



TECHNICAL REPORT

TR-NAVFAC EXWC-SH-2213

Region-wide Integration of UAS Technology into DOD Natural Resource Management through Demonstration, Coordination, Training, and Outfitting

ESTCP Project RC19-D3-5218

August 2020

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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) 31-08-2022		2. REPORT TYPE Technical Report		3. DATES COVERED (From - To) January 2019 – August 2022	
4. TITLE AND SUBTITLE Region-Wide Integration of UAS Technology into DOD Natural Resource Management Through Demonstration, Coordination, Training, and Outfitting				5a. CONTRACT NUMBERS N3943019C2140, N3943019C2141, N3943019C2142	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Salinda Bachelor, Duke University Marine Lab Susan Cohen, UNC Institute for the Environment Cristiana Falvo, Duke University Marine Lab David Johnston, Duke University Marine Lab Jonathan Putney, Attollo LLC Justin Ridge, Duke University Marine Lab Antonio Rodriguez, UNC Institute for Marine Science Joey Trotsky, NAVFAC EXWC Troy Walton, Attollo LLC				5d. PROJECT NUMBER TR-NAVFAC EXWC-SH-2213	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NAVFAC EXWC - 1100 23rd Avenue Port Hueneme, CA 93043 University of North Carolina, 104 Airport DR STE 2200, Chapel Hill NC 27599 Duke University, 2200 W Main ST STE 710, Durham NC 27708 Attollo, LLC, 30 Martin ST STE 3f, Cumberland RI 02864				8. PERFORMING ORGANIZATION REPORT NUMBER RC18-5187	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of the Deputy Assistant Secretary of Defense (Energy Resilience & Optimization) 3500 Defense Pentagon, RM 5C646 Washington, DC 20301-3500				10. SPONSOR/MONITOR'S ACRONYM(S) ESTCP	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) RC18-5187	
12. DISTRIBUTION / AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Integrating commercial Unoccupied Aircraft System (UAS) platform and sensor technology into Department of Defense (DoD) installation natural resource management has the potential to dramatically improve the way natural resources are managed. UAS provide access to real-time information from a broader field of view, reducing the need for 'boots on the ground' and creating opportunities to monitor and manage resources with high-resolution data over time. The United States Marine Corps Installations East (MCIEAST) leadership provided an opportunity to demonstrate the goal of a regional, standardized approach for integrating UAS technology, led by installation natural resource managers, to address a broad set of environmental challenges. The project met three objectives: 1) developing accepted pathways for pilot certification through BUQ II training and program protocols, 2) the creation and delivery of UAS mission kits and training, and 3) demonstrations for environmental applications. Project UAS mission kits were designed around environmental uses including mapping for habitat characterization, monitoring and tracking change over time, and situational awareness via real-time video. Demonstrations were designed to showcase uses and applications, review mission planning and data processing training, and bring the MCIEAST UAS community together. The project successfully demonstrated the value and effectiveness of deploying drone programs on regional levels with flexibility to meet installation needs and missions.					
15. SUBJECT TERMS unoccupied aerial systems, drones, natural resource management					
16. SECURITY CLASSIFICATION OF: Unclassified			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 82	19a. NAME OF RESPONSIBLE PERSON Joey Trotsky
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (include area code) 805-982-1258

Abstract

Introduction and Objectives

Integrating commercial Unoccupied Aircraft System (UAS) platform and sensor technology into Department of Defense (DoD) installation natural resource management has the potential to dramatically improve the way natural resources are managed. UAS provide access to real-time information from a broader field of view, reducing the need for ‘boots on the ground’ and creating opportunities to monitor and manage resources with high-resolution data over time. The United States Marine Corps Installations East (MCIEAST) leadership provided an opportunity to demonstrate the goal of a regional, standardized approach for integrating UAS technology, led by installation natural resource managers, to address a broad set of environmental challenges.

Technology Description

The project met three objectives: 1) developing accepted pathways for pilot certification through BUQ II training and program protocols, 2) the creation and delivery of UAS mission kits and training, and 3) demonstrations for environmental applications. Project UAS mission kits were designed around environmental uses including aerial mapping for habitat characterization, monitoring and tracking change over time, and situational awareness via real-time video. Demonstrations were designed to showcase uses, execute flights for monitoring airfields or wetlands, review mission planning and data processing training, and bring the MCIEAST UAS community together.

Performance and Cost Assessment

This project is the first of its kind in DoD. While individual installations across services use drones, this regional approach codifies protocols that eliminate one-off approvals and facilitates drone use in workflows and on-demand. The project created regionally accepted guidelines and dynamic training that promotes fundamental skills that can be applied to a host of environmental challenges. The creation of a MCIEAST Order was the result of this program, presenting the leadership at MCIEAST both a viable pathway for safe drone flights on installations, and demonstrating the clear utility of drones. The leadership acceptance of the BUQ II level pilot training certificates is a critical step for sustaining programs. An active drone program is constrained by the cost of drones and associated sensors, analysis and processing components, and continued training. Demonstrating and filling installation data gaps and cost savings by incorporating drones into workflows should incentivize this portion of installation drone programs.

Implementation Issues

Covid-19, enforcement of the 2020 National Defense Authorization Act, and “Blue drone” requirements created implementation challenges, execution delays, and loss of momentum. Demonstrations initially planned for the final year - to create multiple opportunities to bring pilots together to reinforce skills, create community, and transition the program- were filled by remote events. However, ‘boots-on-the-ground’ flying is the only way to really socialize these programs. Despite the challenges, the project successfully demonstrated the value and effectiveness of deploying drone programs on regional levels with the flexibility to meet installation needs and missions. The partner installations are prepared to use drones in their environmental departments and are working to implement the programs.

Acronyms

BASH	Bird/Animal Strike Hazard
BUQ	Basic Unmanned Aircraft Systems Qualification
CJCSI	Chairman of the Joint Chiefs of Staff Instruction
CONFIRM	Coastal Erosion and Fire Management
DoD	Department of Defense
DIU	Defense Innovation Unit
ESTCP	Environmental Security Technology Certification Program
EO	Electro-optical
EOD	Explosive Ordnance Division
FAA	Federal Aviation Administration
FOD	Foreign Object Debris
GIS	Geographic Information Systems
GPS	Global positioning system
IR	Infrared
MCAS	Marine Corps Air Station
MCBCL	Marine Corps Base Camp Lejeune
MCIEAST	Marine Corps Installations East
MCRD	Marine Corps Recruit Depot
MCLB	Marine Corps Logistics Base
MCSF	Marine Corps Support Facility
MTT	Mobile Training Teams
MUG	Marine Corps Installation East UAS Working Group
NAVAIR	Naval Air Systems Command
NC	North Carolina
NDAA	National Defense Authorization Act
POR	Program of Record
REDDIE	Regional Drone Demonstration for Installations and Environment
RGB	Red, Green, Blue
SC	South Carolina
SfM	Structure from Motion
SLR	Sea level rise
UAS	Unoccupied Aircraft Systems
USMC	United States Marine Corps

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Acknowledgements

This project required the support and assistance of Department of Defense (DoD) military and civilian leadership from several different organizations across Marine Corps East.

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Executive Summary

Introduction

Integrating commercial Unoccupied Aircraft System (UAS) platform and sensor technology into Department of Defense (DoD) installation natural resource management has the potential to dramatically improve the way natural resources are managed. UASs provide access to real-time information from a broader field of view that reduces the need for boots on the ground and creates opportunities to monitor and manage resources with high-resolution data over time. UAS can vastly improve the quality of monitoring data, while providing the data more efficiently and with reduced risk. Other projects are demonstrating UAS technology for natural resource applications locally at individual installations across the country; however, a demonstration path towards broader DoD adoption, ad-hoc UAS applications, and a community-driven UAS support network had not been developed prior to this Regional Drone Demonstrations for Installations and Environment project (REDDIE).

The DoD at large lacks a standardized approach for integrating UAS technology into its civilian workforce and in general environmental programs lack the capacity to establish those protocols. The United States Marine Corps (USMC) Installations East (MCIEAST) leadership provided an opportunity to demonstrate a regional, standardized approach for integrating UAS technology into its civilian workforce, specifically with regards to natural resources. This project capitalized on the skill set, experiences, and momentum of the Environmental Security Technology Certification Program (ESTCP) UAS Coastal Erosion and Fire Management (CONFIRM) demonstration project team (RC18-5187) and took the demonstration from a single installation (Marine Corps Base Camp Lejeune) to the broader, regional MCIEAST. This project was timely because UAS technology is currently being considered as a tool for DoD installation management, and best practices for the operation and implementation of UAS are essential and should be developed collaboratively across installations.

While the benefits of integrating UAS technology into DoD land management are clear, the pathway to a comprehensive approach to adoption was complex. This is because of the need for proper coordination with installation range control divisions, a lack of universal UAS protocol among DoD installations, and the lack of training standards for new UAS pilots. A lack of training standards increases risk for DoD personnel and property, including disruption of cybersecurity, training exercises, and other base activities. The REDDIE project addressed those complications holistically by providing: 1) scientific expertise in DoD-relevant natural resources; 2) UAS-technical knowledge to capture data and transform it into useful information; and 3) the creation, integration, and implementation of DoD standards and protocols. This format can serve as a framework for other DoD regions and services seeking to bring UAS to enhance workforce capabilities.

The overarching project goal was to provide a strategic, operational framework to integrate UAS technology into present and future civilian-led management of the natural resources at MCIEAST installations (Figure 1). The six participating installations share a coastal setting and the associated challenges of climate change. Four of the installations (Marine Corps Base Camp

Lejeune, Marine Corps Recruit Depot Parris Island, Marine Corps Support Facility Blount Island, and Marine Corps Air Station Beaufort) are considered to be in the ten most vulnerable Marine Corps installations to climate-related events.



Figure 1. Map of MCIEAST locations. MCRD Parris Island is not technically part of MCIEAST, but, for the purposes of this report, is included within that grouping.

Objectives

The project objective was to demonstrate a framework for region wide adoption of a UAS program for civilian-led DoD natural resource management.

Technical Objectives

1. Develop regional, MCIEAST level, UAS protocols and pathways to remote pilot certification.
2. Creation and dissemination of standardized UAS mission kits and training materials, established on objective-based requirements.
3. Integrate UAS technology through broad demonstrations that represent a range of UAS applications for DoD natural resource management that exist across installations.

The project focused at a regional, institutional scale and substantially broadened the applicability of the CONFIRM project's impact and built on ESTCP's investment in bringing drones to DoD civilians.

Technology Description

UAS have been used for environmental monitoring for the last several decades, with a variety of applications that include coastal zone monitoring, fire management, and wildlife surveys. The combination of state-of-the-art imaging sensors and automated software processing has streamlined tedious environmental and infrastructure assessments. Advancements in camera sensors, compactness, UAS extended flight capability, and integration of real-time kinematic

GPS have made precise 3D measurements and landscape delineation over large areas (square kilometers) possible.

Project UAS mission kits were designed around specific sets of environmental requirements, to include aerial mapping for habitat characterization and monitoring, surveys tracking change over time, and situational awareness via real-time video. The release of the 2020 National Defense Authorization Act (NDAA) grounded the original mission kit aircraft due to the presence of Chinese made internal components. Shortly after the release of the 2020 NDAA, the Defense Innovation Unit (DIU) released a list of approved drones that did not require a cyberwaiver due to all critical components being manufactured outside of restricted countries. Policy compliant commercial UAS, once vetted by Blue UAS On-Ramp effort, do not require a continuous exception to DoD policy renewal, reducing the administrative burden on end users.

The Vantage Robotics Vesper (Figure 2) was chosen to replace the original mission kit UAS. The Vesper reports a 50-minute flight time and is equipped with a 3-axis, stabilized gimbal, which hosts dual electro-optical (Recon and navigation) cameras and a thermal camera (Figure 2). The Greenseer Recon telephoto lens has a 25mm focal length and is capable of producing orthomosaics with a ground sampling distance (resolution) of 1 cm/pixel at 120 m AGL. While this aircraft is optimized for live feed and still image collection, it is capable of mission planning through QGroundControl to conduct mapping surveys and create orthomosaics.



Figure 2. Vantage Robotics Vesper.

The numerous applications of UAS to natural resource management varies among installations and we identified topics of broad interest, selecting airfield monitoring and wetland monitoring as the demonstration topics. Most MCIEAST installations are located along the coast and have large areas of vulnerable saltmarsh that provide broad ecosystem services and two of the installations (Beaufort and Cherry Point) primarily focus on aviation. In addition to saltmarsh and airfield monitoring, this project leveraged demonstrations developed for the previously funded CONFIRM project, namely fire management and coastal zone (beach) monitoring. Each MCIEAST installation hosted a demonstration and was invited to participate in all demonstrations conducted. This provided an opportunity to build collaborations and a MCIEAST drone community.

Performance Assessment

Creating UAS standards, mission kit delivery and pilot training, drone use demonstrations, and additional support meetings took place throughout the 3.5 year project timeframe, resulting in more than fifty trained personnel across 6 MCIEAST locations (Table 1). The creation of an actionable MCIEAST Order (MCIEAST-MCB CAMLEJO 3710.30B) was the result of this program presenting the leadership at MCIEAST both a viable pathway for safe drone flights on installations and demonstrating the clear utility of drones. The order represents codified protocols for execution of installation level UAS programs managed by civilian federal employees. This is the first regional UAS program to be led by federal civilians across DoD.

Mission kits were successfully created and delivered to the installations. Reliability and appropriateness for natural resource applications drove equipment selection. Connected to this objective is the training of pilots to use the mission kits and apply the training to various use cases (executed through both the two-week training and the demonstrations). Once the initial mission kit was no longer usable because of the 2020 NDAA, new drone platforms were purchased, and pilots retrained. The UAS programs on each installation are non-POR (Programs of Record) and thus have no built-in funding. By providing all the essentials to collect quality data and transform it into usable information, each program has time to establish themselves and further demonstrate the utility of drones on the installation to safely and efficiently collect high quality data. Training also emphasized documenting cost savings when drones are able to replace conventional methods of data collection.

Table 1. Synopsis of REDDIE Project events: trainings, demonstrations, webinars, working group meetings.

Event	Number
MCIEAST Mission Kit Trainings and Demonstrations	56 personnel trained across 6 installations*
MCIEAST UAS Working Group	5 meetings**
Data Processing Webinars	2 webinars
MUG Program Managers Meetings	3 meetings
Final Demonstration - MCIEAST	1 meeting
<i>*Includes 5 two-week trainings, 5 one-to-two-day blue drone trainings, and 6 one-day demonstrations</i>	
<i>**Final MUG Working Group to take place Fall 2022</i>	

Each installation successfully hosted a demonstration which included the execution of flights on demonstration topics which incorporated mission planning and data analysis refreshers. Demonstrations included multiple dimensions of airfield monitoring (mapping habitat around airfields, detecting bird air strike hazards (BASH) and foreign object debris (FOD), assessing runway condition) as well as wetland surveys and monitoring. These activities demonstrated the utility of multiple sensor payloads (e.g., standard RGB, red, green, blue; and multispectral/thermal cameras). This combination of demonstrations can easily be expanded to

other management purposes, particularly with a focus on broad habitat mapping efforts, situational awareness, and wildlife surveys. The fundamentals of mission planning and data processing included in the trainings and outreach were designed to support expanded use cases.

