoreline change, e.g., beach profiles, erosion, topographic changes
- Nearshore oceanography
- Pollutant tracking
- Real estate surveys, e.g., for insurance claims after severe weather
- Sampling whale snot and blow holes
- Monitoring tidal marsh stability
- Tide and current measurements

- Emergency response
- Testing accuracy of dispersion models
- Measuring gases and mapping fissures at Hawaiian volcanoes

Q1-3: Which aspects of coastal management are UASs regularly used for?

- Monitoring shoreline change (e.g., erosion, beach profiles before and after severe weather events, 3D mapping)
- Mapping flood zones (e.g., Norfolk and Virginia Beach)
- Fisheries management (e.g., oysters and other shellfish)
- Management of beaches and sand resources (i.e., determining where and when to replenish sand on beaches)
- Oil spill management and damage assessment
- Harmful algal bloom (HAB) detection and tracking
- Habitat/ecosystem mapping and monitoring (e.g., seagrass, kelp, oyster beds, marshes, coral reefs)
- Wildlife monitoring (e.g., sea otters, marine mammals, shorebirds)
- Marine mammal management and research (e.g., response to strandings, deployment of hydrophones), as drones can be less disruptive to wildlife and more cost effective
- Carbon sequestration and payment for carbon credits (e.g., marshes, seagrass)
- Legal aspects of coastal infrastructure and communities (e.g., surveys of development impacts and sand resources, zoning/permitting, history of erosion at potential development sites)
- Enforcement of no-discharge zones (e.g., release of bilge water)
- Education and outreach

Q1-4: How is information from UASs combined with other data?

- Satellite data complement drone data by providing greater spatial coverage, but with lower temporal resolution.
- Ground/underwater surveys (on land/boats or with buoys/divers) provide in situ measurements to compare with and improve classification of drone data.
- NOAA uses drone data in combination with transect data for beach profiles.
- Sensor fusion techniques are used for navigation issues and obstacle avoidance, telemetry and animal tracking, coastal monitoring with GIS, emergency response, and monitoring of fish population densities for fishery management.
- Many important issues often arise when attempting to combine drone data with land survey data. For example, people use various coordinate systems and datums, which can lead to confusion or misinterpretation. Users need to be aware of these differences and convert data if necessary. There is an increasing need for standards such as for metadata and filenames. Even different branches of federal government, such as NOAA, USGS, and the military, use different metadata formats. For researchers who are not aviators or surveyors, it is difficult to know all the issues involved, and they may need to engage experts who do know. Many

issues arise as people increasingly collect and exchange different datasets. What is each dataset validated to? What does it really mean? How accurate do the data need to be, given the tradeoff between cost and accuracy? What is needed in terms of accuracy within a dataset versus accuracy between datasets (e.g., for monitoring HABs in the same place over time, absolute accuracy does not matter too much, as long as the images match up from one to the next)? How do you perform quality control (e.g., AirShark brings in licensed surveyors to verify ground control points)? Who has liability if the survey result was not accurate?

Q1-5: How are UASs used to influence / benefit management decisions?

- Issuing public bulletins about harmful algal blooms (HABs) based on data collected by drones
- Management decisions about oyster beds based on drone surveys
- Determining management action (e.g., assisted tree cutting) to facilitate marsh migration based on drone monitoring of marsh and other vegetation
- Mapping elevation in tidal marshes more accurately than traditional LiDAR, due to density of vegetation
- Identifying hotspots for invasive species, algal blooms, and coral bleaching
- Aerial footage of fish spawning events (e.g., anchovy) informing fishery management
- Telemetry to detect presence of tagged birds in foraging habitat
- Oil spill tracking
- Determining storm damages monitoring of coastal infrastructure (e.g., breakwaters)
- Power line monitoring
- Dam break analysis (structural integrity)
- Orca monitoring
- Disaster response: using drone data to direct resources to places with greatest need
- Deciding where to establish no-boating areas to protect manatees or seagrass
- Potential use of drones for marsh vegetation surveys instead of quadrats and stem counts, which damage the marsh, while recognizing that drones will not be able to provide the same kind of data (i.e., need to figure out what data can be collected by drone to answer the management questions)
- Decision-making about beach nourishment (e.g., Town of Sandwich, MA)
- In terrestrial systems, prevention of poaching of large game animals by keeping track of animal populations and people's activities
- At this time, it seems that drones are used more often in terrestrial applications (agriculture, animal populations, oil pipelines, infrastructure) than marine, which translates into many potential management uses for drones in a marine environment similar to how they are being used terrestrially.
- Important to make sure lines of communication between managers and scientists are open so that managers are aware of what data may be available
- As with any data, drone data need to be transformed into information, which can then be used for management.

- Managers are eager to use drones, but how to use them is not always well understood. It is important to start by asking, “What is the management question or problem?” This will determine what data are needed and how they should be collected, which may be drones.
- Education is needed to help managers understand how drones can be useful and when drones offer advantages that justify cost and other concerns.
- People should consider hiring out drone work because there are so many skills, so much expensive hardware, and so much time needed to do it right. “If you’re not going to devote all your time to drones, you’re not going to do it well.”

Panel 2: State of Technology & Limitations / Logistical Challenges

Unmanned Aerial System-Based LiDAR and Imagery in National Estuarine Research Reserve Marshes

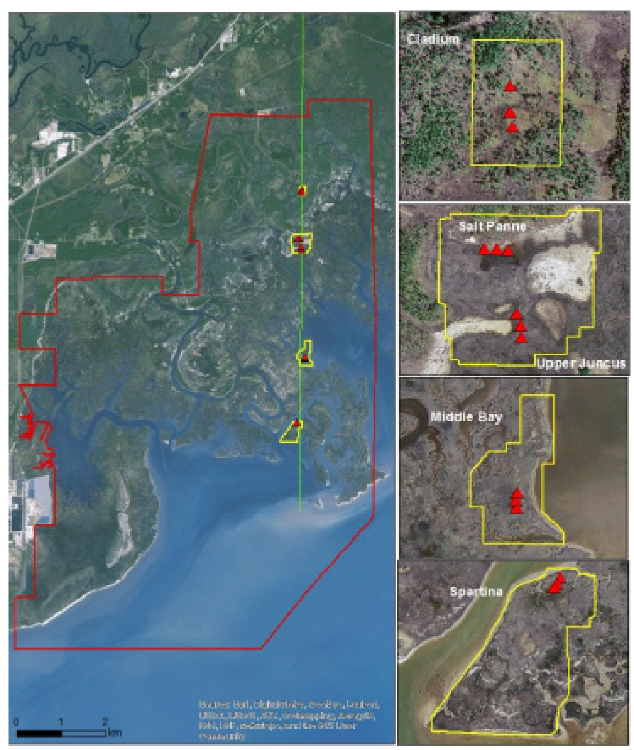
Kirk Waters, NOAA Office for Coastal Management

In 2016 and 2017, the NOAA Office for Coastal Management (OCM) contracted with private-sector UAS service providers to acquire multispectral imagery and LiDAR data at three National Estuarine Research Reserves: Jacques Cousteau NERR (JCNERR, New Jersey), Grand Bay NERR (GBNERR, Mississippi), San Francisco Bay NERR (SFBNERR, California). The objectives of the project were to evaluate the efficacy of unmanned aerial system imagery and LiDAR, compare UAS data to manned data, and evaluate the value of private sector contracting for an operational program. The project was designed to help address general questions related to vegetation mapping and measurement of elevation, primarily in marsh systems: Can UAS imagery provide better data for monitoring habitat and vegetation changes, and at what price? Can UAS improve LiDAR performance in marsh areas? On beaches, how do 3D elevation data from UAS LiDAR compare to transect data? Can the canopy be visualized by combining imagery structure-from-motion (SfM) and LiDAR data?

Project area at Jacques Cousteau NERR flown in March 2017.