Efficient and safe airfield operations require effective management on and around airfields. Hazards occurring on runways (FOD and poor runway conditions such as pavement cracks) were monitored by mapping runways using high resolution optical sensors. Bird activity contributes to FOD (e.g., shells and other debris carried and dropped on runways by birds) as well as BASH (e.g., birds directly interfering with or posing a risk to airfield operations). Because the hazards present on and around airfields are complex and overlapping, we demonstrated UAS data collection and analysis approaches that could aid in the management of a spectrum of airfield hazards. A habitat mapping and FOD detection application at Michael J. Smith Airfield, NC is shown in Figure 3 below.

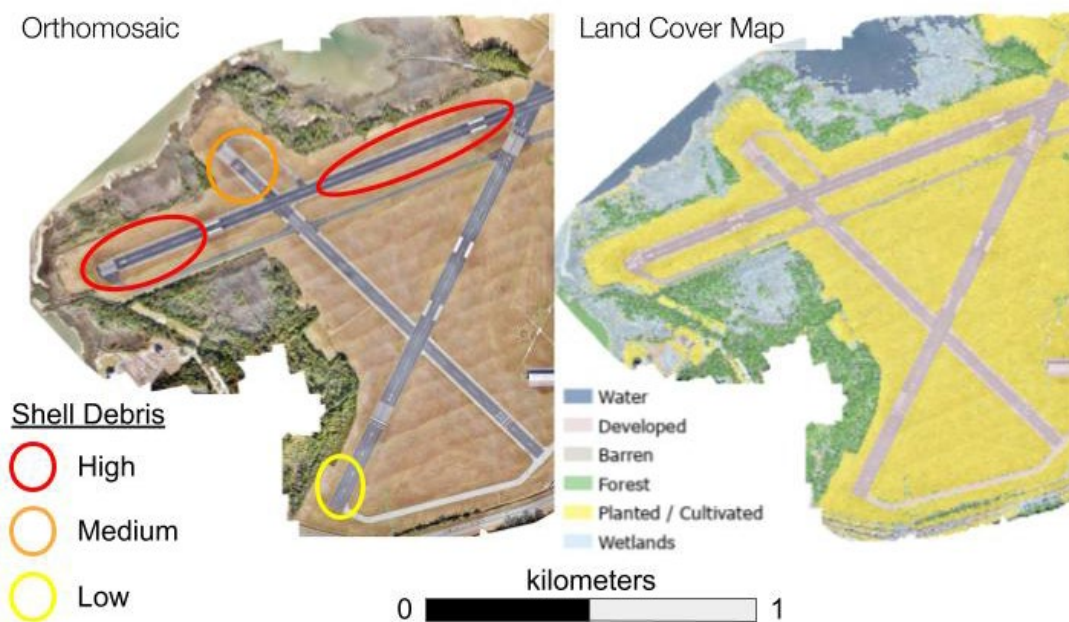


Figure 3. Habitat Mapping and FOD Detection with Classified RGB Imagery at the Michael J Smith Airport in Carteret County, NC.

Fringing coastal saltmarsh provides many services to coastal military installations and communities including infrastructure protection, erosion control, water purification, fish and wildlife habitat, carbon sequestration, and tourism/recreation. Saltmarsh can expand in area at the upland boundary with the conversion of forest into wetland (saltmarsh transgression), but this margin is difficult to study due to lack of access. Using UAS as a monitoring tool can help advance understanding of saltmarsh resilience and improve best management practices by providing high-resolution metrics of spatial and biological change. These surveys will address other broad wetland dynamics applicable across installations, including marsh die-off and recovery. Figure 4 (below) shows a variety of UAS-derived data for monitoring salt marsh change.

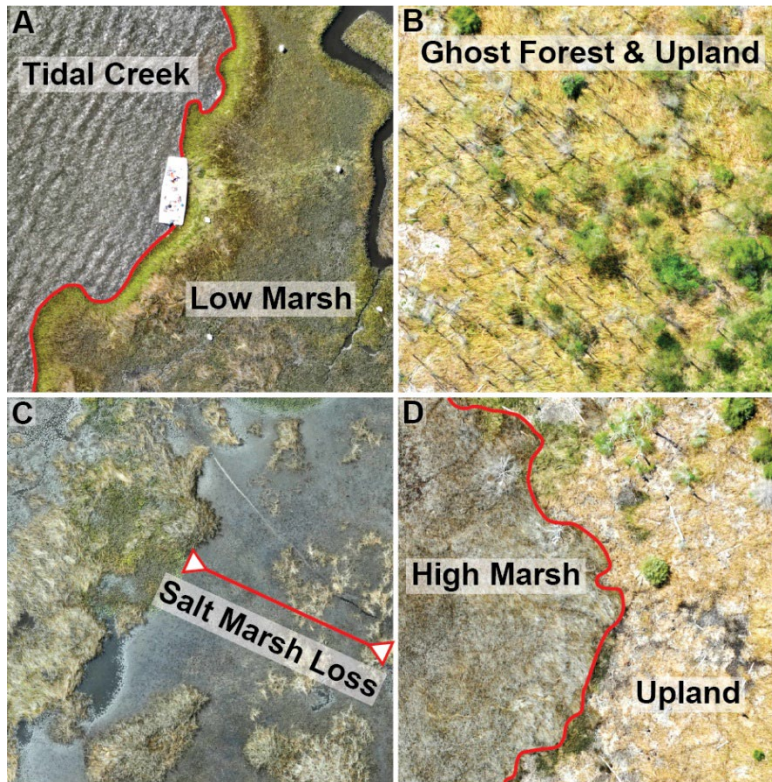


Figure 4. Unoccupied Aircraft Systems (UAS) provide superior data for mapping the salt marsh shoreline (A), health indicators such as ghost forest (B), marsh die off (C), and upland boundary (D).

Cost Assessment

Costs for an active drone program are constrained by key elements: drones and associated sensors, analysis and processing components, and continued training and new equipment for program sustainment.

A number of factors influence the choice of drones for environmental management. The choice will be driven by fundamental factors of cyber security status (waiverable or approved BlueUAS platforms), the ability of the drone and associated sensors to meet the goals of the natural resource managers, and available funding. Additionally, drone-based data collection may not be optimal for single instance data collection exercises. Rather, the cost model for drone-based applications is better suited to programs requiring repeated data collection, and especially so in unpredictable systems. Current limitations regarding which UAS are able to fly on DoD property means selecting from a small pool of equipment like those provided in the BlueUAS program or ones that are eligible for cybersecurity waivers. Blue drones are generally much more expensive than their unapproved Commercial Off-the-shelf (COTS) counterparts, like the Anafi government BlueUAS version (\$14,000) compared to the standard Anafi Thermal (\$2,000). However, as these systems become more prominent in the UAS market, their pricing should decrease and the availability of NDAA compliant drones will increase.

The costs of analysis and software are a requirement for mapping and monitoring. Under current IT rules, it is far easier for the drone programs to operate on a stand-alone computing system that is not on the USMC network, and there is precedence for this approach across MCIEAST. A laptop with adequate computing power was included in the mission kits and should be considered a long-term, periodic cost. Software is both a one-time cost and annual maintenance cost that can operate as a stand-alone endeavor or be included in the extensive GIS department of MCIEAST. The initial investment can be high, but yearly costs are minimal. Without these resources, end-products would be limited to the capabilities of open-source software or to videos and images.

Training costs are a fundamental part of continuing the programs long-term as new employees join the effort and need training. This funding may be problematic until the drone programs become Programs of Record and have line-item funding. Demonstrating and filling installation data gaps and cost savings by incorporating drones into workflows should incentivize this portion of installation drone programs.

Implementation Issues

The REDDIE project, in collaboration with MCIEAST installations, stood up a regional drone program to be led by installation natural resource managers and address a broad set of environmental challenges. This program is the first of its kind in DoD, and while individual installations across the services use drones, and pathways exist in all services, this regional approach codifies protocols that eliminate one-off approvals and facilitates drone use in everyday workflows and on-demand. The MCIEAST Order, which was a direct result of this project, brought drones to the forefront for federal civilians and enabled users and leadership to socialize drones into the workforce. It provides safe guidelines that are accepted on the regional level and allows for customizing the program to satisfy each installation's particular settings and mission. There were however important implementation issues with lessons for the future.

Delays in execution were the biggest challenge and translated into loss of momentum in a number of meaningful ways over the lifetime of the project. Covid-19 delayed training events scheduled for early 2020, although remote connections were established through MCIEAST UAS Working Group meetings and webinars. Training was delayed but was ultimately implemented with strict Covid protocols. Demonstrations were initially planned to be executed across the entire third year and create multiple opportunities to bring pilots together on a timed schedule to reinforce skills and program progress, as well as transition the program management from the project team to the installations. While demonstrations were successful, valuable follow-up and reinforcement time was sacrificed, and program transfer has suffered. Gaps were filled by webinars, but 'boots-on-the-ground' flying is the only way to really socialize these programs.

The enforcement of the 2020 NDAA prompted a shift in the mission kit. The original mission kits constructed for the program were designed to meet multiple environmental needs, provide multiple aircraft, be reasonable in price, and transition the installations until they secured funding to carry replacements. The shift by DoD to Blue UAS in early 2021 created an additional layer of complication and procurement challenges resulting from high demand creating months-long waiting lists and extremely high costs. This cost shift may prove to be too much for early,

unfunded programs to sustain. As new Blue UAS are added to the approved list and more manufacturers become a part of the process, this landscape will change once again and perhaps be more affordable for non-military uses. Additionally, a growing market of NDAA compliant, but not DIU approved blue drones, offers an affordable, high-quality alternative for use on DoD lands. The cumulative impact of the delays meant the final planned year of demonstrations and transitions was compressed.

The culture on military installations around new technology can be a challenge for implementation. The project team had vast experience working with DoD prior to this project, and were prepared with strategies to succeed (e.g., briefing the right people early and often, a comprehensive understanding of the MCIEAST military mission and the environmental challenges on installations, understanding the range and air space systems on installations). In spite of the challenges, the project moved forward and successfully demonstrated the value and effectiveness of deploying drone programs on regional levels with the flexibility to meet installation needs and missions. The partner installations are prepared to use drones within their environmental departments and are working within their organizations to implement the programs. The use of drones by other groups on the installation is an outgrowth of this project and installations are already looking to train additional pilots.

1.0 INTRODUCTION

1.1 BACKGROUND

Integrating Unoccupied Aircraft System (UAS) platform and sensor technology into Department of Defense (DoD) installation natural resource management has the potential to dramatically change the way natural resources are managed. UAS provide access to real-time information from a broader field of view that reduces the need for boots on the ground and creates new opportunities to monitor and manage resources with high-resolution data over time. UAS can vastly improve the quality of monitoring data, while providing the data more efficiently and with reduced risk. UAS technology is currently being demonstrated for natural resource applications at individual installations across the country (through several Environmental Security Technology Certification Program, ESTCP, efforts); however, a demonstration path towards broader DoD adoption and ad-hoc UAS application had not been developed prior to this project, Regional Drone Demonstration for Installations and Environment (REDDIE).

Each service in DoD follows uniform cyber security requirements and then develops their own set of policies and procedures. Those pathways to flying tend to be executed on the installation level as a stand-alone entity. Service and regional levels lack a standardized approach for integrating UAS technology into its civilian workforce and in general environmental programs lack the capacity to establish those protocols. The United States Marine Corps (USMC) Installation East (MCIEAST) provided an opportunity to demonstrate a regional, standardized approach for integrating UAS technology into its civilian workforce, specifically with regards to natural resources (Scalise and Plummer, 2018). This project capitalized on the skill set, experiences, and momentum of the ESTCP UAS Coastal Erosion and Fire Management (CONFIRM) demonstration project team (RC18-5187) and took the demonstration from a single installation (MCBCL) to the broader USMC east coast region (i.e., MCIEAST). This project was timely because UAS technology is currently being considered as a tool for DoD installation management, and best practices for the operation and implementation can be developed collaboratively across installations as opposed to individually per installation promoting wider socialization and accepted practices.

While the benefits of integrating UAS technology as a tool into DoD land management are clear, the pathway to a comprehensive approach to this adoption was complex and required 1) scientific expertise in DoD-relevant natural resources; 2) UAS-technical knowledge to capture data and transform it into useful information; and 3) the creation, integration, and implementation of DoD standards and protocols. These integrative steps are complicated by the need for proper coordination with installation range control divisions, a lack of universal UAS protocol among DoD installations, and the lack of training infrastructure for new UAS pilots. Notably, the lack of training infrastructure increases risk for DoD personnel and property, including disruption of cyber-security, training exercises, and other base activities. This project addressed those complications holistically. This format can serve as a framework for other DoD regions and services seeking to bring UAS to enhance workforce capabilities.

The aforementioned ESTCP CONFIRM project (RC18-5187) focused on specific natural resource questions targeted at a single installation (MCBCL), whereas this project created a comprehensive framework for regionally incorporating UAS technology, bringing together a

project team, installation commanders and staff, and the delivery of transitional products (e.g. training materials, operational standards, mission kits) to all MCIEAST installations. The project provided a strategic, operational framework that MCIEAST installations will use to integrate UAS technology into present and future civilian-led management of natural resources.

1.2 OBJECTIVE OF THE DEMONSTRATION

The project objective was to demonstrate a framework for region wide adoption of a UAS program for civilian-led DoD natural resource management.

Technical Objectives

1. Develop regional, MCIEAST level, UAS protocols and pathways to remote pilot certification.
2. Creation and dissemination of standardized UAS mission kits and training materials, established on objective-based requirements.
3. Integrate UAS technology through broad demonstrations that represent a range of UAS applications for DoD natural resource management that exist across installations.

The project focused at a regional, institutional scale and substantially broadened the applicability of the CONFIRM project's impact and built on ESTCP's investment in bringing drones to DoD civilians.

1.3 REGULATORY DRIVERS

Environmental regulatory drivers are a part of natural resource management across the DoD, and in concert with increasing fence line encroachment and challenges of climate change, managers benefit from any improvements in tools to manage their natural resources. Drone technology offers safer, more efficient data collection and, often, better quality data. The use of drone technology can assist managers in complying with regulatory drivers in more efficient ways and open areas to monitoring that in the past proved logistically challenging (e.g., impact areas).

With regards to the use of drones on DoD lands, Federal Aviation Administration (FAA) airspace and DoD/Installation specific rules provided the regulations for this project and for the installation programs as well. Where airspace surrounding DoD installations is restricted and not governed by standard FAA regulations for the use of UAS, DoD regulatory drivers are in place. Those drivers include the use of blue drones or a UAS COTS waiver and installation level coordination with range control and other relevant offices. There are no rules or regulations that specifically enable or prohibit civilian operation of UAS on DoD lands for environmental management. This project addressed the need for protocol development in collaboration with installation regulators to help facilitate the incorporation of UAS technology into base management. In addition, the FAA has implemented Special Security Instructions (SSI) to address the potential threat posed by malicious drone operations. Specific UAS airspace restrictions were established over select, national security sensitive locations and permission from the FAA was acquired.

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

Detailed specifications are provided in relevant sections of 5.0 (Test Design).

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

UAS obtain high-resolution imagery, finer than what airplanes or satellites can achieve, but are limited to mapping relatively small areas (<10 km²) due to battery technology and/or line-of-sight regulatory restrictions. Technology and policy are constantly improving and, in the future, UAS will in some instances replace airplanes for rapidly mapping large areas. Currently, the commercial UAS niche is high-resolution, highly precise and accurate, versatile, on-demand, affordable, and safer data collection. These specifications make UAS the ideal tool for examining landscape changes that occur rapidly, unpredictably, and are difficult, hazardous and/or expensive to assess on the ground.