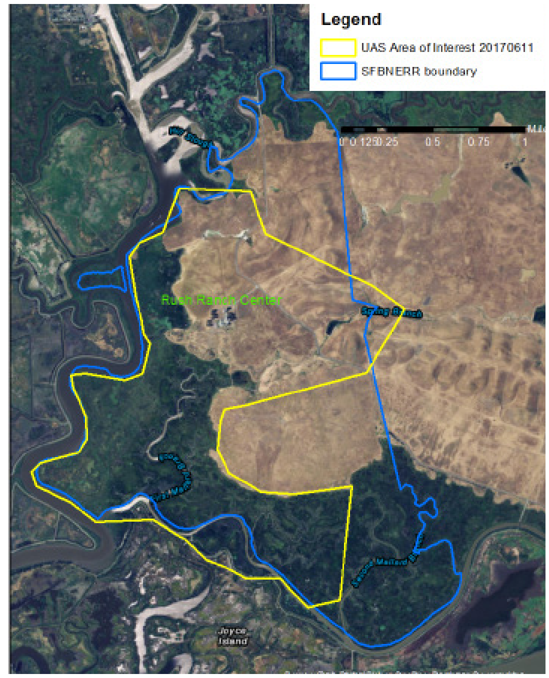
The planned products were multi-spectral (at least four-band) imagery with 3-centimeter resolution or better; LiDAR flown on the same platform to produce elevation data; LiDAR data classified for ground, water, and unclassified, with a non-vegetated vertical accuracy of 10 centimeters or better; and a digital surface model from structure from motion. The exact specifications were determined by the contractor to meet the data requirements.

In the pre-mission phase of the project, OCM encountered significant challenges and delays related to regulations, land ownership, and contracting. The process of obtaining a Certificate of Authorization (COA) from the Federal Aviation Administration was time consuming, and the delays pushed back data collection by over a year. At SFBNERR, the presence of a state- and federally listed bird species, the California black rail, nesting in the marsh meant



Project areas at Grand Bay NERR flown in May 2017.

that no flights could occur until September 2017. Similarly, UAS operations at JCNERR were constrained by a bird closure beginning March 15. Obtaining permission to use private lands for UAS deployment took considerable time, and in one case permission was denied and arrangements had to be made to access an alternative site. The contracting process necessary to work with private-sector vendors took three months, which would make rapid-response UAS operations challenging. Altogether, delays from the COA, bird nesting, and many iterations of the area of interest (AOI) meant that the pre-mission process for SFBNERR, for example, took from April 2016 to September 2017.



Project area at San Francisco Bay NERR flown in September 2017.

Platforms used by the contractors included a fixed-wing Lancaster 5 at JCNERR (LiDAR and imagery) and GBNERR (LiDAR), a Matrice 100 quadcopter at GBNERR (imagery), and a Matrice 600 hexacopter at SFBNERR (LiDAR and imagery).

In addition to pre-mission challenges, SFBNERR proved to be the most challenging site for data collection and processing. Covering more than two square miles with a 200-foot flight ceiling, the mission generated more than 380,000 images over 6 days of flying. Changes in illumination during those days required breaking the data into discrete blocks for processing, which took 7 months.

Key results from the study:

- LiDAR data: OCM found that UAS data can meet similar accuracy requirements used for manned flights with proper care (e.g., ground control). UAS data had smaller errors and greater consistency. UAS LiDAR appears to penetrate marsh vegetation better than manned LiDAR, and it has much higher point density. However, UAS may not be the best choice for surveys of large areas.
- Structure from motion: SfM results were generally not satisfactory. SfM may not be a good choice in homogeneous marsh areas.
- Habitat mapping: UAS imagery's advantages for habitat mapping are still being evaluated. Compared to satellite data, UAS data provided approximately the same overall accuracy. UAS imagery is capable of mapping detailed features, but the UAS image mosaic had problems with spectral uniformity across the scene. UAS band-offset caused problems in forested areas.
- Private-sector UAS contractors: The contractors in this project were good partners and produced higher-quality data than previous UAS data acquisition efforts in GBNERR.
- Cost: UAS data can be cost effective, but the right technology (e.g., UAS, manned, satellite) is situation dependent.

UAS Use in Marine Environments: State of Technology

Garrett Johnson, Applied Research Laboratory, University of Hawai'i

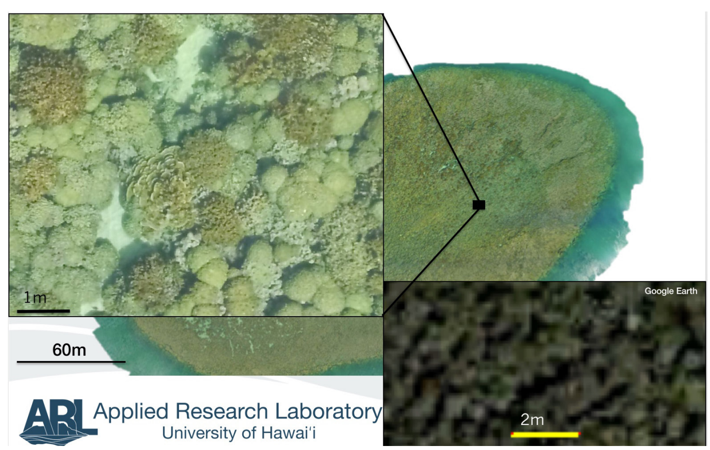
The Applied Research Laboratory (ARL) at the University of Hawai'i is one of five University Affiliated Research Centers (UARCs) that fall under the U.S. Navy. ARL provides research, development, test and evaluation, system engineering, and other engineering capabilities related to remote sensing. It focuses on maritime domain awareness from satellites to seafloor sensors, including rapid development/prototyping and data processing/visualization.

The choice of UAS platform for a mission depends on the question being addressed, how much data need to be collected, how much area is to be covered, the ground sampling distance required, and logistical issues related to launching and landing. Sensor options are platform specific and include topo-bathy LiDAR, water quality, oil, and multispectral.

ARL has several types of UAS platforms in its fleet, including multi-rotors (quad, hex, octo), fixed wing, and vertical takeoff and landing (VTOL). Each type has its strengths and limitations:

- Multi-rotor
  - Quad: Compact, versatile, approximately 25- to 30-minute flight time, efficient
  - Hex: Payload approximately 16 lbs, motor/controller redundancy, approximately 20- to 25-minute flight time, cumbersome
  - Octo: Payload approximately 20 lbs, motor/controller redundancy, approximately 15- to 40-minute flight time, cumbersome
- Fixed Wing: Endurance, payload approximately 4 lbs, difficult launch and land logistics
- Vertical Takeoff and Landing (VTOL): 10 km range, payload approximately 300 g, 120-minute maximum flight time at 95% cruise speed

Specific models in the ARL fleet include the DJI M600 Pro, DJI Phantom 4 Pro, Swellpro Splashdrone 2, FlightWave Edge, PSI Instant Eye, and Skyfront Perimeter. For security purposes, DJI drones cannot be used by many government agencies because it was observed that their "phone home" feature transmits the drone's metadata to the manufacturer's facilities in China.



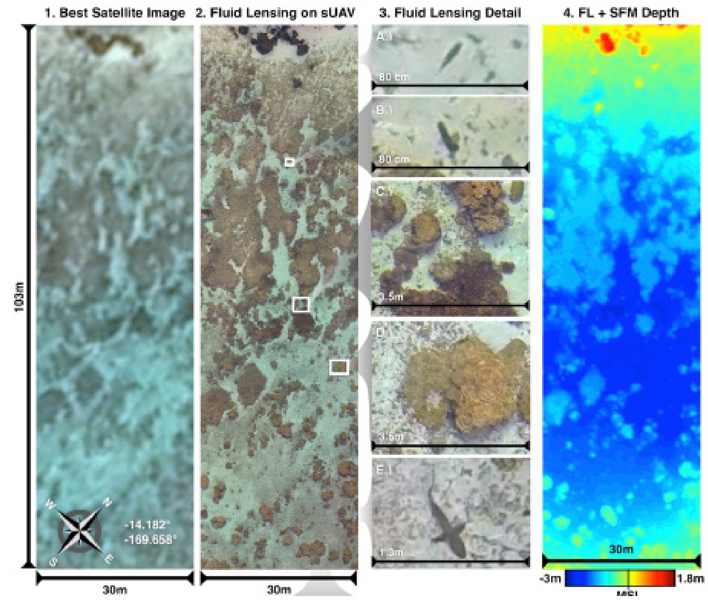
Coral reef mapping.

ARL is involved in a wide range of UAS applications, including port and harbor security, illegal fishing detection, protection of marine living resources, imaging ice ridges in polar regions, ship tracking, oil spill detection and tracking, automated tracking of protected species (e.g., sharks, sea turtles), monitoring coral reef bleaching and recovery, real-time communications from Integrated Ocean Observing System (OOS) benthic observatories and AUVs, and interfacing with high-altitude long-endurance UASs for high-bandwidth communications.