Small consumer drones are now available with standard Electro-optical (EO), multispectral, hyperspectral, and thermal Infrared (IR) sensors. Advancements in sensor technology and photogrammetry software are continuing to enable more precise measurements with fixed-wing aircraft (Hugenholtz et al. 2013, Klemas 2015, Seymour et al. 2018), and with higher sampling resolution and greater stability, multirotor aircraft have already been used to achieve highly precise measurements and digital surface models in coastal environments (Mancini et al. 2013).

A key component of this project was its reach across a group of installations under regional management, to provide an operational foundation for UAS in natural resources that can then be independently developed into other parts of installation management. The project workflow (Figure 1) was designed to bring installations together around demonstrations. The process of being able to fly UAS on a Marine Corps installation in the MCIEAST family was well known to the project team and workflows were established with relevant offices (e.g., FAA; Naval Air Systems Command, NAVAIR) prior to training and demonstrations, to include UAS COTS waivers and FAA approvals. The project team established a chain of command within MCIEAST to facilitate the approval of waivers. Common DoD cyber-security issues and solutions to those issues were addressed during training.

Mission planning for landscape mapping, flying UAS for situational awareness, or the collection of spectral information using sensors all began with the same fundamental steps executed in a comprehensive training course (Figure 1), and there are numerous applications. Considering the shared coastal locations and environmental challenges with consequences to meeting the military mission, UAS technology uses for the MCIEAST DoD installations include:

- Before and after storm impact assessments of DoD property along with recovery from disturbance
- Mapping extreme tidal flooding events
- Monitoring wetland growth/loss and elevation change
- Monitoring species of special interest, including invasive species
- Bird/animal strike hazards
- Forest stand characterization

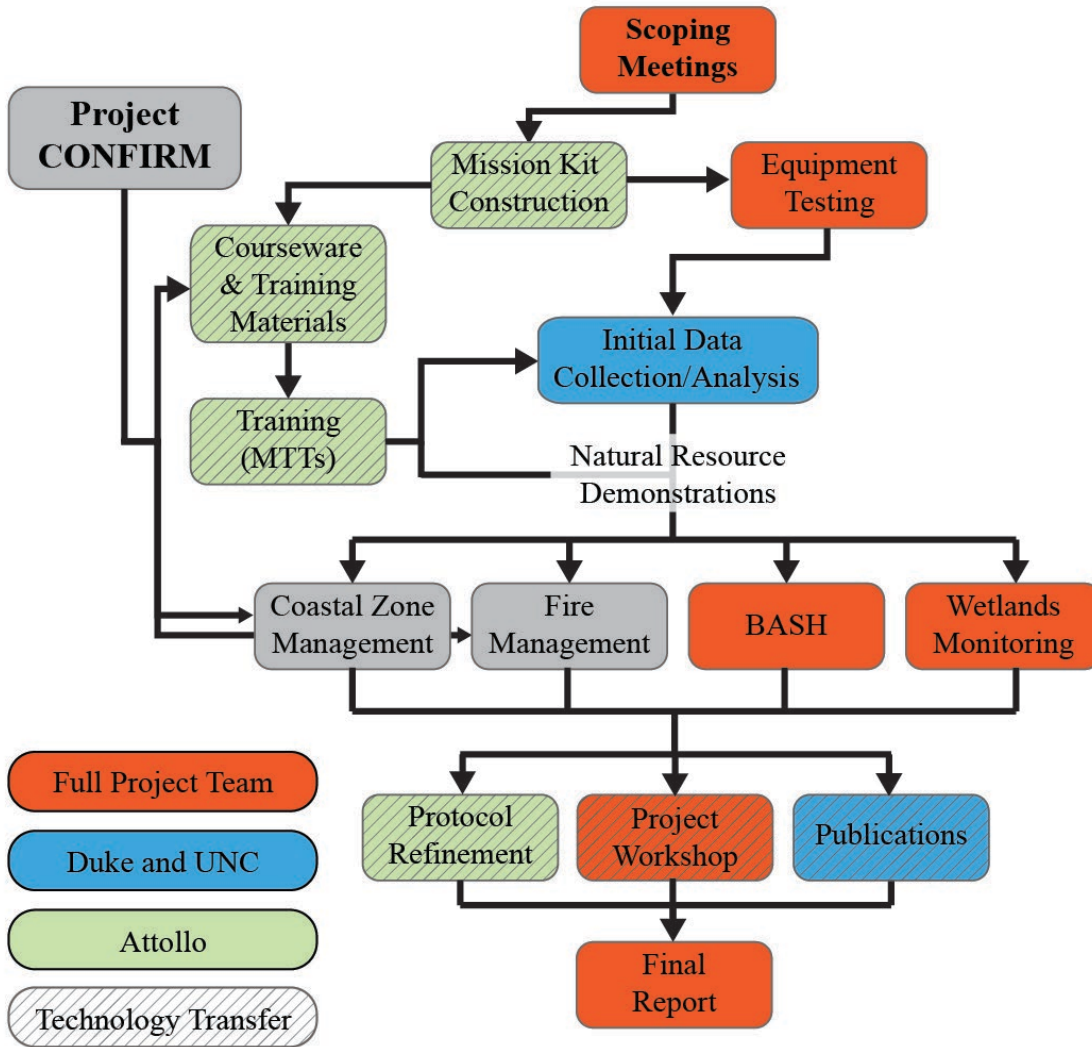


Figure 1. Project workflow. Colors designate which project team members had primary responsibility for the action. Technology transfer actions are indicated with striping.

2.2 TECHNOLOGY/METHODOLOGY DEVELOPMENT

UAS have been used for environmental monitoring since the early 2000s (Klemas 2015), with a variety of applications that include coastal zone monitoring (Seymour et al. 2018), fire management (Olero et al. 2006), and wildlife surveys (Watts et al. 2010). The combination of state-of-the-art imaging sensors and automated software processing has streamlined tedious environmental and infrastructure assessments. Advancements in camera sensors, compactness, UAS extended flight capability, and integration of real-time kinematic GPS have made precise 3D measurements and landscape delineation over large areas (square kilometers) possible with Structure from Motion (SfM) image processing (Seymour et al. 2018).

2.3 ADVANTAGES & LIMITATIONS OF THE TECHNOLOGY/METHODOLOGY

There are currently no tools of equal ability to UAS available to federal civilian employees managing natural resources on DoD installations, and in this instance, MCIEAST. While there are limited individual events and research projects on DoD installations, there are no established civilian led UAS programs aboard an installation. New tools create efficiencies and enhance the capabilities of the natural resource professionals aboard MCIEAST installations.

This program sought to enable real-time uses and non-burdensome processes and workflows for using drone technology on installations for natural resources management. By leveraging and coordinating cross-installation demonstrations between CONFIRM and this project, managers were brought together to understand UAS capabilities across a greater range of scenarios, in addition to their specific installation demonstration. Demonstrations included multiple dimensions of airfield monitoring (mapping habitat around airfields, detecting Bird Aircraft Strike Hazard (BASH), and Foreign Object Detection (FOD), assessing runway condition) as well as wetland surveys and monitoring. During engagement with Installations, whether in training or during webinars, additional uses to include fire and forestry applications were also emphasized.

Project activities were initially developed to demonstrate the utility of multiple aircraft platforms (fixed and rotary wing), types (commercial, consumer, and compact), and sensor payloads (e.g., standard red-green-blue (RGB), multispectral, hyperspectral cameras). Due to changes in regulations from the 2020 NDAA for using drones in regulated airspace and for government work during the project timeline, the original mission kit had to be replaced to remain compliant with the new regulations. Thus, the project initially began demonstrating applications using a wider range of aircraft and sensors, before paring down the mission kits and objectives to focus on a 2020 National Defense Authorization Act (NDAA) compliant aircraft and its associated sensor payloads.

Regardless, the combination of demonstrations can easily be expanded to other management purposes, particularly with a focus on broad habitat mapping efforts, situational awareness, and wildlife surveys. The skill set behind these types of data collection is broadly applicable. The courseware and protocols developed with cooperation from MCIEAST management personnel constituted a rigorous training program for safe and effective UAS operation across military environmental management divisions.

Employing UAS to collect remotely-sensed data is the solution to monitoring coastal areas because they solve the main problems with traditional sensor platforms, such as satellites and airplanes. Those platforms are not ideal for on-demand utilization because they require a high-level of funding, coordination, and specialized training. Furthermore, use of UAS reduces the risk of injury or death to personnel conducting airborne monitoring (Butler et al. 2015). As UAS technology has rapidly developed, its application in many industries has outpaced the regulatory environment, making it confusing for managers seeking to employ it. This regulatory lag exists in both governmental and institutional regulation and policy. Despite this, UAS are increasingly deployed for natural resource missions across the US, by governmental and private institutions.

3.0 PERFORMANCE OBJECTIVES

Table 1. Performance objectives.

Performance Objectives	Metrics	Data Requirements	Success Criteria	Results
<i>Technical Objectives/Tasks</i>				
Develop regional, MCIEAST level protocols and pathways to pilot certification	A formalized and codified pathway to pilot certification Implementation of protocols	N/A	MCICOM approval and adoption to fulfill USMC training requirements (based on Chairman of the Joint Chiefs of Staff Instruction, CJCSI, BUQ II standards) Acknowledgement of certified pilots on installation level	MCIEAST Order (MCIEAST-MCB CAMLEJO 3710.30B) MCICOM acceptance of courseware after review by cognizant authority appointed by the Designated Acting Authority (DAA)
Creation and distribution of mission kits	Mission kit capability to meet natural resource requirements Individuals trained Kits delivered to installations	Number of individuals trained Number of installations receiving kits	Installation personnel trained and UAS kits delivered to all involved installations	Itemized list of installations and mission kits (See Table 6)
Develop demonstrations that represent the range of UAS applications for natural resource management	Documentation of demonstrations (airfield and wetland monitoring)	Study sites of demonstrations Imagery, orthomosaics, digital elevation models	Documentation of workshops and data products that explain the demonstrations	See Table 6 (also Appendices C and D)

The goal of this project was to integrate UAS technology into natural resource management across MCIEAST. The work reached across a group of installations under regional management to provide an operational foundation for UAS in natural resources that could then be independently maintained and developed into other parts of installation management. This overarching, primary goal was achieved through the successful completion of the three technical objectives.

1. Develop regional, MCIEAST level protocols and pathways to pilot certification

- **Relevance:** The first objective was written to develop permanence of the UAS technology into the workflows of natural resource professionals on MCIEAST installations. It is executed through leadership approved pathways and procedures, to include at its core training and certification of federal civilian employees for flying.

- Metric Description: A codified and approved pathway to pilot certification; implementation of protocols.
- Data Required: There is no data, per se, to meet this objective but executable actions that secure the ability to fly drones.
- Success Criteria: We considered the objective met if the training course was accepted by MCICOM as the requirement for this project's course pilots to fly aboard their respective installations and as the standard for future pilots as their programs mature.

2. Creation and distribution of mission kits

- Relevance: Mission kits were designed to maximize utility and acceptance as the starting equipment for a UAS program that considers the geographic settings of the MCIEAST installations and relevant environmental challenges. Lessons learned from the CONFIRM project guided mission kit production.
- Metric Description: Mission kits developed to meet natural resource requirements; mission kits sourced, tested, and distributed; personnel training to include passing the FAA Part 107 and course certification. Cyber waiver certificates were also required for original kit drones. Compliance with the 2020 NDAA shifted the metric to include blue drones that meet the cyber security requirement through a different path.
- Data Required: Number of installations receiving kits by end of project timeline and exposure to the kits and capabilities in training and demonstrations; number of trained personnel.
- Success Criteria: This objective was met when UAS kits were delivered to and accepted by trained pilots at installations.

3. Demonstrations that represent the range of UAS applications for natural resource management

- Relevance: The third objective sought to demonstrate two UAS applications, airfield monitoring and wetlands monitoring. This objective leveraged demonstrations developed for the CONFIRM project (RC18-B5-5187), fire management and coastal zone monitoring. Each MCIEAST installation hosted a demonstration to build the UAS MCIEAST community.
- Metric Description: Demonstrated UAS use for airfield assessments, extent and resolution of wetland mapping.
- Data Required: Study site imagery, orthomosaics, digital elevation models
- Success Criteria: This objective was met through documentation of workshops, webinars, and data products that explained the demonstrations. Additionally, all demonstrations share the same fundamental mission planning and training to enable students to apply skills to a variety of applications. Production of white papers (see Appendices C and D).

4.0 SITE DESCRIPTION

4.1. SITE LOCATION AND HISTORY

Marine Corps Installations East (MCIEAST) was designated a singular command on April 3, 2012 and includes: MCBCL, North Carolina (NC) (includes Marine Corps Air Station, MCAS, New River, NC); Marine Corps Support Facility, MCSF, Blount Island, FL; Marine Corps Logistics Base, MCLB, Albany, GA; MCAS Beaufort, South Carolina, SC; and MCAS Cherry Point, NC. *NOTE: Marine Corps Recruitment Depot, MCRD, Parris Island, SC is not a part of MCIEAST but, due to its location, collaborates frequently with MCIEAST installations and shares similar natural resource challenges. For the purposes of this project, references to MCIEAST also include MCRD Parris Island.* While MCB Camp Lejeune was a part of the CONFIRM project for training and mission kits, they were also included in REDDIE demonstrations and meetings to encourage regional adoption and coordination (Table 1, Figure 2). With installations located in North Carolina, South Carolina, Georgia and Florida, a unique combination of ocean, coastal, riverine, and airspace training areas make MCIEAST foundational to national defense to prepare and support Expeditionary Forces.



Figure 2. Map of MCIEAST locations

4.2 SITE CHARACTERISTICS

Participating installations share a coastal setting and the associated challenges of climate change. Four of the installations (MCB Camp Lejeune, MCRD Parris Island, MCSF Blount Island, and MCAS Beaufort) are considered to be in the ten most vulnerable Marine Corps installations to climate-related events (Conger 2019). While Albany is not directly on the coast, the remainder

of the installations share coastal wetlands, with a need for monitoring of eroding shorelines and wetland conditions.

The Region’s installation assets and training resources are substantial and include 172,000 acres of land, 7,254 square miles of training airspace, 9,400 buildings and facilities, and 105 ranges and 98 training areas encompassing 100,000 acres. According to the MCIEAST Strategic Plan 2040, “MCIEAST will posture its installations to meet future strategic environment challenges by providing guidance and direction, enabling planning, identifying revolutionary sustainability solutions, supporting the development of public and private relationships, advocating for scarce resources, and leading the transition to smart, integrated problem solving. These functions will be enabled by automation, robotics, and algorithmic-based artificial intelligence (MCIEAST 2017).”

Many MCIEAST installations present unique challenges due to the associated airspace surrounding and above the facilities. Before flights could be conducted at MCAS Cherry Point and MCSF Blount Island, approval was required from the Federal Aviation Administration (FAA) via local air traffic control (ATC). Flights at MCSF Blount Island proved extra challenging due to approval needed from both civilian and military air traffic control as this had not been previously conducted according to all parties involved. The Dayson dredge spoil site is split by civilian controlled airspace at Craig Municipal Airport and military controlled airspace at Naval Airstation Mayport. The team conducted several coordination meetings with both organizations to ensure adherence to all regulations, and then received approval for flights across the entirety of MCSF Blount Island. These coordination protocols were then shared with Blount Island staff and they successfully led the same process on their own.

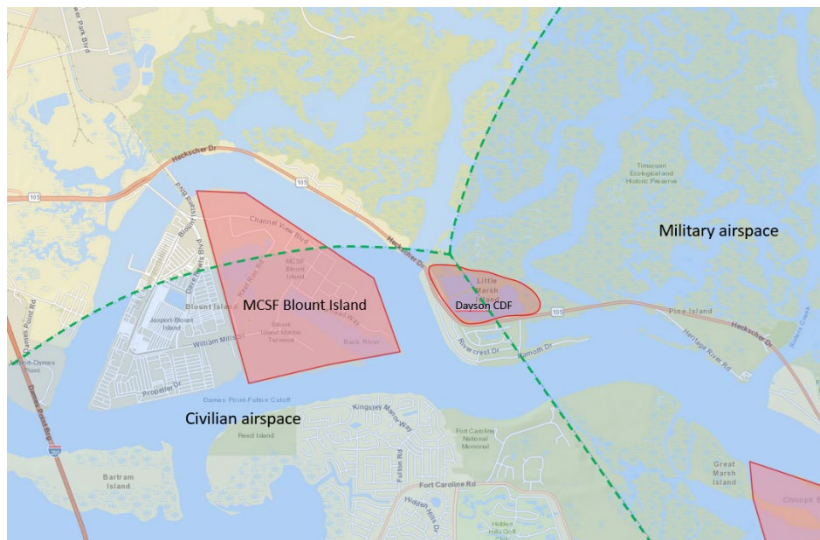


Figure 3. MCSF Blount Island Airspace.

Table 2. Installation Descriptions.

Installation	Description
MCAS Beaufort, SC	MCAS Beaufort is home of the Marine Corps' Atlantic Coast fixed-wing, fighter-attack aircraft assets. It consists of 6,900 acres and is 70 miles southwest of Charleston, SC. The mission of MCAS Beaufort is to support establishment operations in support of 2nd Marine Aircraft Wing, attached II MEF units, and MCRD Parris Island/Eastern Recruiting Region.
MCAS Cherry Point, NC	MCAS Cherry Point is the home of the Marine Corps' 2nd Marine Aircraft Wing. The airfield is located in Havelock, North Carolina and the air station proper consists of 13,000 acres (with an additional 15,975 auxiliary acres, including Marine Corps Auxiliary Landing Field Bogue, NC).
MCRD Parris Island, SC	MCRD Parris Island is a Marine corps training facility that trains 17,000 recruits per year. It consists of 8,095 acres military installation located within Port Royal, SC approximately 5 miles (8.0 km) south of Beaufort. MCRD Parris Island consists of 8,095 acres, of which almost 5,000 acres are salt marsh.
MCLB Albany, GA	MCLB Albany is the home of Marine Corps' Logistics Command and Marine Depot Maintenance Command/Production Plant. Located just outside of Albany, Georgia, and is 3,300 acres. The mission of MCLB Albany is to provide integrated logistics/supply chain and distribution management; depot level maintenance management; and strategic pre-positioning capability.
MCSF Blount Island, FL	MCSF Blount Island is home to the Blount Island Command and serves as the Marine Corps' prepositioning programs to the Marine Air Ground Task Force. Blount Island Command supports three Maritime Prepositioning ship squadrons that fall under the Maritime Prepositioning Ships Program. Blount Island approximately 2,000 acres on the St. Johns River in Jacksonville, Florida, nine nautical miles (16.7 km) west of the Atlantic Ocean.
MCB Camp Lejeune, NC (CONFIRM)	MCB Camp Lejeune is home to the Marine Corps' II Marine Expeditionary Force, Marine Air Ground Task Force. Located next to Jacksonville, North Carolina, Camp Lejeune is over 150,000 acres and is the largest Marine Corps facility on the east coast. The 14 miles of beach shoreline is a critical amphibious assault training asset.

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

This project demonstrated a regional, strategic approach to enable UAS natural resource capabilities across MCIEAST installations. While the advantages of integrating UAS technology into DoD management are clear, the pathway to a comprehensive approach to adoption was a complex problem addressed through the project's objectives of training, outfitting with mission kits, and broad demonstrations. Project objectives of training, protocols, and mission kits proceeded with buy-in and approval of MCIEAST leadership that ultimately cleared the path for UAS adoption and implementation. The courseware and protocols developed constitute a rigorous program for safe and effective UAS operation across military environmental management divisions and acceptance as the standard.

Successful integration of UAS technology for MCIEAST natural resource managers occurred by: 1) developing the skills and knowledge base new UAS pilots require, 2) providing operational integration into range and airspace control systems, 3) equipping DoD land managers with skills and tools for UAS data collection, and 4) providing commanders with a uniform, safe, and effective starting point for UAS use in natural resources that can be readily expanded to other areas. By leveraging and coordinating cross-installation demonstrations between CONFIRM and this project, managers were brought together to understand UAS capabilities across a greater range of scenarios, in addition to their specific installation demonstration. Demonstrations included multiple dimensions of airfield monitoring (mapping habitat around airfields, detecting BASH and FOD, assessing runway condition) as well as wetland surveys and monitoring. These activities demonstrated the utility of multiple sensor payloads (e.g., standard RGB and multispectral/thermal cameras). This combination of demonstrations can easily be expanded to other management purposes, particularly with a focus on broad habitat mapping efforts, situational awareness, and wildlife surveys.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

Baseline characterization for this project began with lessons learned from the CONFIRM project being applied to all three technical objectives, moving towards full regional deployment. Installation staff were involved in the planning of each demonstration event in order to tailor each to the needs of the installation. Prior to each training event, a kick-off call was conducted to plan for the two-week event to include designating areas for classroom and flying time. Training included flying in the relevant demonstration environmental scenarios. A review of environmental challenges and concerns with installations were outlined. The demonstrations (airfield and wetland monitoring) were developed with prior communications with the installations and review of the Installation Natural Resource Management Plans for each Base.

The foundation of the project relied on establishing and receiving support from a Designated Acting Authority (DAA). The project team established a series of coordination meetings between MCIEAST and Marine Corps Installations Command (MCICOM) to develop supporting orders that laid the framework for a UAS program. During this meeting series, the project team was

asked to provide guidance on topics including program management, UAS deconfliction measures, and training baselines. The Commanding General of MCICOM serves as the DAA and appointed installation commanders as Aircraft Reporting Custodians (ARC). Each installation had an onsite meeting shortly after project award to understand the goals, what support and commitment was required, and how the project would be executed. These meetings included Base Commanding Officers, range managers, natural resource professionals, and GIS staff. This effort was critical for complete installation buy-in and to the development of the demonstration plan.

Coordination with the Federal Aviation Administration (FAA) was also required due to 49 USC §40102(a)(41), which states that Public Aircraft are owned and operated by the federal government, U.S. military or government of a State. Certification for UAS pilots within DoD is dictated by CJCSI 3255.01 - Joint Unmanned Aircraft Systems Minimum Training Standards, Basic Unmanned Qualification (BUQ).

5.3 DESIGN/LAYOUT OF TECHNOLOGY & METHODOLOGY COMPONENTS

The methodology included the execution of each task to collectively integrate UAS into natural resource management across MCIEAST.

Training Protocol Application

- 1) Using the developed training and protocols from the CONFIRM project, information was validated and finalized for regional project demonstrations. Mobile Training Teams (MTT) were deployed for on-site training for MCIEAST end-users (MCAS Beaufort, MCRD Parris Island, MCAS Cherry Point, MCLB Albany, MCSF Blount Island). MTTs included both 14 Code of Federal Regulations Part 107 and DoD Basic UAS Qualification (BUQ) II or greater trained instructors. This training exceeded BUQ II standards and met the highest standards of the Marine Corps.
- 2) The MTT led four, 2-week training courses (MCRD Parris Island and MCAS Beaufort held a joint course). The first week consisted of the aviation fundamentals required for basic and advanced flight operations. Students learned proper preflight planning, mission and contingency planning, launch operations, flight maneuvers, the conduct of mapping, dynamic sensing and situational awareness mission sets, recovery operations including post recovery inspections, and data transfer. The second week consisted of practical application of ground course material by focusing on live-flight training. The students gained familiarity with mission kit equipment; conducted mission rehearsals, as well as received training on software/GIS workflows for processing and analyzing data.
- 3) Protocol documents were refined to best standardize practices that integrate UAS and piloted platforms in close proximity for both DoD range space and occupied/unoccupied teaming. The products included the following:

1. Remote Sensing Field Guide with UAS remote sensing methods, techniques, and procedures (Appendix B)
 2. FAA Certificate of Authorization, writing guidance for DoD facilities.
 3. Cyber-security issue awareness and resolution
 4. Preflight checklists for aircraft
 5. Supplemental resources
 - (a) Data processing manuals and access to software
 - (b) General information about project and mission kits
 - (c) MCIEAST Order (MCIEAST-MCB CAMLEJO 3710.30B)
 - (d) Demonstration white papers (Appendices C and D)
- 4) Due to the COVID-19 pandemic, in-person training was not possible for a significant period of the project. To counter this, the project team took advantage of the MCIEAST UAS Working Group (MUG) - the project's effort to create a community for the MCIEAST drone pilots. Virtual webinars were held quarterly to keep installations up to date with the latest MCIEAST order updates, provide refresher training on data processing software, connect environmental managers across MCIEAST on the use of UAS for management practices, etc.
- 5) The difficulties of ever-changing cybersecurity protocols from the DoD caused many shifts across the project. Initial MTTs trained students on the original mission kit which included the senseFly eBeeX and Parrot Anafi Thermal. As of May, 2021, those aircraft were no longer allowed to be flown due to the NDAA. Due to the demand on compliant drones and supply chain shortages caused by the COVID-19 pandemic, it took one year from purchase for all installations to receive their NDAA compliant drone, the Vantage Robotics Vesper. A new training course was developed for utilization of the Vesper and the MTT visited each installation again to re-train students.

Mission Kit Production

Building on experience from CONFIRM mission kit production for MCBCL, kits were designed to be produced around the requirements for two sets of mission types:

A - Aerial mapping and survey (survey-grade multirotor and fixed wing aircraft), demonstrated in wetland and airfield monitoring

B - Situational awareness via real-time video (commercial quadcopter) continued to emphasize uses in prescribed fire and post-extreme event surveys

The initial, pre-2020 NDAA mission kit UAS were included on NAVAIR's UAS approval list with a category III flight clearance making the only requirement to receive a DoN COTS UAS cyber waiver. For the first half of this project, the team became very efficient with the Department of the Navy's (DON) commercial-off-the-shelf (COTS) UAS and received seven consecutive waivers to fly at all installations. The cyber-waiver request packages were robust and included:

- Endorsement from Flag Officer or SES equivalent
- Letter of support from installation Commanding Officer

- Map of approved flight areas
- Cyber Security Mitigation Plan
- Detailed questionnaire for each aircraft type

The original drone platforms selected for inclusion in the mission kits were the Parrot Anafi Thermal and the Sensefly eBeeX. Sensor payloads included in the mission kits were chosen for environmental applications (Tables 3 and 4). Continuing lessons learned from CONFIRM, a large quadcopter drone was replaced by the compact Parrot Anafi Thermal. The small, foldable design of the Anafi Thermal made it ideal for quick response and ease of flight. Ancillary equipment included a VHF radio, walkie talkies, tablet for flying Anafi Thermal, and ruggedized cases among others. The SenseFly eBeeX is a proven and reliable mapping drone that has been around for many years. Equipped with a modular payload system, sensors can be easily swapped in the field to meet the mission's need. An enhanced ground control station (GCS) laptop to fly the eBee was included as part of the lessons learned from CONFIRM. The GCS has the capability to process imagery collected from all aircraft included in the mission kit.

The release of the 2020 NDAA grounded the original mission kit aircraft due to the presence of Chinese made internal components. Shortly after the release of the 2020 NDAA, the Defense Innovation Unit (DIU) released a list of approved drones that did not require a cyberwaiver due to all critical components being manufactured outside of covered countries. Policy compliant commercial UAS, once vetted by Blue UAS On-Ramp effort, **do not** require a continuous exception to DoD policy renewal, reducing the administrative burden on end users (DIU, 2021). This placed the project team at a critical decision point on the path forward. Option one was to select a NDAA compliant drone and continue to pursue cyberwaivers through the DON COTS UAS board. Due to the rapidly changing nature of cyber protocols, this felt like a high-risk decision. Instead, the team chose to investigate the five approved Blue UAS and select the best fit for our performance objectives. The Vantage Robotics Vesper (Figure 4, Table 5) boasts a 50-minute flight time and is equipped with a dual EO and thermal cameras.



Figure 4. Vantage Robotics Vesper.

Table 3. Parrot Anafi specifications.

Diameter	241x315x64 mm
Airframe weight	315 g
MTOW	315 g
Power	Electric
Motors	Brushless
Flight Control	2 x 6-axis IMU, 2 x 3 axes accelerometer, 2 x 3-axes gyroscope
Endurance	26 minutes
Speed	34 MPH
RC Control	Skycontroller 3 (2.4-5.8 GHz)
Video Telemetry	HD 720p resolution return

Table 4. SenseFly eBeeX specifications.

Wingspan	116 cm
Weight	1.1 kg- 1.4 kg (camera dependent)
Power	Electric
Motor	Brushless DC motor
Endurance	59 min max
Max Speed	59 KTS
Payload	RGB, Thermal and Multispec still cameras
Flight control	Sensefly Autopilot via Microhard 2.4ghz modem

Table 5. Vantage Robotics Vesper specifications.

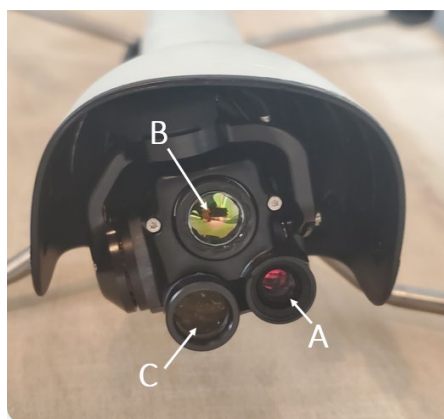
Diameter	241x315x64 mm
Airframe weight	597 g
MTOW	697 g
Power	Electric
Motors	Brushless
Flight Control	Redundant GNS, GNSS, VIO, and optical flow for position control indoors and outdoors
Endurance	50 minutes
Speed	45 MPH
RC Control	Vision GCS (2.4GHz)
Video Telemetry	1080p, h.265 encoding

This project demonstrated a number of sensors to collect data. The senseFly Duet T and MicaSense RedEdge-MX were part of the original mission kit and are not compatible with the Vesper. The Vesper drone carries RGB and Thermal sensors that are high resolution and can be used in a variety of applications.

Duet T: The senseFly Duet T is a rugged dual RGB/thermal mapping camera rig. It is used to create geo-accurate thermal maps and digital surface models quickly and easily. The Duet T thermal mapping camera includes a high-resolution thermal IR (640 x 512 px) camera. The Sensor Optimized for Drone Application (S.O.D.A.) is a high resolution (5,472 x 3,648 px) RGB camera capable of capturing 2.7 cm/px at 120m AGL.

MicaSense RedEdge-MX: The RedEdge-MX is a rugged and precise multispectral camera for advanced analysis. This camera captures both the spectral bands required for crop health indices (green, red, red edge, and near-infrared), a blue band for deeper insights into specific issues, plus composite RGB imagery.