For monitoring of coral reef bleaching, UASs provide much better resolution than satellite imagery, particularly with Fluid Lensing software removing the surface wave field.

In the northwest Hawaiian Islands, ARL has launched VTOL UASs from 18-foot rigid inflatable boats (RIBs) using specially built platforms. The VTOLs collect imagery for detection of marine debris, including spectral analysis of suspected debris.

Huge data files are a problem because of limited data storage available on UASs. Ideally, McInnes would like UASs to be capable of some basic processing to trim files of data. Increased in-flight data storage and new in-flight data processing capabilities have the potential to enable multi-scale data integration.



Example of post-processing UAS imagery Fluid Lensing Data: 1) satellite photo; 2) processed UAS imagery with surface wave field removed by Fluid Lensing software; 3) details showing resolution; 4) bathymetric elevation map.

ARL has developed methods to track objects in the marine environment using UASs. The project began with assisting the US Coast Guard in identifying man-overboard (MOB) situations. The system has since been adapted for detection and tracking of sea turtle poachers in Malaysia. The poachers keep the turtles in pens and use a particular type of blue barrels, making it possible to find them using UAS data.

Important UAS challenges that require further research include long-range communication limitations, payload limits for long-range systems, and ground truthing.

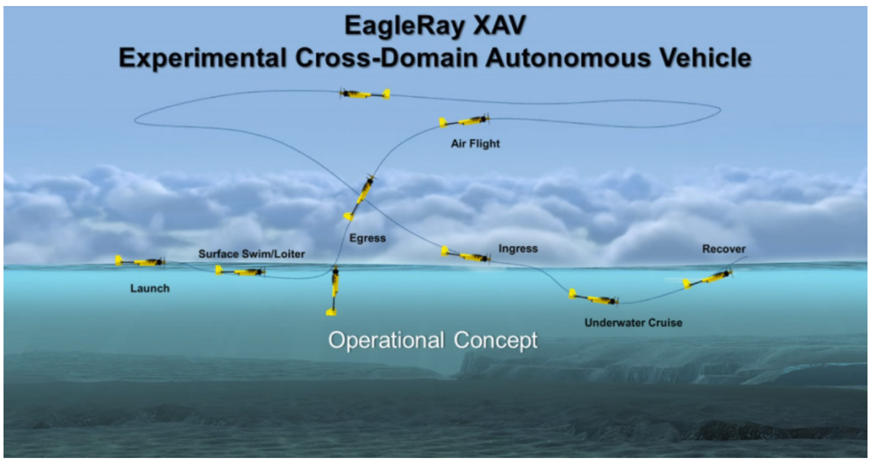
EagleRay XAV: Experimental Cross-Domain Autonomous Vehicle for Air and Underwater Flight

Matthew Bryant, North Carolina State University

Bryant and his research collaborators developed the EagleRay XAV, the first unmanned, fixed-wing aircraft that can fly both through the air and underwater. It is capable of transitioning repeatedly between airborne and underwater flight during a single deployment.

The researchers have developed a fully functional prototype with a wingspan of 59 inches and a length of 55 inches, weighing 12.6 pounds. The design is intended to be scalable so that smaller or larger sizes could be built depending on the size of the desired payload, how long it needs to operate, and other factors. The craft has one propeller, powered by an electric motor, that propels it through both air and water. When it enters the water, the EagleRay fills with water as ballast. On egress, the water drains, allowing the craft to become airborne.

Bryant showed a video of the EagleRay in action during a demonstration flight at a pond. After being placed on the water surface, the EagleRay cruised at the surface for some distance. Then it took off and became airborne, soaring high in the air, turning to travel away from the pond, and then returning. Finally, it descended, entered the water, and "flew" briefly underwater before returning to the surface. Another video clip, taken underwater in a swimming pool where the clarity was better, showed more of the EagleRay's underwater capabilities, demonstrating that it can travel a distance underwater and move up and down to different depths. The EagleRay video can be seen here: https://www.youtube.com/watch?v=Aw01NnG9hu0. A paper in the *IEEE Journal of Oceanic Engineering* (https://doi.org/10.1109/JOE.2017.2742798) presents test results and performance characterization.




Time lapse photograph of EagleRay XAV leaving the water and entering the air.

Breakout Group Discussion 2: State of Technology & Flight Logistics

Q2-1: What drones are commercially available and are currently being used in the coastal zone to address the management issues?

The breakout groups said that Panel 2 presentations (see above) largely answered this question. They identified the following additional points:

- When choosing a drone, it is important to consider not only availability but people's experience with the platforms. What are the platforms capable of, and how do they compare with others? Also consider longevity of the company and the need for parts in the future.
- Products are updated quickly and staying up to date with them can become difficult. A database of people and equipment/technology would be very useful as a support network for those interested in using drones to address coastal management issues. The database should include not only specs of the equipment but also experiences, as a way to educate people on the choices they make.
- U.S. Fish and Wildlife is developing a document to help people select the appropriate UAS technology, including whether the technologies are compliant with certain regulations. Another informational resource is *Beyond the Edge*, a free e-book from PrecisionHawk.
- Multi-drone systems (swarms) are available, but regulations currently require a different pilot for each drone.

Q2-2: How do you choose which drone and sensor for a particular scenario? When to use drones?

The breakout groups said that Panel 2 presentations (see above) largely answered this question. They identified the following additional points:

- As noted under Q2-1, U.S. Fish and Wildlife is developing a document to help select the appropriate UAS technology. Another informational resource is *Beyond the Edge*, a free e-book from PrecisionHawk.
- The best choice of drone and sensor depends on the answers to questions such as: What are you trying to sense or measure? How much does that sensor weigh? How do you plan to launch and land the equipment, and from where? How large is the area that is being surveyed?
- Budget and many other factors play into whether using a drone is the best choice instead of a manned or satellite platform. For example: Drones are more easily deployed, and the time and location of the deployment can be more flexible or exact compared to hiring a boat or plane and running into bad conditions. If the UAS mission takes a long time (many hours or days), changes in illumination can complicate data processing. Drones are subject to more limiting rules and regulations about air space and height, compared to manned aircraft. Logistical constraints such as the delays associated with obtaining an FAA COA may be an important consideration in deciding whether to use a drone or manned aircraft.

Q2-3: What are the logistical constraints to deployment (data storage, flight length, weather, etc.)?

The breakout groups said that Panel 2 presentations (see above) largely answered this question. They identified the following additional points:

- Regulations and restrictions: Rules about flying over people; National Environmental Policy Act (NEPA); marine sanctuaries, airports, and other restricted-use areas; requirement to keep the drone in line of sight; low flight ceiling for drones means it takes longer to collect data.
- Platforms: Endurance, range, payload flexibility; autonomous flight means the operator cannot respond quickly to rectify any issues that happen in flight; traveling with a UAS with large batteries can be challenging (only two large batteries per person allowed in luggage on commercial flights); many restrictions when trying to ship a UAS
- Operational: Georeferencing, particularly in areas with few features (e.g., ocean, desert); obstructions such as power lines and heavily contoured shoreline that require operator to move to keep drone in line of sight; avoiding densely populated areas and finding clear landing areas; calibration issues, such as interference with calibration while on the ground, RF interferences or interferences from other frequencies, and changes in illumination during a mission; data management including avoiding data loss; low bandwidth available for data transmission (e.g., wifi can only transfer a subset of LiDAR data)
- Staff capacity: Skill development for pilots and other staff, including mission parameters, QA/QC and metadata; logistical challenges of analyzing data, and the training to work with the data; funding to get the software to analyze data; lack of training programs or guidebooks focused specifically on coastal management applications of drones (general drone programs available, e.g., Cochise College, University of Maine, University of Maryland, and University of North Dakota, and a company called Skyward; the U.S. Geological Survey Unmanned Aircraft Systems (UAS) Roadmap is useful resource)

Q2-4: What are the challenges of doing truly quantitative remote sensing in coastal marine environments? What are the best management practices to ensure high quality data?

- Challenges: Georeferencing over water and beach sand; calibration issues (see previous sections above); obtaining reference data, comparison data
- Best practices: Conducting ground surveys and ground-truthing is the key difference between just taking a photo and actually collecting scientific data; need to know the relationship between drone data and what's on the ground
- It would be very helpful to have a data collection "competition" comparing platforms, sensors, and data processing methods to get a real assessment of how they perform. Data would be collected at the same time. This would help us understand the "gold standard" when it comes to data collection platform performance. A database of the results, for sensors and the data they collect, would be very useful, along with guidance on best practices.