Vesper Dual EO/thermal camera: Vesper is equipped with a 3-axis, stabilized gimbal, which hosts dual EO (Recon and navigation cameras) and a thermal camera (Figure 5). The Greenseer Recon telephoto lens has a 25mm focal length and is capable of producing orthomosaics with a ground sampling distance (GSD) of 1 cm/px at 120m AGL.



	Lens Speed	Horizontal FOV	Resolution
Navigation	f1.0	63 degrees	3840x2160
Telephoto	f2.4	17 degrees	3840x2160
Thermal	f1.0	24 degrees	320x240

Figure 5. Vesper sensors - A) Navigation lens, B) Telephoto lens, C) Thermal.

Natural Resource Demonstrations

The numerous applications of UAS to natural resource management varies among installations and we identified topics of broad interest, selecting airfield monitoring and wetland monitoring as the demonstration topics. Most MCIEAST installations are located along the coast and have large areas of saltmarsh and two of the installations (Beaufort and Cherry Point) primarily focus on aviation. In addition to saltmarsh and airfield monitoring, this project leveraged demonstrations developed for the previously funded CONFIRM project, namely fire management and coastal zone (beach) monitoring. Each MCIEAST installation hosted a demonstration and was invited to participate in all demonstrations conducted. This provided an opportunity to build collaborations and a MCIEAST drone community.

Data management and access were clarified during the initial stages of this project, and MCBCL and MCIEAST representatives and leadership (including the Regional GIS office) requested that all data collected during the project be given to them on external hard drives. This is a reasonable and secure way to share the data we collected during training and demonstrations. MCIEAST maintains their own portal systems, including GIS sharing services, that facilitates the movement of data within and among the various Marine Corps groups.

Mapping changes in wetland edges (shoreline and upland boundary) and airfield debris and condition requires precise and accurate positioning. The theoretical and practical components for data QA/QC were addressed during training (both classroom and field). We conveyed ground truth requirements by providing explicit examples for wetland monitoring, BASH, and FOD demonstrations comparing methods, driven by agency requirements (e.g., FAA FOD detection limits) when available. For example, elevations for wetlands monitoring work, gathered from structure from motion (UAS data), were assessed by comparing surface elevation models with numerous ground control points obtained using traditional ground-based surveying methods. Because end-users were on-site during demonstrations when both UAS data and ground truth data were collected, they witnessed key elements of ground-truthing that began with collection of the data and then transitioned to the results of surveys and how they compared.

Each natural resource demonstration (Objective 3) was detailed in a short white paper (Appendices C and D) that clearly communicated the scope, operational parameters, analytical approaches and relevant scientific management objectives and outcomes. These white papers will serve as useful references for installations seeking to adopt UAS into their management workflows.

Demonstration: Airfield Monitoring

Efficient and safe airfield operations require effective management on and around airfields. Hazards occurring on runways (FOD and poor runway conditions such as pavement cracks) were monitored by mapping runways using high resolution optical sensors. Bird activity contributes to FOD (e.g., shells and other debris carried and dropped on runways by birds) as well as BASH (e.g., birds directly interfering with or posing a risk to airfield operations). Because the hazards present on and around airfields are complex and overlapping, we demonstrated UAS data collection and analysis approaches that could aid in the management of the universe of airfield hazards.

Collisions between birds (and other wildlife) and aircraft are a serious economic and safety concern. Some estimates indicate that wildlife strikes cost the civil aviation industry over \$300 million dollars per year between 1990 and 1998, and that the combined costs of these interactions in both civil and military aviation likely exceed \$500 million per year (Dolbeer et al. 2000). Aviation accidents are a key factor in mortality risk for wildlife biologists (Sasse 2003). In the US alone, at least 179,000 wildlife strikes with civil aircraft occurred between 1990 and 2016, resulting in 262 fatalities (FAA Wildlife Strike Database, see https://www.faa.gov/airports/airport_safety/wildlife/). Any tool that aids in the prevention of aircraft mishaps of the magnitude of BASH should be considered.

Considering these statistics, developing a strong understanding of bird species composition, density, and behavior at airfields and the surrounding area is critically important for reducing BASH. Detailed monitoring and assessments of airfields can inform management strategies to reduce the attractiveness of the area for bird activity and provide greater situational awareness for pilots. In this context, UAS can be used to quickly record avian presence and activity across an airfield, as well as providing details on the regions and habitat types (e.g., breeding locations) that may increase the likelihood of wildlife interactions at those locations. As not all birds pose the same threat level in terms of BASH, generating details on the presence and timing of bird species occupancy at airfield locations is critical. For example, large birds like vultures and geese can present a greater BASH level, and their presence may be linked to habitat factors that are manageable at the individual airfield level (Dolbeer et al. 2000).

Demonstration: Wetland Monitoring

Fringing coastal saltmarsh provides many services to coastal military installations and communities including infrastructure protection, erosion control, water purification, fish and wildlife habitat, carbon sequestration, and tourism/recreation (de Groot et al., 2002; Barbier et al., 2011). These services scale with the width of the saltmarsh separating forested upland or development from the water (rivers, creeks, and estuaries). Although saltmarshes have some capacity to accrete vertically and keep up with sea-level rise (SLR), erosion at the saltmarsh shoreline due to anthropogenic and natural forces is reducing saltmarsh area globally. Importantly, reducing saltmarsh width decreases wave damping by grasses and the capacity of a saltmarsh to buffer a military installation from erosive wave and storm energy.

Research on saltmarsh resilience has mainly focused on platform vertical accretion and saltmarsh-edge shoreline erosion (Fagherazzi et al. 2012 and Kirwan et al. 2016). Vulnerability of saltmarsh to submergence (conversion to subtidal sandflat or mudflat) with relative SLR is commonly assessed by comparing rates of vertical saltmarsh platform accretion to rates of relative SLR (Cahoon and Turner 1989; Reed 1990; Boumans and Day 1993; Cahoon et al., 2002; Morris et al. 2002; Reed et al. 2007; Kirwan et al. 2010). Saltmarsh shoreline erosion rate is directly controlled by wave energy, with moderate frequent storms (> 4 events/year) causing the most erosion (Leonardi and Fagherazzi 2015; Eulie et al. 2016). Saltmarsh can expand in area at the upland boundary with the conversion of forest into wetland (saltmarsh transgression), but this margin is difficult to study due to lack of access. If unimpeded by development, saltmarsh transgression will offset some saltmarsh loss due to inundation and/or erosion at the estuarine shoreline. Facilitating saltmarsh transgression by modifying shoreline-development plans could offset losses of saltmarsh area from shoreline erosion along military installations.

The main objective of the saltmarsh monitoring demonstration was to examine changes in saltmarsh area from transgression (marsh expansion) and erosion at the shoreline. The saltmarsh-upland boundary is difficult to map using aerial photography collected from a fixed-wing aircraft because the upland boundary is commonly obscured or hidden by tree cover. In addition, aerial photographs are seldom available at both inter- and intra-annual time scales and at low tide, a requirement for examining storm impacts and accurately positioning both upland and shoreline boundaries. The UAS imagery will advance understanding of saltmarsh resilience and improve best-management practices by providing high-resolution metrics of spatial and biological

change. These surveys will address other broad wetland dynamics applicable across installations, including marsh die-off and recovery.

5.4 FIELD TESTING

Initial work on the first half of the project involved using both the fixed-wing and multirotor drones to collect imagery and live video feed. Thus, the original suite of demonstrations included the fixed-wing eBee and Anafi Thermal aircrafts with multiple sensors (optical RGB, multispectral, and thermal) that were utilized to achieve our various objectives (mapping, situational awareness, etc.). The final Vesper aircraft carries a multi-camera payload, equipped with high and low-resolution RGB and thermal IR. Images from mapping missions were used to create orthomosaic and digital elevation models.

For mapping missions, detailed flight planning was conducted prior to deployment using mission planning software (e.g., eMotion, QGroundControl). The aircraft followed a pre-programmed 3D flight path guided by an onboard GPS sensor, a high-resolution barometer, ground-sensing camera, and wind-speed indicators. Rotary-wing aircraft could switch between autonomous and manual control depending on the pilot's needs.

Demonstrations were designed to include a project update, execute flights for monitoring airfields or wetlands, review flight planning and data collection, and bring the MCIEAST UAS community together. In general, demonstrations occurred over one-two days throughout the project and were designed to reinforce the primary training and refine operational skills. All installations had funding to attend all demonstrations. Demonstrations also allowed for a “check-in” between the project team and the end-users.

5.5 SAMPLING PROTOCOL

Sampling protocols for Objectives 1 and 2 are executing training and providing mission kits. Training for REDDIE installations was refined from the first version developed by the CONFIRM project. Each course was also iteratively refined as each MCIEAST installation was trained over the lifetime of the project. Equipment was selected based on criteria in Section 5.3 to meet natural resource applications. Below are the sampling protocols for Objective 3 (Demonstrations), where methods and techniques were presented to apply to environmental challenges.

As part of our process for demonstrating the use of drones for these applications, we surveyed multiple locations. These sites included:

- Michael J. Smith Airport, Beaufort, NC
- Marine Corps Outlying Landing Field Atlantic, Atlantic, NC
- Rookery, MCSF Blount Island, FL
- Indian Lake, MCLB Albany, GE

- Page Field, MCRD Parris Island, SC
- Dayson dredge spoil site, MCSF Blount Island, FL
- Neuse River shoreline, MCAS Cherry Point, NC
- Oyster Creek, NC
- Long Bay, NC
- Gales Creek, NC
- Ward Creek, NC

For the purposes of this report, we use specific sites to outline the process for each of our demonstrations.

Airfield Monitoring

Multiple facets of airfield monitoring were demonstrated using a variety of data collection approaches and analyses. Surveys of the runways themselves were designed to help detect removable debris (FOD) and monitor long term damage (cracks forming in pavement). Surveys of birds and viable bird habitats were designed to formulate an understanding of the density, spatial distribution and frequency of bird occurrences on and around runways. The ability to monitor hazards on and around runways in a comprehensive and repeatable way can help facilitate more effective airfield management.

Flight breakdown

1. ***Habitat Mapping Flights*** - Collected survey data with a UAS equipped with RGB and multispectral cameras that characterized viable avian habitats with the goal of identifying high risk BASH areas and regions amenable to habitat management to reduce risk.
 - a. Specifically, we mapped the entire Michael J. Smith Airfield in Beaufort, NC, and included the forest and tidal wetland habitats that border the airfield. Our analysis involved a classification of the orthomosaic into distinct habitat types; this allowed us to assess the proximity of viable bird habitat to specific areas of the airfield.
2. ***Bird Detection Flights*** - Collected survey data with a UAS equipped with RGB and thermal cameras to assess the viability of a small quadcopter drone to detect different sized birds in the airfield region from various flight altitudes.
 - a. Specifically, we systematically captured a series of RGB and thermal still images of the same group of birds sitting in the water at low tide; the group of birds photographed contained multiple species and a variety of body sizes. Three sets of images were taken from high (~50 m), medium (~35 m) and low (~20 m) altitudes, and were then fed through a Python processing workflow that detected and visualized the warm bodies in the thermal imagery. Capturing a variety of birds at different altitudes allowed us to determine optimal flight parameters and targets for detection.
3. ***FOD and Runway Condition Flights*** - Collected data with an UAS equipped with RGB cameras on runways to assess surface condition (through photogrammetry) and locate presence of FOD hazards.

- a. Specifically, we conducted surveys of a runway area to identify presence of pavement cracks and other surface damage and demonstrate the detection and geolocation (< 5m accuracy) of several objects listed under FAA performance standards of FOD hazard detection (e.g. detecting 90% of objects placed within a 30 m x 30 m square in the study area, including but not limited to: any portion of a runway light fixture, an adjustable crescent wrench (20 cm in length), a piece of rubber from an aircraft tire, a fuel tank cap (aircraft or automotive) and a white PVC pipe 5 cm in diameter. For full details on FAA FOD performance standards, see: FAA Advisory Circular 150/5220-24 "Airport Foreign Object Debris (FOD) Detection Equipment"). We used a combination of visual analysis of elevation models in Pix4D and an automated detection tool through ArcGIS. The elevation models allowed visual detection of FOD of various sizes and colors. The automatic pavement crack detection tool in ArcGIS allowed both visual detection and quantification of cracked pavement on the airfield runways.

Wetlands Monitoring

The shoreline-erosion protection that saltmarsh provides scales with area and width, which is why the main objective of this demonstration was to examine changes in the position of the saltmarsh shoreline and upland boundary.

Data processing of collected images generated orthomosaics and 3D point clouds. Images were collected during flight with enough overlap (typically 75%) that software could be used to identify key points within each picture to tie the entire mosaic together. Then the telemetry from the aircraft and image angles were used to create three-dimensional surface models. Maps were analyzed in a Geographic Information System where the shoreline elevation contour was defined, environments were delineated as shapefiles, manually, and area change was measured.

Changes in wetland extent at sites in North Carolina close to MCAS Cherry Point and MCB Camp Lejeune (Oyster Creek, Long Bay, Gales Creek, and Ward Creek) were examined using the general approach outlined below:

Flight breakdown

1. The site was surveyed using a survey-grade RTK-GPS by collecting a transect from the shoreline to the upland boundary. We also distributed five ground control points (black and white colored targets) around the site that were surveyed using the RTK-GPS. Ground control points were mounted on 1.5 m-high rods to position them above the water's surface and marsh grass.
2. The flight mission was planned using Pix4Dcapture and uploaded to the Anafi Thermal or DJI Mavic 2 Pro drone, so that it could collect RGB images autonomously.
3. Flights were at a height of 76 m, resulted in a ground surface distance of ~2.5 cm, and flown during low tide. The drone launched and landed from the bow of a small boat.
4. UAS images were compared to images collected from a plane during high tide and during low sun angles.
5. The successful demonstration resolved high-resolution changes (both spatial and temporal) in saltmarsh shoreline and upland boundary positions and health.

5.6 SAMPLING RESULTS

Objective 1: Develop MCIEAST level protocols and pathways to remote pilot certification

This objective was met through MCIEAST-MCB CAMLEJO 3710.30B and MCICOM acceptance of courseware after review by cognizant authority appointed by the DAA.

Objective 2: Mission Kit Distribution

Sampling results for mission kit distribution are best represented as a compilation of the MCIEAST installations drone platform training and additional regional support (Table 6). Outreach efforts were a combination of in-person training and remote webinars to maintain momentum and engagement, particularly during Covid-19 periods of no travel being permitted.

Table 6. MCIEAST regional mission kit delivery and trainings, demonstrations, and additional support.

Date	Installation	Mission Kit Trainings		Demonstrations		Additional Support			
		Original # Trained 2-week BUQH	Vesper # Trained	BASH/FOD	Wetlands	Data Processing Webinar	MUG Working Group	MUG Program Managers	Final Demonstration
Sept 2020	MCLB Albany, GA	9							
Mar 2022	MCLB Albany, GA		6		X				
Dec 2020	MCRD Parris Island, SC	5							
Apr 2022	MCRD Parris Island, SC		5		X				
Apr 2021	MCSF Blount Island, FL	8							
Apr 2022	MCSF Blount Island, FL		4		X				
Dec 2020	MCAS Beaufort, SC	4							
Apr 2022	MCAS Beaufort, SC		1*	X					
July 2020	MCAS Cherry Point, NC	7							
July 2022	MCAS Cherry Point, NC		4	X	X				
Sept 2019	MCB Camp Lejeune, NC	9**							
July 2022	MCB Camp Lejeune, NC		3		X***				
Dec2020	Virtual						X		
June 2021	Virtual						X		
Dec 2021	Virtual						X		
Apr 2022	Virtual						X		
Apr 2021	Virtual					X			
Oct 2021	Virtual					X			
Feb 2021	Virtual							X	
Mar 2021	Virtual							X	
May 2021	Virtual							X	
July 2022	Hosted by MCRD Parris Island****								X
Sept 2022	Planned final MUG						X		
*installation leadership declined to continue									
**part of RC18-5187; CONFIRM Project									
***forestry/fire review									
****all MCIEAST installations represented									

Objective 3: Demonstrations

Airfield Monitoring

Airfield monitoring includes a variety of pieces of information that can be gleaned from imagery collected around airfields: habitat mapping, bird detection (BASH), and FOD/runway conditions.

Habitat Mapping

Imagery from the mapping missions successfully created orthomosaics and reflectance maps of our demonstration airfields (Figures 6 and 7). Airfield personnel were also able to provide on-the-ground observations of airfield bird activity where they drop shells for feeding, allowing us to reference this on our maps (Figure 6 left panel). Post-processing workflows in ArcGIS allowed us to conduct habitat classification for the environment around the airfield (Figure 6 right panel). Multispectral imagery (Figure 7) provided additional bands (NIR and Red Edge) to help better classify different habitats, like vegetation, water, and human-made structures.

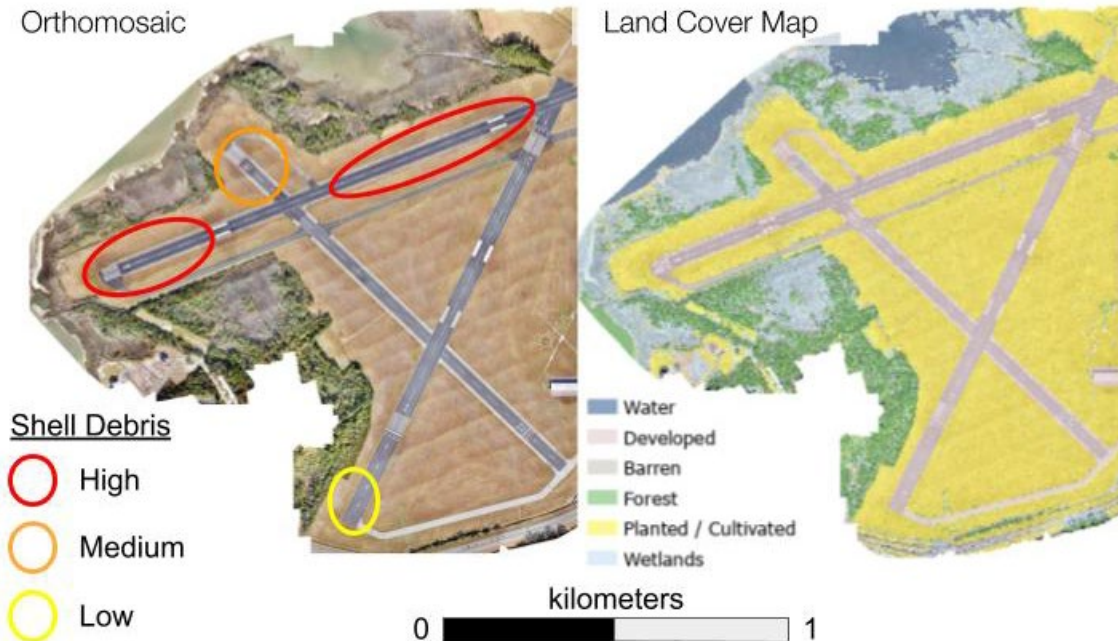


Figure 6. Habitat Mapping and FOD Detection with Classified RGB Imagery. A mapping mission was flown over the Michael J. Smith Beaufort Airport (North Carolina) and surrounding environment to assess bird activity and shell-debris runway hazards (left image). Using image classification tools in ArcGIS, a high-fidelity land cover map of the airport was generated (right image).

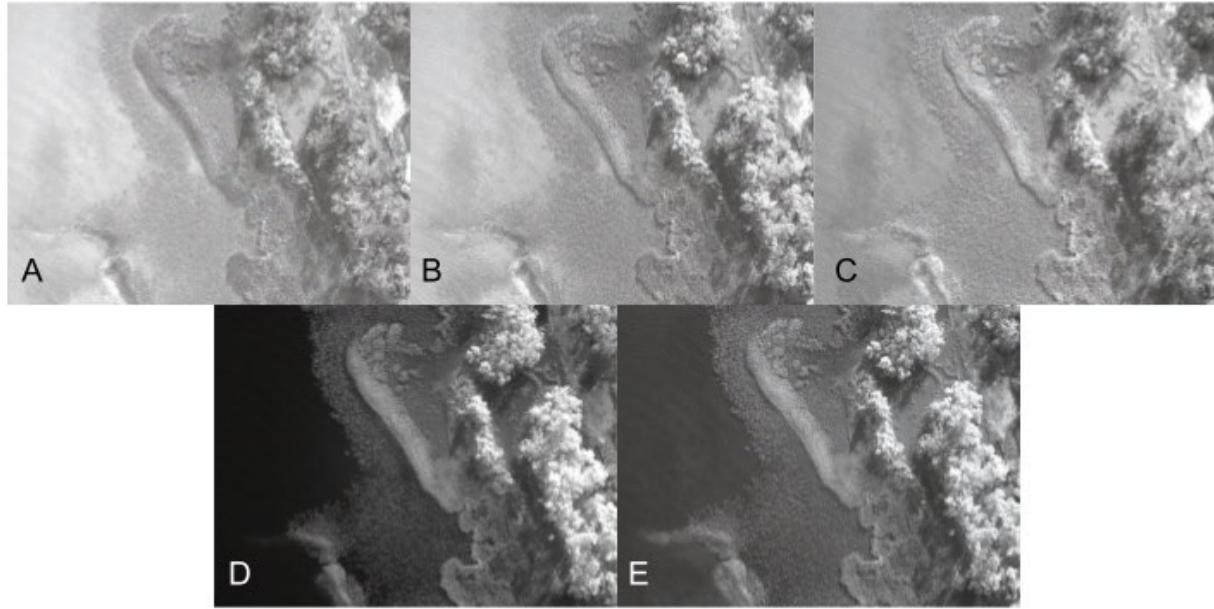


Figure 7. Habitat Mapping with Multispectral Imagery. Higher reflectance appears as whiter areas of the images. Panels are from the following individual bands: (A) Blue, (B) Green, (C) Red, (D) Near Infrared, (E) Red Edge.

Bird Detection

The utility of UAS in detecting BASH was demonstrated using the small multirotor aircraft with colocated thermal and RGB cameras. Using a combination of RGB and thermal imagery from the aircraft (Figure 8) provided the opportunity to assess the strengths and caveats associated with this method. Birds can be visualized using the Hybrid RGB/thermal live feed imagery (E) and can be further isolated through processing workflows (B and D). Bird size was the largest contributor to visibility. The panels above show small birds in both RGB (A) and thermal (B) views are barely visible, while large birds are more easily detected in both RGB (C) and thermal (D) views.

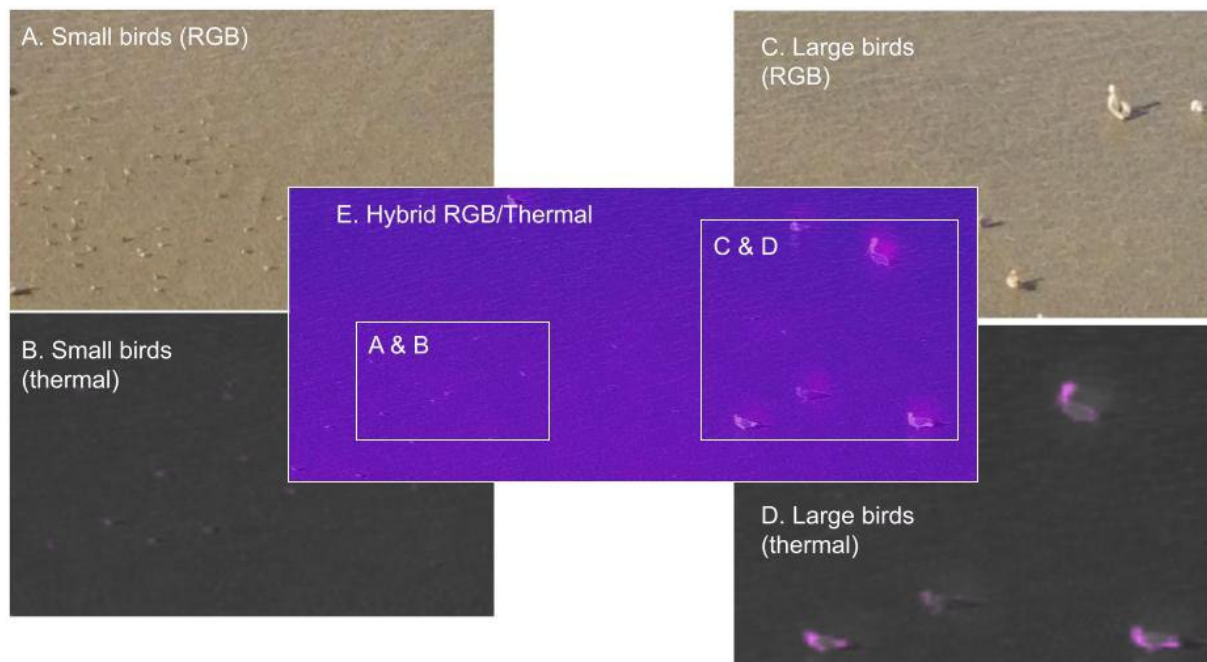


Figure 8. Bird Detection with RGB and Thermal Sensors. The ability to detect birds in drone imagery depends on the size of the birds, the surface they are sitting on and the flight altitude from which images are captured. The above figure shows views from the Parrot Anafi Thermal data collection and processing workflow. Small birds viewed in raw RGB imagery (A), hybrid RGB/thermal live feed imagery (E), and processed thermal imagery (B) are more difficult to detect and count, especially from far away. Larger birds can be more easily detected in raw RGB imagery (C), hybrid RGB/thermal live feed imagery (E), and processed thermal imagery (D) and are easier to detect from farther distances.

FOD and Runway Condition

In the same missions capturing the airfield and surrounding environment, the resolution of the resulting orthomosaics was high enough to successfully use an automated road crack detection tool available through ArcGIS (ESRI). The tool processed segments of the roadway and created georeferenced polyline features of the cracks (Figure 9).

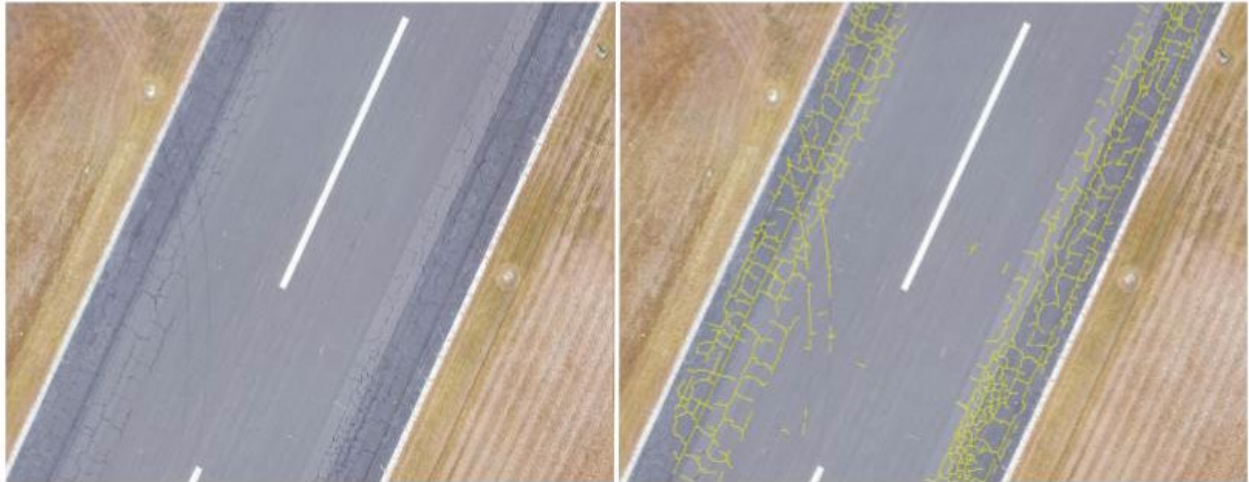


Figure 9. Runway Condition Assessment with ArcGIS Tools.

Wetland Monitoring

Changes in the position of the upland boundary, the position of the shoreline, and marsh-grass cover were all captured across a one-year timestep at Oyster Creek, NC using orthomosaics generated from quadcopter imagery (Figure 10). Using the two images of Oyster Creek, visible changes occurred in the presence and absence of wrack in the subsequent survey (Figure 11).

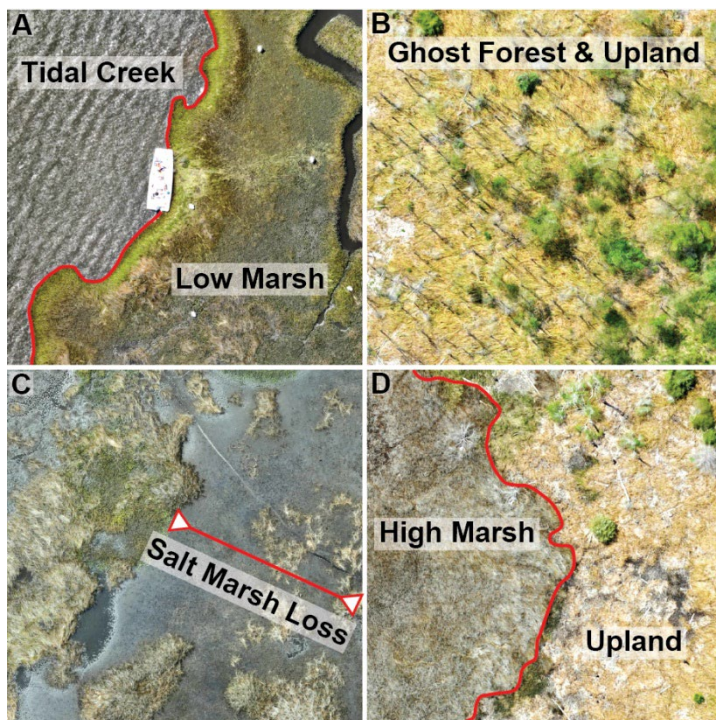


Figure 10. Unoccupied Aircraft Systems (UAS) provide superior data for mapping the salt marsh shoreline (A), health indicators such as ghost forest (B), marsh die off (C), and upland boundary (D).