Q2-5: What are the legal and privacy issues associated with using drones in public and private lands, ocean spaces?

- FAA regulations
- It is often difficult to know who you need to get permission from when it comes to land and air rights, military, airports, schools, etc. Is there a list for who to contact at a given location? Some apps have been developed for pilots to easily check what regulations are applicable in a given area (hobby vs. commercial vs. research). ForeFlight is an app that gives weather, flight restrictions, and related information for a subscription fee.
- Practitioners also need to know about insurance and liability coverage in certain air spaces.
- In practice, privacy issues generally haven't really restricted UAS operations yet. The Hakai Institute did have an experience when they were launching out of a public park and were required to talk to a city employee about privacy concerns.

Panel 3: Data Management and Analysis Best Practices

UAS Operations at Woods Hole Coastal and Marine Science Center

Sandy Brosnahan, Aerial Imaging and Mapping Group, US Geological Survey

The USGS Aerial Imaging and Mapping (AIM) Group provides services to scientists who come to them with research needs. AIM uses the following general process for UAS data collection:

The pre-flight phase involves two people for 3-5 days. Flights require 3-8 hours of work by a team of 5-6 people (1-2 pilots, 1 visual observer/data recorder, 2 target placers, 1 navigation specialist). In the post-flight phase, 4 people (1 Photoscan processor, 1 metadata compiler, 2 metadata reviewers) spend 2 weeks generating the product, and the product is published in 6-12 months.

Pre-flight:

- Planning session with investigator
- Site visit
- Flight plans
- Notify air traffic control/civilians
- File Notice to Airmen (NOTAM)
- Create a Project Aviation Safety Plan
- Create benchmarks
- Set ground control points

During Flight:

- Safety briefing
- Verify camera settings
- Switch batteries every 10-15 minutes, aiming to land with 20% charge
- Download photos and navigation files between flights

Post Flight:

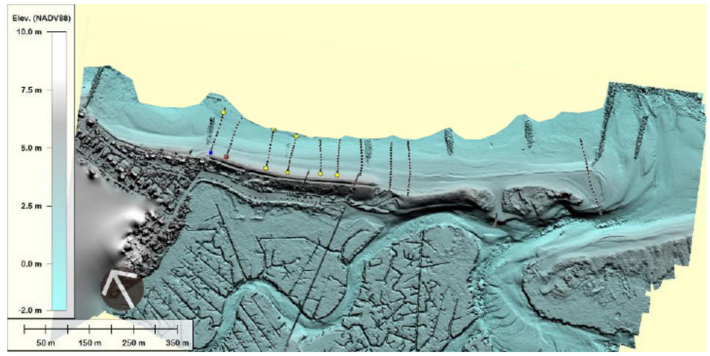
- Clean gear
- Download all data
- Geotag photos
- Process with Photoscan
- Publish photos, point cloud, digital surface model

The start-up budget in the first year of the AIM Group totaled approximately $160,000.

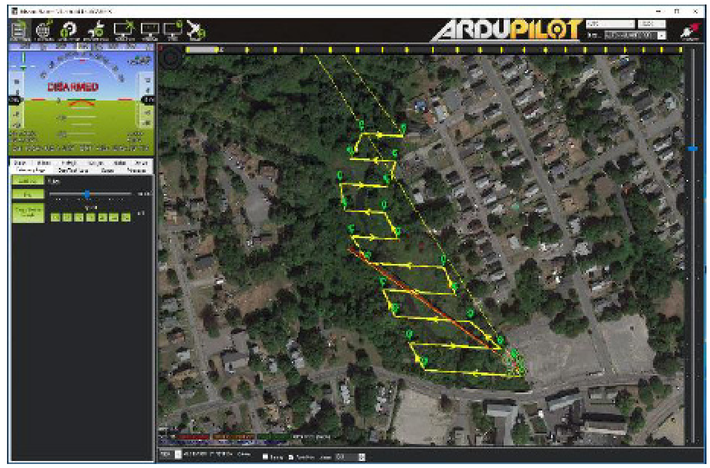
Item	Cost	Quantity	Subtotal
UAS Platforms			
• 3DR Solo (quadcopter)	$1,200	3	$3,600
• Bird's Eye View FireFLY6 Pro (fixed wing)	$15,000	1	$15,000
Cameras			
• Gopro4 (video)	$400	1	$400
• Ricoh GRII (high resolution, global shutter)	$600	3	$1,800
• MicaSense RedEdge (multispectral)	$5,000	1	$5,000
GPS Systems			
• Spectra Precision SP80 GNSS receivers	$20,000	4	$80,000
Processing			
• Agisoft Photoscan licenses	$3,500	4	$14,000
• High-powered processing computers	$10,000	3	$30,000
• Synology disk station raid storage	$10,000	1	$10,000
		TOTAL:	**$160,000**

The budget for the second year was $30,000. It covered travel, training, replacing broken parts, software fees, computer upgrades, and electronic components. The cost for a week in the field is approximately $40,000 to cover an area approximately 2-4 km^2 with multispectral and RGB cameras.

Pilots in the AIM Group are required to pass Part 107 certification administered by the FAA and take the Department of the Interior (DOI) A-450 Basic Remote Pilot Course. To remain current, they must take a semi-annual DOI refresher, receive Part 107 re-certification every 2 years, and fly 3 takeoffs and landings within a 3-month period. To process data, members of the AIM Group receive training in Agisoft Photoscan and Python scripting.



Elevation model from UAS data.



In a recent project, the AIM Group worked with the New England Water Science Office to help create new flood inundation maps after dam removal at the West Britannia Dam site in Taunton, Massachusetts. In a comparison of UAS data with 224 RTK-GPS points at the site, they found that they were very similar with an RMS difference of 3.9 cm. This result was produced comparing an elevation map made with photogrammetry to transect points made with handheld RTK GPS equipment.

For data storage and analysis, they have an 80 TB Synology NAS data server. They plan to begin publishing on the USGS database EROS EarthExplorer. A useful, free tool for visualizing point clouds is Potree, an open-source WebGL-based point cloud renderer for large point clouds (potree.org, e.g., https://cmgds.marine.usgs.gov/data/whcmsc/data-release/doi-F74F1PX-3/2017042FA_BraddockEast_PointCloud.html).

Brosnahan prefers Global Mapper to ArcGIS because it handles point clouds better and is more intuitive for those who are not ArcGIS experts. Global Mapper offers more control than Photoscan for creating DEMs from point clouds. For QA/QC, Global Mapper makes it easy to import a base map so you can plot your data and make sure it lines up with the base map.

UAS Survey at Wells National Estuarine Research Reserve in March 2018

Tayler Engel, AirShark

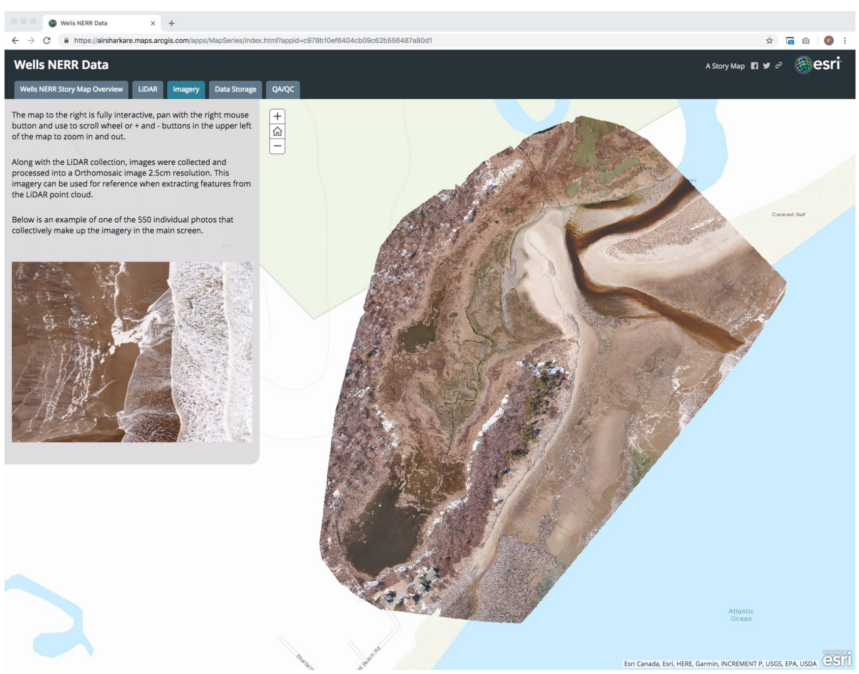
AirShark was contracted by the Wells National Estuarine Research Reserve to collect LiDAR data and imagery covering a portion of the Reserve in March 2018. The survey included the mouth of the Little River, a barrier beach (Laudholm Beach), and the salt marsh (with creeks and pannes) behind the barrier beach. Engel presented the results in an online ESRI story map. The LiDAR point cloud consisted of over 35 million points with 95 points per square meter and vertical RMSE of 0.027 meters. The LiDAR was also classified with ground, vegetation, and water. The story map displayed an interactive 3D model with the LiDAR visualized as elevation with red for high and blue for low elevation. Story map users could manipulate the model by rotating, panning, and zooming to explore the river mouth, barrier beach, and marsh in three dimensions.

As part of AirShark's QA/QC protocols, four control points were set up throughout the marsh. The average RMSE was 0.027 cm. In addition to control points, the point cloud was run through multiple algorithms to find "noise" points. Along with the LiDAR collection, the survey collected 550 individual photographs that were processed into a orthomosaic image with 2.5 cm resolution. Each photo that went into the orthomosaic was briefly opened to look for potentially blurry or bad photos. This imagery can be used for reference when extracting features from the LiDAR point cloud.

Although this was a relatively small project, it generated more than 10 GB of data. It is an example of how quickly data can add up during UAS surveys, creating challenges for data storage:

- Individual Photo Capture = 5GB
- Orthomosaic = 2GB
- LiDAR Point Cloud = 2GB
- DEM and DSM = 3GB
- Miscellaneous = 2GB

One potential constraint on the project was the seasonal presence of endangered piping plovers nesting on the barrier beach. The UAS flights were completed one day before the first piping plover of the season was observed at the site.



Imagery from UAS survey of marsh, river, and barrier beach at WNERR.

Best Management Practices for UAS Missions

Sue Bickford, Wells National Estuarine Research Reserve

The PrecisionHawk e-book *Beyond the Edge*, PIX4D User Workshop materials, and the USGS *Unmanned Aircraft Systems Data Management Plan* are useful sources of guidance on best practices for UAS missions.

- Optimal areas for UAS imagery are heterogeneous, non-reflective, static scenes with simple geometry. Examples include aggregate (gravel) and urban areas.
- Difficult areas for UAS imagery are homogeneous, reflective, dynamic scenes with complex geometry. Examples include water, tree canopy, and sand dunes.
- Images need to overlap sufficiently. Recommendations:
    - Single grid: 75% front overlap, 60% side overlap, at least one flight line beyond extent
    - Corridor mapping: 85% front overlap, 60% side overlap
    - Double grid: 85% front overlap, 70% side overlap, side oblique camera angle to obtain greater facade details
- Windy conditions: Adjust the image capture rate to ensure sufficient image overlap. Quality of your input data will degrade before it is unsafe to fly due to high wind. Fly parallel to the wind.
- Cloudy conditions: Capture images under similar lighting conditions; avoid discrete clouds moving across scene. Capture under flat or diffuse light; avoid direct sunlight; avoid deep shadows.
- Georeferencing: Without ground control points, absolute accuracy will be a few meters and relative accuracy will vary. With ground control points, absolute accuracy and relative accuracy will be 1-2 GSD (horizontal) and 1-3 GSD (vertical).
- Ground Control Points
    - Targets: Static, flat, matte finish, highly contrasting, at least ten times the average GSD, and have a discernible center at pixel level.
    - Distribution: No fewer than 5-8 GCPs per project, more with larger project areas. Evenly distributed, near features of interest. Inset from edges of project area. Not in a straight line.
    - Tools: Collect coordinates with survey-grade instruments (differential GPS, total station). Avoid consumer-grade instruments (cell phone, handheld GPS, Google Earth).
    - Tips: Document GCPs for reference when processing (textual description of each target, rough sketch of distribution, contextual photos of target on site). If surplus measurements are available, withhold when processing and use check points.
    - Common Errors: Ensure that the correct GCP Coordinate System is selected in Pix4Desktop when creating a project. Ensure the syntax of GCP measurements is correct when importing coordinates.
- Check Points
    - Withheld from processing and used to verify accuracy of results.
    - Placed as far from control as possible.
    - 20% of a project's control points should be withheld from the solution.

Breakout Group Discussion 3: Data Management and Analysis Best Practices

Q3-1: Are there commonalities between UAS systems?

- They all fly pretty well, share a lot of the same sensors, store data locally, and require similar post processing. Since they use similar sensors, they produce similar types of data and require the same types of software.
- Everyone's missions are relatively similar. They need to get it out and then back safely to capture the data. The mission planning process is similar for all UASs. Most people use the same open-source software like Mission Planner.
- At the end of the day, 90% of what's captured by drones today are image or video files, with some multispectral or hyperspectral being the other types. As long as you are working with the standard file types, and not locking the data into a vendor-specific format, then the data can be readily shared or integrated with data from other drones.
- Despite the similarities among systems, there seem to be very few people who can do it all from pre-flight plan to publishing. Each person on a team can be specialized in a certain area, especially in regard to using different data systems.

Q3-2: What are the QA/QC best practices?

- For some practitioners: Determining the level of accuracy needed for the intended purpose of the data, and planning mission to hit that accuracy level. For other practitioners: Always going for highest accuracy that the technology allows (e.g., flying as low and slow as possible, even if the accuracy isn't necessary) because most of the cost of data collection is in the logistics, rather than the actual fieldwork.
- Putting out markers and setting ground controls
- Manually checking data before populating your processor
- Checking images/data in the field and fixing any issues before the full data-collection flight
- Going through the lower resolution before a high resolution
- Manually controlling settings of camera (aperture, shutter speed)
- Using polarized lenses to help remove reflections for high visual quality, not necessarily for other data acquisition types
- Naming files with specific metadata from the flight with a description; metadata also should include contacts
- Scanning through imagery initially to cull out bad photos and data
- Holding back some of the data for testing the model
- Doing an initial QC by putting data into GlobalMapper and seeing if it lines up with the basemap or is way off, meaning there is error
- Retaining all data; saving all fields in your data files in case you need data provenance info or other details later
- Producing an accuracy report stating known errors
- For some practitioners: Avoiding stating an exact accuracy because of the

variability; instead just achieving the accuracy range that was required in specs
- Saving the coordinate system correctly in GlobalMapper before using in ARC
- The USGS Unmanned Aircraft Systems Data Management Plan discussed in Sue Bickford's and Sandy Brosnahan's presentations is a useful resource for QA/QC best practice.

Q3-3: Where and how is the data stored and analyzed?

- Initially stored on a memory card
- Mostly locally stored, but as the project progresses a combination of local and cloud-based storage and processing becomes necessary due to sheer size of files. Amazon Glacier is a very good place to park things in the cloud: free bandwidth to put data in, cheap to keep it there, and then 15 or 20 cents per GB to get it out (not cheap, but better than some other option).
- Managing the storage and processing of multiple projects over multiple years plus data retention policies becomes an issue.
- Raw data can be stored locally and deliverables provided online.
- At some point data may have to be deleted or archived.
- Always get your IT department into the discussion early because you will have lots of data to store and work with. Make sure they have background and system for handling large amounts of data.
- Need to have redundant storage
- There are no version control systems for data files this large.
- USGS is required to provide public access to raw data. One issue is that they can only upload files to their server in 10 GB pieces. USGS posts data with several pages of metadata but not QA/QCed; data are provided without warranty. However, USGS does require two reviewers to approve the data; the reviewers are USGS staff, but they must be "external" in that they weren't involved in the project.

Q3-4: What are other data management challenges?

- Knowing the life expectancy of a data set; defining what "long term" would be for storage. Technology is changing rapidly, so what is a reasonable length of time to keep data? The data could become outmoded or replaced.
- In addition, it would be valuable to store not just raw data but processes such as QA/QC used with the data. Or conversely, keeping raw data for when processes change and improve.
- With longer time series of data, there is an issue of storage as the data set keeps growing.
- Interpretation of the data can also be an issue. The data may have value, but it's not useful if it can't be interpreted. Input of data could outpace our ability to interpret it effectively. The value of the data may decrease with our inability to process it and assign value. Or the data may be other types of value that we don't know about yet. For example, if there are pictures of a bridge when it is being inspected, how long are those images stored? Who needs the raw data after the integrity of the bridge

has been reported on? If an event (e.g., collision) happens later, maybe those images would be useful. There is similar potential with biological/ecosystem data.