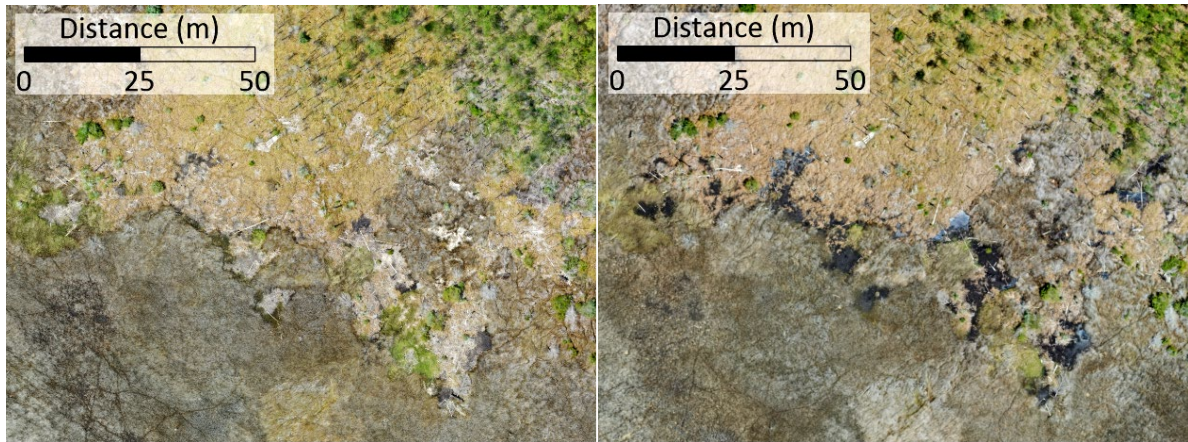


Figure 11. Orthomosaic of Oyster Creek, NC salt marsh in 2021 (left) and 2022 (right).

The shoreline mapping mission over Gales Creek, NC was flown in 2021 also using a quadcopter to examine changes in shoreline position (Figure 12). The 2012 shoreline (white line on Figure 12) was positioned in the estuary, and the average retreat rate measured from 2012-2021 was 0.33 m/yr. The saltmarsh shoreline at Long Bay, NC was mapped by the state in 2012 at low tide and again in 2021 at high tide (Figure 12) using a plane. These examples demonstrate the benefit of being able to collect imagery on demand using a drone to address a particular management issue, such as movement of an intertidal shoreline.



Figure 12. Orthomosaic of Gales Creek from drone data (left) in 2021 and imagery of Long Bay (right) obtained by the State of NC using a plane in 2012 (image) and 2021 (white line depicting the shoreline position).

6.0 PERFORMANCE ASSESSMENT

This project demonstrated the integration of UAS technology into MCIEAST natural resource management and met three technical performance objectives:

1. Develop regional, MCIEAST level, UAS protocols and pathways to remote pilot certification.
2. Creation and dissemination of standardized UAS mission kits and training materials, established on objective-based requirements.
3. Integrate UAS technology through broad demonstrations that represent a range of UAS applications for DoD natural resource management that exist across installations.

6.1 OBJECTIVE 1

The project met Objective 1 in several ways. The creation of an actionable MCIEAST Order (MCIEAST-MCB CAMLEJO 3710.30B) was the result of this program presenting the leadership at MCIEAST both a viable pathway for safe drone flights on installations, and demonstrating the clear utility of drones. The order represents codified protocols for execution of installation level UAS programs managed by civilian federal employees. This is the first regional UAS program to be led by federal civilians across DoD.

The leadership acceptance of pilot training certificates resulting from the project BUQ II training is a critical step in the Order protocols. All pilots that took the initial two-week training were successful and had the credentials to be a part of the drone program at their respective installations. The subset of those pilots that took the Vesper training also passed that effort. Each installation has trained pilots that meet the Order training requirement and have the skills to collect a variety of data types. Recently MCAS Cherry Point exercised the training and protocols developed to fly a new living shoreline project to monitor erosion. MCB Camp Lejeune used drone flights to document an herbicide application. These uses begin to integrate drones into natural resource workflows.

6.2 OBJECTIVE 2

Objective 2 was met as mission kits were successfully created and delivered to the installations. Reliability and appropriateness for natural resource applications drove equipment selection. Connected to this objective is the training of pilots to use the mission kits and apply the training to various use cases (executed through both the two-week training and the demonstrations in Objective 3). Once the initial mission kit was no longer usable because of the 2020 NDAA, new drone platforms were purchased and pilots retrained. Included in mission kits was ancillary equipment designed to create the safest and most efficient working platforms and the equipment included a data-processing laptop, radios for field communication, and external hard-drives for longer-term data storage. No detail was overlooked and kits also included items like SD card converters, field tables, and sun shades to aid in glare reduction. Installations were also provided with analysis software to be continued for one year after project end.

The UAS programs on each installation are non-POR (Programs of Record) and thus have no built-in funding. By providing all the essentials to collect quality data and transform it into usable information, each program has time to establish themselves and further demonstrate the utility of drones on the installation to safely and efficiently collect high quality data. Training also emphasized documenting cost savings when drones are able to replace conventional methods of data collection.

6.3 OBJECTIVE 3

Objective 3.1: Airfield Monitoring

Habitat Mapping

The land cover map combined with on-the-ground observations, allows airfield managers to assess BASH risk based on surrounding habitat types. The spatial distribution of shell debris (Figure 6) showed that bird activity was greatest on runway areas in close proximity to wetlands and water, where birds forage for shellfish. This type of habitat mapping could help airfield managers to more accurately assess risk areas as these habitats shift through time, and especially with increasing sea level.

Bird Detection

The advantage of using UAS to detect bird activity on and around airfields is that UAS imagery provides perspective on areas that are not easily accessible by foot. However, while lower altitude RGB flights (using rotary-wing aircraft with live visual feed) can be used to identify the presence of birds, operating a drone too close to birds often results in birds flushing before identification or detection is possible. The ability of a thermal sensor to successfully detect birds depends on the temperature of the environment and size of the birds. Flying in the early morning created a higher temperature contrast between birds and background, and birds on water were more visible in the thermal imagery than birds on land (Figure 8).

FOD and Runway Condition

The resolution and products provided by drone surveys and image processing allows airfield managers to assess runway condition on multiple levels. The extent of deterioration can be quantified by showing the amount and severity of cracks in the runway that form through time. This is further aided by tools provided in ArcGIS like the deep learning tool for pavement crack detections (Figure 9). This enables detection of runway damage in imagery and provides the means to quantify and monitor cumulative runway damage over time. The 3D surface can also be constructed from Structure from Motion photogrammetry software (like Pix4D or Drone2Map). This can show how the runway surface is changing through time, where areas may need to be resurfaced, and how much volume of material will be needed for repairs.

Objective 3.2: Wetland Monitoring

Results from the Oyster Creek flights were informative, showing changes in vegetation cover, shoreline erosion, and upland boundary migration (Figure 10). None of these changes could have been as easily recognized from on-the-ground field work or infrequent flights using planes.

Even over the 1-yr timescale, we were able to detect effects from marsh debris (dead grass, wood, and trash) that had been transported landward during storm surge and accumulated on top of high-marsh vegetation (Figure 11, left image). This debris is called wrack, can be 1.0 m thick, and smothers the underlying vegetation. As the wrack decomposes and/or is transported away during a subsequent storm, it leaves behind a depression that forms a pond (Figure 11, right image), which may persist, or become recolonized with salt marsh over time. Ponds tend to increase in size during wind events that produce erosive currents, reducing marsh area.

Drones have the advantage over piloted aircraft in this application because images need to be collected during low tide. Salt marsh is intertidal and the shoreline edge is submerged at high tide. The 2021 shoreline (white line, Figure 12) is seaward of the 2012 shoreline, which was obtained during high tide from an occupied aircraft. This could incorrectly indicate salt marsh expansion, underscoring the importance of data collection at low tide.

In some areas, the upland edge is marked by a rock wall or bulkhead aimed at protecting infrastructure from storm surge or sunny-day flooding. The upland edge of natural areas is difficult to access and map on the ground due to dense vegetation, muddy substrate, and hazards such as abundant poison ivy and cottonmouth snakes. A drone is a very useful tool for mapping this setting.

The upland edge is commonly hidden in the shadows cast from the forest canopy. This is reduced if flight times are planned during high sun angles. Including digital terrain models based on structure from motion in the data set will ensure that the forest-salt marsh boundary is clearly delineated. Salinization of upland soil from sea-level rise and storms promotes salt marsh landward expansion. This is evident over short time scales and illustrated by tree loss in Oyster Creek, NC (Figure 10).

6.4 COMPUTING PERFORMANCE ASSESSMENT

To take full advantage of drone imagery for landscape assessment, it is necessary to use software packages that stitch images together and generate 2D and 3D products. These come in the form of the aforementioned Structure from Motion (SfM) software like Pix4D or the Pix4D-based ESRI (ArcGIS) companion package Drone2Map. These software require windows machines and can run on most central processing units (CPUs), although Pix4D recommends at least Intel i5/i7/Xeon processors. A graphics processing unit (GPU) that is compatible with OpenGL 3.2 is also required, but the quality of the GPU is less important than the CPU. At least 8 GB of RAM along with ample hard drive space are recommended but Pix4D indicates that this scales with the size of the image set being processed:

- Small projects (under 100 images at 14 MP): 4 GB RAM, 10 GB HDD Free Space.
- Medium projects (between 100 and 500 images at 14 MP): 8 GB RAM, 20 GB HDD Free Space.
- Large projects (between 500 and 1000 images at 14 MP): 16 GB RAM, 40 GB HDD Free Space.
- Very Large projects (1000 -2000 images at 14 MP): 32 GB RAM, 80 GB HDD Free Space.

Pix4D has provided documentation as to how hardware specifications impact processing performance. These can be accessed through their [Hardware and Pix4D](#) web documentation, which includes access to their system requirements, processing speed, and hardware case study documentation. As Drone2Map is Pix4D based, this documentation also applies to its performance.

As an example, the following are the processing details from some of our sites we monitored for this project. The Michael J. Smith Airfield is a 180 ha airfield, where we collected 1,193 images (24 MP), which would fall into the Very Large Projects designation above. The image set was processed on a machine with an Intel Core i7 CPU @ 3.3 GHz, 64 GB RAM, and an NVIDIA GeForce GTX 980 and took approximately 9.5 hours to fully generate 2D and 3D products. In comparison, the image set collected at Atlantic Airfield covered 227 ha, included 1,882 images and took only 5.5 hours to fully process when using a machine with the AMD Ryzen Threadripper 1950X 16-Core CPU, 64GB RAM, and an NVIDIA GeForce GTX 1080 Ti.

The upgraded CPU and RAM capacity drastically changed the speed at which the image sets could be processed. However, the automation of these SfM software packages means that users could easily set their image datasets to process and then continue working on other tasks. With the multicore processors like the Ryzen one just mentioned, we are able to dictate which cores can be dedicated to the processing software, which helps maintain the ability to multitask while processing (a CPU-intensive activity) occurs.

7.0 COST ASSESSMENT

7.1 COST MODELS

The following tables pertain to the four core cost categories relevant to this project: aircraft and sensors; flight control software; image processing software; and BUQ training. Cost elements that are not applicable have been removed from the tables.

Table 7. Cost model for Aircraft and Sensors.

Cost Element	Data Tracked During Demonstration	Estimated Costs
Procurement	Component costs for demonstration	eBee X: \$13,500 Real time kinematic/post-processing kinematic activation: \$5,500 Duet T: \$10,000 MicaSense RedEdge MX: \$6,300 Vesper: \$7,700 Ancillary Equipment*: \$2,400
Operation costs	Individual's full-time salary plus benefits scaled with each hour of flight time including two-hours of preparation/data management Cost per flight hour = (total operating and support cost)/(total flying hours)	Remote Pilot in Control (RPIC): \$115/flight hour Visual Observer (VO): \$90/flight hour
Maintenance	Frequency of required maintenance developed over course of project Labor and material as required	Firmware updates: 3 hrs/yr Hardware maintenance: 10 hrs/yr
Lifetime	Develop life expectancy and technological obsolescence. Estimate is two years based on new model release study conducted on COTS aircraft**	2-3 years. Also dependent on regulatory items from cyber perspective
Benchmark	Cost of mission kit compared to other NDAA compliant aircraft	Skydio X2D Start Kit 1.8 GHz: \$23,543 Wingtra Drone (no camera): \$18,852 eBee Tac (no camera): \$24,500

*Ancillary equipment includes equipment necessary to supplement the aircraft and sensor kit (e.g., spare parts, walkie-talkies).

**In real world applications, the replacement of individual parts may significantly extend this timeline. We have found that we can use drone and sensor technology upwards of 5 years.

The aircraft and sensors form the foundation of project equipment. In an effort to cover as many mission sets as possible, the project team originally selected both fixed-wing and rotary-wing aircraft to allow launch/land from most environments. After the 2020 NDAA was released, we chose the Vantage Robotics Vesper due to its sensor specifications and extended flight time for a quadcopter. This drone best filled the gap of losing the fixed-wing mapping aircraft. Blue UAS drones are being sold through GSA Advantage and to ensure compliance, that is the path we chose for procurement. Figures supplied in the table above are from GSA Advantage in August, 2022.

Table 8. Cost model for Software (Flight Control).

Cost Element	Data Tracked During Demonstration	Estimated Costs
Procurement	Estimates made based on component costs for demonstration.	Included with aircraft cost
Operation costs	No additional costs after initial purchase.	
Maintenance	Complete updates with latest firmware. No additional costs expected for updates.	
Lifetime	Indefinite assuming patches downloaded with latest version and firmware corresponding to aircraft and software.	
Benchmark	Cost of mission kit software compared to data acquisition and processing software.	

Vantage Robotics Vesper is designed around the free, open-source software QGroundControl (QGC). This software supports free flying and pre-planned mapping missions.

Table 9. Cost model for Software (Image Processing).

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Procurement	Estimates made based on component costs for demonstration and recurring annual license.	Pix4D purchase options: - Perpetual one-time license: \$4,990/yr -\$291/month (yearly billing) -\$350/month (monthly billing)
Operation costs	Image processing software is based upon a yearly subscription. Will have to be re-purchased annually.	\$600/yr
Maintenance	Complete updates with latest version.	No additional costs expected for updates outside of annual fee.
Lifetime	Indefinite assuming patches downloaded with latest version and firmware corresponding to aircraft and software.	N/A
Benchmark		ESRI Drone2Map: \$3500

Scientific data collection is reliant upon transitioning hundreds of individual photos into orthomosaics and/or DSMs. Pix4DMapper is the industry standard for photogrammetry applications of UAS and was therefore used for cost analysis. ESRI's Drone2Map is a comparable software and was used for comparison.

Table 10. Cost model for BUQ Training.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Procurement	Cost estimates are based on two trainers to provide two-weeks of BUQ training.	Course length: 9 days Lead Instructor: \$115/hr Instructor: \$100/hr Total: \$15,480
Operation costs	The cost to the installation, participant salary time.	Participant's lost time for attending course (two-week salary).
Benchmark	BUQ certification requires training	Currently, no other known contractor outside of the DoD conducting BUQ training, so no relevant benchmark comparison

This cost element pertains to the cost of one two-week BUQ training at one installation. Training materials are provided and can be reviewed by participants indefinitely. Currency is dictated by the MCIEAST Order (MCIEAST-MCB CAMLEJO 3710.30B).

7.2 COST DRIVERS

Costs for an active drone program are constrained by key elements: drones and associated sensors, analysis and processing components, and continued training for program sustainment.