- In different industries, there are different standards for file formats or software that need to be converted to be able to communicate with each other. When converting, however, you end up with two versions of the same data set, which leads to more storage or archiving issues.
- We need a centralized source of guidance on data storage, as well as a data repository for people to access, such as some type of federal group.

SeaHawk: Development of a "Flying Submersible" Product Line

Jason Clark, Igloo Innovations

Igloo Innovations is a full-service engineering design firm that helps customers solve problems in all stages of the product development cycle. Marine technology is one of the company's areas of expertise. They have designed and supported offshore technology solutions from surface to seabed, including development, testing, assembly, integration, deployment, and operations. The company is developing what it calls flying submersibles, which are UASs that are designed to both fly and provide capabilities for underwater data collection. Three models—SeaHawk Alfa, SeaHawk Chimera, and SeaHawk Freebird—will be commercially available in 2019. As an example of a potential application, a SeaHawk vehicle could be used for inspection and maintenance of aquaculture farms. It could be parked to charge on a "solar dock" at a farm and deployed to collect still/video imagery and data in aquaculture pens.

SeaHawk Alfa: The Alfa looks much like a standard quadcopter and performs similarly in airborne flight. Unlike a typical quadcopter, the SeaHawk Alfa has a circular float on top that contains wireless communication technology to transmit imagery and data to the control station. When the vehicle submerges, the float remains on the surface and tethered to the vehicle to maintain communication. The float may also be removed for autonomous-only underwater operations. The Alfa has a payload capacity of 5 kg (10 lbs) and a maximum flight speed of 60 km/hour (37 mph). A dedicated underwater propulsion system moves the Alfa at speeds of up to 4 knots while submerged. Its operational depth is 50 m (150 ft), and it can operate for approximately 60 minutes combined in either medium.

SeaHawk Chimera: The Chimera appears similar to the Alfa, except that the vehicle stays at the surface and only the payload is deployed underwater. With a payload capacity of up to 20 kg (40 lbs), the vehicle is intended as a modular platform to carry a wider range of payloads than the Alfa. For example, the payload can be an ROV or AUV, providing advanced underwater capabilities. The Chimera can also hover high above the water and lower down a tethered sampling device to collect a sample without blowing on or otherwise disturbing the water surface.

SeaHawk Freebird: The Freebird is also similar to the Alfa, but with an untethered floating component. This vehicle uses the latest in underwater wireless communications, AI, and swarming technologies to enable data collection in way never before possible. This allows the user to potentially conduct data collection in the air and underwater simultaneously.

MBARI's UAS Program

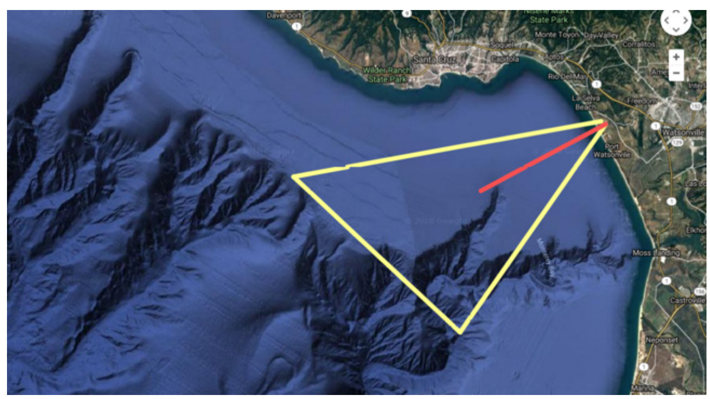
Tom O'Reilly, Monterey Bay Aquarium Research Institute

The Monterey Bay Aquarium Research Institute (MBARI) is a non-profit founded by David Packard that emphasizes robotics and automation. It is located on the shores of Monterey Bay, California, at the head of the underwater Monterey Canyon.

MBARI will begin a UAV project in 2019 to support research into air-sea interface processes:

- Phytoplankton, including HABs
- Animals population and behavior – jellies, fish, birds, whales
- Thermal structure
- Ocean/atmosphere interactions
- Bioluminescence
- Long (30+ km) monthly transects to provide regular sampling of ocean conditions
- The UAV project will also be used in public outreach efforts, locating robotic vehicles/assets, and autonomous vehicle collaboration (e.g., drone providing data to Wave Glider, which relays to AUV via acoustic).

MBARI has chosen to use two drone platforms: DJI Phantom 4 and Flightwave Edge. The Phantom 4 has endurance of approximately 28 minutes / 13 km and an Ultra High-Definition (UHD) camera payload with a 3-axis gimbal. MBARI plans to use the Phantom for cinematography and foraging ecology research. The FlightWave Edge is a fixed-wing UAS offering greater endurance: 45 min/38 km with 300 g payload or 90 min/76 km with 180 g payload. The Edge will be used for biotransects and foraging ecology research.



Range comparison of Phantom 4 (red) and Flightwave Edge (yellow).

In May 2017, MBARI tested the Edge with a FLIR Vue Pro thermal camera and a Foxeer Legend 16 MP RGB camera. The Edge was launched from and landed on the RV Paragon, which chased the drone in flight. The MBARI team flew approximately 8 km transects at 60 m altitude across a known thermal front. The Paragon stopped every few minutes to take CTD readings at approximately 0.5 m depth. On a NE-SW transect across Monterey Bay, the FLIR on the drone resolved the location of the thermal front better than the CTD measurements did. However, there were large discrepancies between temperature measurements by the FLIR and CTD. MBARI is working to determine to reason for the discrepancy. The RGB camera captured high-resolution images of jellies near the ocean surface and birds in flight above the ocean.

Two payloads are planned for the Edge in 2019. The total payload weight includes the nose cone and plastic brackets, which weigh approximately 70 g. Payload A is a FoxTech Map-02 25 MP camera weighing 178 g for a total weight of 248 g. Payload B is a FLIR Duo (84 g) and Foxeer Legend-1 16 MP camera (48 g) for a total weight of 203 g.

MBARI is working on addressing several key challenges:

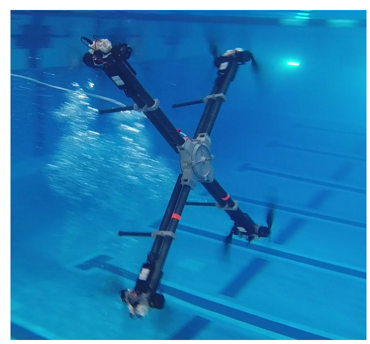
- Ensuring accurate data given the lack of ground control points at sea: To improve accuracy, they could potentially use onshore real-time kinematic (RTK) or post-processed kinematic (PPK) GPS correction technology when the drone is within approximately 80 km of the coast.
- Balancing tradeoffs among range, endurance, and payload: Other platform options that MBARI has looked at include the FlightWave Jupiter (110 minutes with 1000 g payload) and the Impossible Aero US-1 (78 minutes with 1300 g payload).
- Working within UAS flight restrictions: Drones must be operated within visual line of sight (VLOS) and are restricted to flying no higher than 400 feet above the ocean, ground, or buildings. They are prohibited in sensitive areas such as the Monterey Bay National Marine Sanctuary, although a waiver may be possible.
- Risk of ditching aircraft in water: Currently, no commercially available drones can go in or near the water. Crashing on water is a real concern. While some UASs may float for perhaps 15 minutes, there is a real risk of losing a UAS before it can be retrieved, and plenty of spare parts need to be kept on hand.

MBARI is looking into the potential for beyond visual line of sight (BVLOS) operations in the future. The video feed currently reaches approximately 10 km maximum, and autopilot is needed beyond 10 km. One option for over-the-horizon communications may be the Iridium NEXT (22 kbps), and for collision avoidance it may be possible to use an ADS-B transponder (e.g., Ping2020, 20 g). Obtaining a BVLOS waiver may be the biggest hurdle. Nationally, only three BVLOS waivers have been granted to date.

The Naviator: A Hybrid Unmanned Air / Underwater Vehicle

F. Javier Diez, Rutgers University and SubUAS LLC

The Naviator is the first unmanned vehicle platform capable of operating in the air, on the water's surface, and underwater and that can transition back and forth between these mediums seamlessly. SubUAS LLC is developing this technology for both commercial and military applications.


The Naviator.

The Naviator has four arms, each with dual propellers at the end. For airborne flight, the Naviator operates much like a typical quadcopter, but it can also enter the water, fly underwater, and then exit the water back into the air. When the craft comes back up to the water surface, the dual propellers on each arm—one pulling up into the air, the other pushing up from the water—ensure that regardless of water conditions the drone can emerge and become airborne. It can operate for up to seven hours underwater or one hour in the air.

In 2017, the Naviator was used to conduct the first combination aerial and underwater bridge inspection on the Delaware Memorial Bridge Twin Spans through a collaborative effort that included the Delaware River Bay Authority. SubUAS LLC is working with the submarine community to develop a drone that can be launched underwater, fly into the air, and then return to the sub underwater. The company also has a contract to increase the Naviator's depth capability to 1,000 m depth. SubUAS LLC is currently developing multiple variants of the Naviator under Department of Defense research and development contracts in excess of $10 million.

Breakout Group Discussion 4: Future Developments and Applications

Q4-1: What are the existing gaps and upcoming capabilities?

- Expanded payload capabilities
- Modularity to allow commercial drones to carry different payloads/sensors
- Drone swarms and networked assets; communication between systems. A swarm of drones that all talk to each other could have fewer operators (if regulations allowed). It would also make it possible to spread out sensors on different drones, rather than putting all sensors on one drone; this makes it less of a problem if one drone goes down.
- All-weather capabilities
- Drones intended for use around waterbodies: waterproof with long float time to reduce hazards associated with crashing on water
- Security of transmission signal (i.e., operating on unlicensed bands vs a secure data link)
- Integration of sensors with the aircraft flight platform and software, so the flight control system can aid in inspection on a local scale (i.e., knowing exactly what you are looking at, situational awareness of the structure and knowing the purpose of inspection)
- Improvements in data management: On-board data processing would be a big advantage. Having some basic recognition of what is in the image. Metadata collected in real time. A way to flag bad data, QAQC in real time. A way to take notes in a program while drone is in flight, so you know where it is and what it is seeing, connected to the photos or video at that time.
- Making drones more 'intelligent' is crucial for going beyond line of sight; might need a companion drone or lighter than air vehicle to act as intermediary
- Real-time data transfer, as well as streaming data or bluetooth transfer or tweet updates. There should be more improvements in data storage, so not relying on swapping in and out SD cards; need improvements in transmission of data from the drone, so it is not such a problem if a drone is lost. Should be more like a phone where all your data is automatically backed up in the cloud. If power and weight weren't a consideration, the technology exists now to transmit broadband wirelessly. 5G cellular will probably open up more transmission possibilities.
- Noise suppression to enable stealth operations, such as monitoring/seeking out poachers and for monitoring of wildlife
- Transmission of large amounts of data underwater is an issue; could be addressed by going up into air and transmitting data in air
- Need a drone that could be tossed from boat into water for launching, instead of having to launch from boat
- Turbidity is an issue for underwater data collection (visual); maybe other types of sensors need to be used.
- In terms of developing solutions, it's not currently possible to test whether different solutions work better than others; need calibration courses; currently calibration courses are available for air, but not for water.

- Better batteries (power for weight) would be very helpful, although a lot of effort/money has recently gone into battery development and nothing much has come of it. Solar panels can't charge batteries fast enough; would have to leave it for a few days to charge. Battery technology is really going to be the game changer; drones won't change much until batteries leap forward.
- Redundancy systems are needed to protect against failure; a lot of people are working on this, lots of theory, but not much in practice yet; in theory you could lose two propellers on a quad copter and still fly; it would spin but still be controllable.
- Better systems/software for geotagging
- Lots of recent developments are focused on removing the "stupid human," such as sensors and software systems that automate functions like different types of video shots.
- Airspace integration is a big thing boxing us in; need to get us above 400 feet and only line of sight; FAA is being pushed to change these things.
- There will eventually be drones that perform a mechanical function like collecting a physical sample, not just having a sensor.

Q4-2: How do UASs complement other forms of management/observing?

- Provide more information with which to make a management decision
- Can make for a more networked monitoring system
- A shift from one to one (person and drone) to one to many (person and at least two drones in a swarm) is more of an engineering exercise but could be very useful with the drones carrying different sensors or being given different missions. Hardware + software + teamwork of and between individual drones. Swarm-level autonomy. Swarm vehicles could each have their area of study and then hand off that data to another vehicle. On top of all of the engineering is the regulatory aspect to move towards this goal.
- Complement other remote sensing platforms (satellite, manned LiDAR)
- Provide increased communications for gliders (range for radio communication, internet)
- Support telemetry and monitoring of animals (e.g., sharks, cetaceans, birds, turtles) such as recovering data loggers or auto-downloading data; data loggers are currently hard to recover, usually using GPS ping

Q4-3: What are the trends in R&D investment and sources?

- Batteries and power supplies
- Machine learning and AI
- Swarms; coordinating multiple vehicles on a mission
- Cross-domain situational awareness
- Hybrid vehicles
- Manned and unmanned teaming: integrating drones and drone data with manned aircraft and ships in real time
- Noise control
- Cyber security

- Solar powered re-charging dock
- Standardization of equipment/hardware, software, protocols
- Technology to enable access to higher airspace: collision avoidance, integration in airspace with manned craft, acceptance of drones into the system with flight towers, participating within and becoming part of that system
- Using radio telemetry for tracking wildlife species: finding the signal of a tagged animal and locating it from there; bypassing the need to physically find the species (driving, hiking, etc.). Contributing to this capability will be longer battery lifespan, lower noise, and changing regulation to height.
- Vast majority of drones are being used for photography or military, not many for science; currently drones are often modified to fit the needs of scientists
- As UAS technology develops one would hope that there would be more government Requests for Orders (RFOs). Private sector could be aware of science needs and select the technology. E.g., NOAA NCCOS, PMEL MERL, NOPP, DOI, USGS, BOEM, Navy, USFWS, IOOS OTT
- How do you encourage investment in a technology that's not going to make a lot of money? Developing a drone that has sensors for a really specific use may only be a niche market, where as a versatile platform (such as a rosette) could be used for many different applications (while being limited by payload and flight plan).
- iRobot has a project currently with the lionfish program. Their engineers are developing a custom AUV through volunteered time. Should be very cheap, e.g., under $1k. Doing it philanthropically, but with an immense engineering program. Could work with them or other agencies with a specific idea, with a one-time investment. Need a problem statement that's broadly needed and compelling.
- If this group identifies a few key coastal management issues that are crosscutting (HABs, coastal observations, etc.), they could be pursued for technology development. For example, if a type of product was effective for mitigating blooms (e.g., clay, vinegar, bleach, etc.), drone technology could be developed to deploy the product. Or time series and fixed data sets with routine observations, e.g., IOOS-type monitoring at specific locations. Deploy drones at specific times to look at temperatures, etc. There could be phase 1 development projects, and then pick a phase 2 that could then be used to create a product.
- Iridium will be huge for improving drone data processing beyond current capabilities. R&D spending is needed for this and for telemetry programs.
- Data management and communications (DMAC) and analysis is a huge effort for managers. Technology for this is an existing gap. Need support for best practices for processing of drone data.
- Communication between underwater and aerial vehicles would be beneficial. One AUV informing another vehicle would be really useful for future application.
- Biggest need right now is for redundancy in software. Bringing the price point down for viability in commercial use. Backup propulsion or motors if something goes wrong / redundancies. Software capable to adapting to loss of propellers.
- Are there open-source or commercially available solutions to link other drone sensors with added geospatial information sensors? Could ACT make recommendations about how do this?

Q4-4: Specific examples of how people could see using drones in the future?

- Search and rescue and not just for humans, but animal species
- Shark monitoring for beach areas
- Creating a beach profile before and after storms with a fixed flight pattern, to help with not just the profile but with forecasting; storm monitoring during an event to know about any danger or breach
- Harmful algal blooms (HABs)
- Enhancing CTD profiles from boats
- Surveying sites for diving, if you have limited funding

Q4-5: What are other considerations for the future?

- Making drones able to do more, adding capacity to do work other than fly and take measurements/photos and video
- Educating and outreach to the public on the use of drones, their tangible benefits. Increasing social acceptance of drones and reducing concerns. E.g., social acceptance when doing storm profiling near private homes or populated areas
- The opposite side of this issue is the responsibility of the drone/work/mission, especially when/if drones are able to do more and initiate their own missions based on data they are receiving. Where does that responsibility lie, and who makes that decision? Could add in a capability for the drone to become socially aware, knowing when or where it is not supposed to operate regardless of the directive of the user.
- Getting a clear and more defined directive from a regulatory or government body on where regulations are heading. If you have a research project using drones, knowing that you will be able to conduct the project in 6 months, or a year, or two years.

Conclusions

- While UASs are still a new tool for coastal management, their value has already been demonstrated for a wide variety of management applications such as habitat mapping, wildlife monitoring, detection of coral bleaching, shellfish management, marine debris detection, monitoring shoreline change, management of beaches and sand resources, mapping flood zones, and inspection of bridges and other structures.

- UASs have the potential to be useful in many additional management contexts such as harmful algal bloom (HAB) detection and tracking, monitoring of human/animal interactions, water quality monitoring, pollutant tracking, and monitoring tidal marsh stability.

- Managers are eager to use drones, but how to use them is not always well understood. It is important to begin by asking, "What is the management question or problem?" This will determine what data are needed and how they should be collected, which may be drones. As with any data, drone data need to be transformed into information, which can then be used for management.

- Education is needed to help managers understand how drones can be useful and when drones offer advantages that justify cost and other concerns.

- The best choice of drone and sensor depends on the answers to questions such as: What are you trying to measure? How much does the sensor weigh? How do you plan to launch and land the equipment, and from where? How large is the area that is being surveyed? What resources (financial and human) do you have available?

- While consumer-oriented drones are now relatively inexpensive and easy to use for photography, using drones to acquire accurate quantitative geospatial data is challenging and requires advanced technical skills and knowledge. Hiring experts in drone operations and data processing is typically necessary. As one workshop participant said, "If you're not going to devote all your time to drones, you're not going to do it well."

- Best practices for using drones to collect geospatial data are well established. A few examples include using ground control points, sufficiently overlapping images during data acquisition, ground-truthing of drone data, and withholding a subset of data points during processing to use as check points. Guidance on best practices is available in publications such as the PrecisionHawk e-book *Beyond the Edge* and the *USGS Unmanned Aircraft Systems Data Management Plan 2015*. The field of remote sensing has a large literature that is relevant to drone-based remote sensing.

- Currently, flying commercially available drones over water is risky because they are not built to withstand submergence. If a drone crashes into water, serious damage or loss could occur. There is a need for waterproof drones that float. Several companies and academic groups are developing drones that operate in both air and water. These hybrid vehicles will open up new possibilities for coastal research and management when they become commercially available.

- Workshop attendees identified short flight times due to battery constraints as one of the biggest limitations in drone operations at present. Other desired improvements in drone technology include expanded payload capabilities, modularity to allow drones to carry different payloads/sensors, all-weather capabilities, "smarter" drones with situational awareness, improvements in data management such as on-board data processing, and capabilities that go beyond imagery and remote sensing such as deploying water sampling devices.

- Federal rules and regulations greatly constrain how drones can be used (e.g., maximum altitude; operation within visual line of sight; one drone per pilot), although sometimes waivers can be obtained. Administrative processes often result in long delays in drone projects. Technological advances, such as improved communication systems, could make it more feasible to integrate drones into airspace currently reserved for manned aircraft.

- Testing and evaluation of UAS platforms and sensors by an independent entity such as ACT would be very useful to researchers, managers, and technicians. Currently, it is difficult for them to find reliable, relevant information about how different drone technologies perform in the context of coastal management.

Appendix A: Workshop Attendees

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Appendix B: Workshop Agenda

Location: Wells National Estuarine Reserve, Laudholm Farm, Wells, Maine

Dates: September 25–27, 2018

This will be a three-day workshop to document the practical uses of Unmanned Aircraft Systems (UASs, commonly known as drones) to management applications in coastal zones.

Goals: The Goals of the workshop are to

1. Summarize state of technology in research and monitoring grade UASs,
2. Compile examples of current use in this area (listed below),
3. Understand the limitations and logistical challenges associated with UASs,
4. Develop operational and data management/analyses best practices, and
5. Describe future developments and applications for coastal ocean observing systems.

Problem Areas that drones can help with:

- Changing coastal water quality, including storm runoff, turbidity, productivity, flow patterns, HABs, marine debris
- Coastal zone physical processes, including water depth measurement, land elevations, vegetation structure, coastal erosion rates, beach profiling, habitat changes, effectiveness of living shorelines. including marsh die offs, seagrass disturbance,
- Animal populations beyond stock assessments and including forage fish; individual animal health, including whale body condition, seabird and seal colony assessments; mass estimation invasive species.

Other Issues/Challenges to be addressed:

- The challenges of doing truly quantitative multispectral and hyperspectral remote sensing in coastal marine environments.
- Legal and privacy issues associated with using drones in public and private lands, ocean spaces.

Agenda:

Day 1

8:30–1:00	Practical demonstration missions The group will meet outside the large barn, next to the visitor parking lot, and will then travel together to the flight area.
6:00	Reception: Pedro's Mexican Restaurant, 181 Port Rd., Kennebunkport

Day 2

9:00–9:30	Welcome and Introductions
9:30–9:45	Setting the Scene: Workshop Goals

9:45–10:45 Panel 1: Examples of Current UAS Use in the Coastal Environment

Chair:	Richard Burt	ACT
Panel:	Will McInnes	Hakai Institute
	Vincent Lovko	Mote Marine Lab
	Donglai Gong	VIMS

10:45–11:00 Break 1

11:00–11:05 Charge to Breakout Groups

11:05–12:30 Breakout 1: Current Uses of UASs

- Are the Problem Areas (listed above) correct? What else?
- How and where are UASs used to survey the coastal zone? Please give specific examples.
- Which aspects of coastal management are UASs regularly used for?
- How is information from UASs combined with other data?
- How are UAS used to influence / benefit management decisions?

12:30–1:15 Lunch (catered on site)

1:15–2:15 Panel 2: State of Technology & Limitations / Logistical Challenges

Chair:	Jamie Carter	NOAA Office for Coastal Management
Panel:	Kirk Waters	NOAA Office for Coastal Management
	Garrett Johnson	University of Hawaii
	Matthew Bryant	North Carolina State University

2:15–2:20 Charge to Breakout Groups

2:20–3:30 Breakout 2: State of Technology & Flight Logistics

- What drones are commercially available and are currently being used in the coastal zone to address the management issues?
- How do you choose which drone and sensor for a particular scenario? When to use drones?
- What are the logistical constraints to deployment (data storage, flight length, weather, etc.)?
- What are the challenges of doing truly quantitative remote sensing in coastal marine environments? What are the best management practices to ensure high quality data?
- What are the legal and privacy issues associated with using drones in public and private lands, ocean spaces?

3:30–4:15 Afternoon Break & Guided Walk

4:15–5:00 Breakout 1 and 2 Report-out with Group Discussion

6:00 Group Dinner: Arundel Wharf, 43 Ocean Ave., Kennebunkport

Day 3

9:00–9:15 Summary of Day 2

9:15–10:15 Panel 3: Data Management and Analysis Best Practices

Chair:	Ru Morrison	NERACOOS

	Panel:	Sandy Brosnahan	USGS
		Tayler Engel	AirShark
		Sue Bickford	Wells NERR
10:15–10:30	Morning Break		
10:30–10.35	Charge to Breakout Groups		
10:35–12:00	Breakout 3: Data Management and Analysis Best Practices • Are there commonalities between UAS systems? • What are the QA/QC best practices? • Where and how is the data stored and analyzed? • What are other data management challenges?		
12:00–1:00	Lunch (catered on site)		
1:00–1:30	Results from Practical Demonstrations		
1:30–2:30	Panel 4: Future Developments and Applications		
	Chair:	Justin Manley	Just Innovation
	Panel:	Tom O'Reilly	MBARI
		Jason Clark	Igloo Innovations Inc.
		Javier Diez	Rutgers University/SubUAS LLC
2:30–2:45	Afternoon Break		
2:45–2:50	Charge to Breakout Groups		
2:50–4:00	Breakout 4: Future Developments and Applications • What are the existing gaps and upcoming capabilities? • How do UASs complement other forms of management/observing? • What are the trends in R&D investment and sources? • Specific examples of how people could see using drones in the future? • What are other considerations for the future?		
4:00–5:00	Breakout 3 and 4 Report-out with Group Discussion		