Many factors influence the choice of drones for environmental management. The choice will be driven by fundamental factors of cyber security status (waiverable or blue), the ability of the drone and associated sensors to meet the goals of the natural resource managers, and available funding. Additionally, drone-based data collection may not be optimal for single instance data collection exercises. Rather, the cost model for drone-based applications is better suited to programs requiring repeated data collection, and especially so in unpredictable systems. Current limitations on which UAS are able to fly on DoD property means selecting from a small pool of equipment like those provided in the BlueUAS program or ones that are eligible for cybersecurity waivers. Blue drones are generally much more expensive than their unapproved Commercial Off-the-shelf (COTS) counterparts, like the Anafi government BlueUAS version (\$14,000) compared to the standard Anafi (\$2,000). However, as these systems become more prominent in the UAS market, their pricing should decrease and the availability of NDAA compliant drones will increase.

It should be noted that costs for implementing a drone-based data collection program will be higher at the start, as users learn to use the equipment and make mistakes. These costs should subside as proficiency increases. Drones are also able to collect a great range of data in comparison to boots-on-the-ground methods like GPS surveys.

The costs of analysis and software are a requirement for mapping and monitoring. Under current IT rules, it is far easier for the drone programs to operate on a stand-alone computing system that is not on the USMC network. A laptop with adequate computing power was included in the mission kits and should be considered a long-term, periodic cost. Software is both a one-time cost and annual maintenance cost that can operate as a stand-alone endeavor or be included in the extensive GIS department of MCIEAST. The initial investment can be high, but yearly costs are minimal. Without these resources, end-products would be limited to videos and images.

Training costs are a cost of continuing the programs long-term as new employees join the effort and need training. This funding may be problematic until the drone programs become POR and have line-item funding. Demonstrating cost savings by incorporating drones into workflows should incentivize this portion of installation drone programs.

7.3 COST ANALYSIS AND COMPARISON

There are instances where drones can replace the conventional methods of research, monitoring, and management in installations while other times it is complementary to existing techniques. Any natural resource application that requires aerial perspectives and images over an appropriate scale (up to about 500 hectares, although more can be flown) where crewed aircraft can be replaced represents a cost savings.

The coastal setting of the MCIEAST installations has become the focus of funding for marsh resilience projects from many organizations. The use of drones to monitor marsh shorelines and the trajectory of coastal habitats over time are new applications well-suited to drones because of the scale of the projects and required resolution. The drones provide on-demand images to track changing conditions that challenge the military mission in coastal settings, whether post-extreme events assessments or shoreline erosion impacting infrastructure.

There are benefits of using drones that are difficult to monetize. Drones can help mitigate risks to environmental managers by reducing their time in occupied aircraft, which has been a major cause of wildlife biologist mortality (Sasse 2003). UAS methods also reduce the disturbance and potential damage to ecosystems caused by on-the-ground methods, like marsh monitoring that can cause persistent changes to the system by removing vegetation and compacting sediment (see Ridge and Johnston 2020). UAS also have a much lower carbon footprint compared to the emissions from occupied aircraft.

8.0 IMPLEMENTATION ISSUES

The REDDIE project in collaboration with MCIEAST installations, stood up a regional drone program to be led by installation natural resource managers and address a broad set of environmental challenges. This program is the first of its kind in DoD, and while there are individual installations across the services using drones, and pathways exist in all services, this regional approach codifies protocols that eliminate one-off approvals and facilitates drone use in everyday workflows and on-demand. The MCIEAST Order, which was a direct result of this project, brought drones to the forefront for federal civilians and enabled users and leadership to socialize drones into the workforce. It provides safe guidelines that are accepted on the regional level and allows for customizing the program to satisfy each installation's particular settings and mission. There were however important implementation issues with lessons for the future.

Delays in execution were the biggest challenge and translated into loss of momentum in a number of meaningful ways over the lifetime of the project. REDDIE began in earnest Fall 2019 after approval of the demonstration plan. It was approximately 6 months later that Covid-19 restrictions were in place. The trainings scheduled in early 2020 were canceled and remote connections were established through group MUG meetings and webinars. Training was delayed but was ultimately implemented with strict Covid protocols. The delays pushed back the demonstrations and the majority of activities were shifted to the second half of the project timeline. Demonstrations were initially planned to be executed across the entire third year and create multiple opportunities to bring pilots together on a timed schedule to reinforce skills and program progress, as well as transition the program management from the project team to the installations. The schedule ended up being compressed and changed frequently in response to Covid outbreaks at installations. While demonstrations were successful, valuable follow-up and reinforcement time was sacrificed, and program transfer has suffered. Gaps were filled by webinars, but boots-on-the-ground flying is the only way to really socialize these programs. However, Covid-19 was not the most significant driving delay.

The enforcement of the 2020 NDAA prompted a shift in the mission kit. This shift in available equipment continues to impact the project today. The original mission kits constructed for the program were designed to meet multiple environmental needs, provide multiple aircraft, be reasonable in price, and transition the installations until they secured funding to carry replacements. The drone commercial market is constantly evolving due to complex issues like cybersecurity concerns, international relations, and trade wars. The shift by all of DoD to Blue UAS in early 2021 created an additional layer of complication and procurement challenges resulting from high demand and extremely high costs. This cost shift may prove to be too much for early, unfunded programs to sustain. As new Blue UAS are added to the approved list and more manufacturers become a part of the process, this landscape will change once again. Additionally, a growing market of NDAA compliant, but not blue drones, may offer an affordable, high-quality alternative for use on DoD lands. While the enforcement of the NDAA and the shift to a new model choice created a pause, the biggest impact here was due to cost and the loss of multiple platforms and sensors capable of a huge variety of tasks.

The most significant delay to the success of the program was created by the inability of the selected blue drone vendor to deliver drones as promised, and unknown at the time, the lack of

performance by the drone. It took a year to deliver the drones (approximately one drone every two months) and the early delivered platforms were constantly suffering from software and hardware failures requiring us to return delivered drones. Blue drones and the companies are supposed to represent capable, secure drone options to meet DoD needs (<https://www.diu.mil/blue-uas>) but this was not the case. The delay created by the blue drone vendor essentially brought the installations' program progress to a halt, requiring the scheduling of new trainings and further impacting the demonstration schedule. As mentioned previously, the delays meant the final planned year of demonstrations and transition was compressed. The delay most significantly meant that the last year could not be spent with each installation having drones. The three month no-cost extension allowed the project to complete all demonstrations and drone delivery.

Finally, related to the delays and loss of momentum were changes in MCIEAST and installation level leadership as they rotated out of positions that supported REDDIE. As with implementing any new technology into a large organization, it is critical for leadership to be supportive of and empower the users to integrate UAS in their regular environmental management activities. A shift often meant re-briefing and educating new leadership on the program as Commanding Officers ultimately approve programs on the installation level. Had there been no delay from Covid-19, mission kits would have been delivered sooner and installations would have been flying under early project leadership - a loss of socializing the workflows with managers of training areas and air space. The project team, with installation counterparts, successfully carried the project across changes in Command, but the time allocation meant less time on program transition and meeting the various requirements embedded in the MCIEAST order (e.g., leadership acceptance of SOPs and medical waivers for pilots).

The culture on military installations with new technology and environmental programs, where the link between the environment and mission readiness is neither understood nor acknowledged broadly by military leadership, is always a challenge. The project team had vast experience working with DoD prior to this project, and were prepared with strategies to succeed (e.g., briefing the right people early and often, a comprehensive understanding of the MCIEAST military mission and the environmental challenges on installations, understanding the range and air space systems on installations). Thus, despite the unexpected cumulative impact of the challenges described above, the project moved forward and successfully demonstrated the value and effectiveness of deploying drone programs on regional levels with the flexibility to meet installation needs and missions. The partner installations are prepared to use drones within their environmental departments and are working within their organizations to implement the programs. The use of drones by other groups on the installation is an outgrowth of this project and installations are already looking to train additional pilots.

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APPENDIX A. Points of Contact

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APPENDIX B. Remote Sensing Field Guide

APPENDIX C. Using Drones to Monitor Airfield Hazards and Conditions

APPENDIX D. Using Drones to Monitor Salt Marsh



REMOTE SENSING FIELD GUIDE

Regional Drone Demonstration for Installations and Environment
August 1, 2022

This project was executed in partnership with the University of North Carolina Institute for the Environment and Institute of Marine Sciences, Attollo LLC, and Duke University Marine Lab with funding from the Environmental Security and Technology Certification Program.

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1. Flight Brief Guide

The flight briefing guide encompasses planning requirements from FAA Part 107, Part 61, and DoD CJCSI. Retrieving the information below and conducting a formal briefing with the flight crew will ensure you have conducted a thorough analysis of the mission.

FLIGHT BRIEF			
Roll Call		Environmentals	
		Time:	Forecast:
Mission Overview		Winds:	Aloft:
Mission Objectives:		Visibility:	
Training Objectives:		Ceilings:	
Risk Assessment Worksheet		Temp/Humidity:	
Equipment Line Up		Solar/Lunar Data:	GPS Quality:
Aircraft/ Payload Configuration		NOTAMS:	
Ground Support Equipment			
Comms Gear & Frequencies			
Ground Ops (Roles Responsibilities)			
Aircraft Preflight (Primary/ Backup):		Mission Procedures	
Firmware /Sensor Checks / SD Cards		Heading / Climbout / Hover Checks:	
Ground Support Equipment Preflight		Route Brief / Checkpoints:	
GCS Preflight / Batteries Charged		Area Mechanics / Scan Profiles:	
Timeline		Go/ No-Go	
Takeoff:	Off Station:	Weather:	Drop Dead Time:
Transit:	Transit:	RTB%	Payload & System Checks:
On station:	Recovery:	Rec%	Emergencies
Fuel Requirements:		Aviate, Navigate, Communicate	
Operating Area- Orientation		Land ASAP vs. Practicable	
Airspace / Maps		Lost Link (Return Home Plan)	
Aerial Imagery		Knock It Off	
LRE Sites / MSA		KIO: Safety of Flight	
Working Areas / MSA		Questions Back Brief	
Contingency Areas			
Hazards			
Restrictions / Waiver Criteria			

The Risk Assessment Worksheet (RAW) is designed to promote safety and assess the hazards and risks of an operation. The Remote Pilot in Command (RPIC) should fill out the RAW before every flight as it also serves as proof of preflight planning.

RPIC Signature: _____

3. Site Survey

Site Survey Checklist

Prior to beginning flight operations at a location that has not been previously operated out of, a survey shall be conducted to determine both safety considerations and the ability to support planned operations. A site survey shall also be completed for any location that has not be operated out of for longer than one year.

STEP	NAME	DATE
1. Determine flight locations		
2. Determine airspace and spectrum requirements		
2. Determine launch and recovery sites		
3. Conduct weather study		
4. Determine COC requirements / location		
5. Determine site requirements		
6. Determine personnel requirements		
7. Determine mission kit requirements		
8. Determine special coordination instructions		
9. Collect points of contact		

4. Best Techniques & Practices

Coastal/Wetland Environments

- Tide: beach mapping is best conducted at low tide to ensure the maximum amount of land is viewed. Mapping during similar tides is crucial for gathering accurate measurements.
- Postflight: landing on sand can cause problems for UAS. It is imperative that all equipment be cleaned, and sand is cleared out of servos, motors, cameras, etc. This is best done utilizing brushes or canned air.
 - Note: many aircraft checklists cover cleaning and smooth servo operation during preflight inspection.

Upland/Fire

- Updrafts: be cautious when flying near fire as updrafts can cause instability and turbulence. In extreme instances, flying directly above a fire could cause the aircraft to lose control and crash. It is best to offset to the side of the plume, which will also assist with visibility of the drone as required by the FAA and MCIEAST order.
- Remote Pilot in Command Position: placing the RPIC with the burn boss is the best way to increase overall situational awareness for the leadership. Utilizing the repeater screen allows the burn boss to have the camera feed without interfering with the RPIC's ability to fly the aircraft.

Deconfliction

Range control or Base Operations can alert and assist, but it is ultimately the RPIC's responsibility to maintain separation and safety. Crews must have a 3-dimensional mindset when thinking of airspace. There are three ways to achieve aircraft deconfliction and separation:

1. Vertical: stagger altitude and ensure the buffer is sufficient.
2. Lateral: scheduling a training area is the most common approach.
3. Time: scheduling away from busy airspace timeframes can greatly assist overall mission safety.

5. Vesper Drone

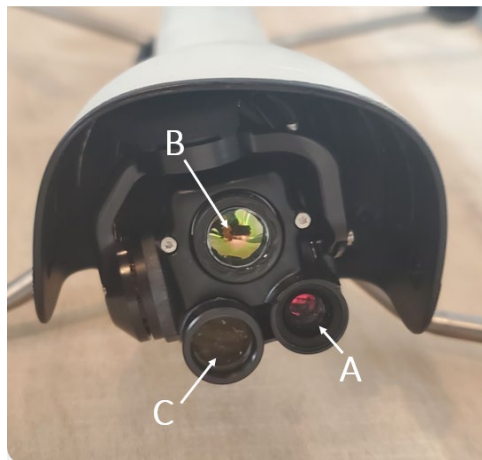
Flight Control

The Vantage Robotics Vesper is flown with the Vision Ground Control System (GCS) and uses QGroundControl, which is an open-source flight control software.

Default Vision GCS Password: Vantage1



- A) Navigation lens: 6mm f/1.0
- B) Telephoto lens: 25mm f/2.4
- C) Thermal: 320 x 240p

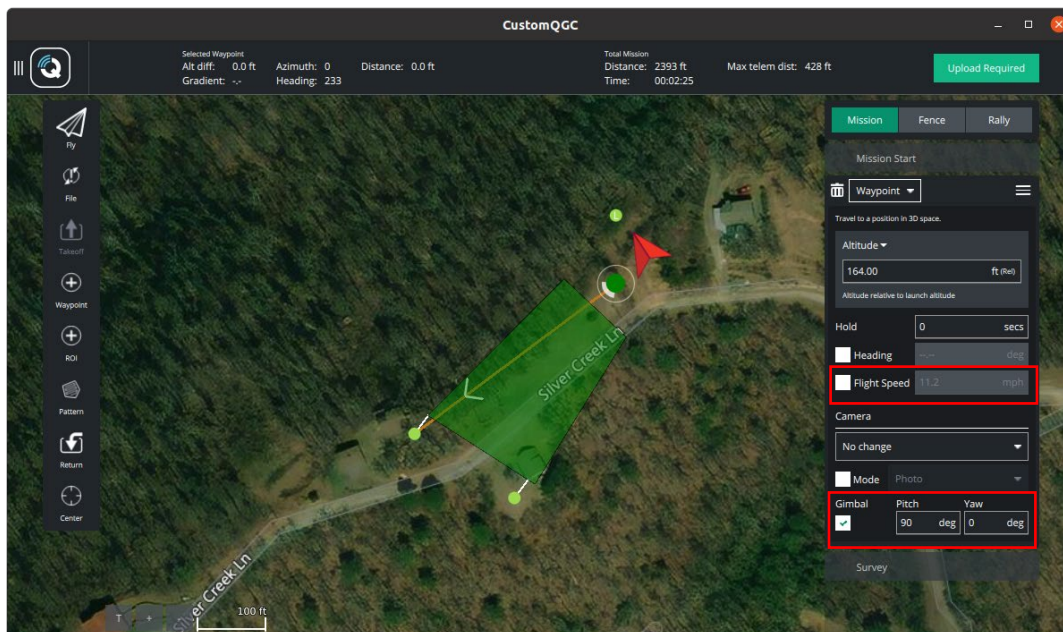


LED lights in the tail indicate flight readiness status starting with cyan/aqua. The boot process takes about 50 seconds and GPS lock speed depends on conditions. Users should understand the meaning of the following light sequence:

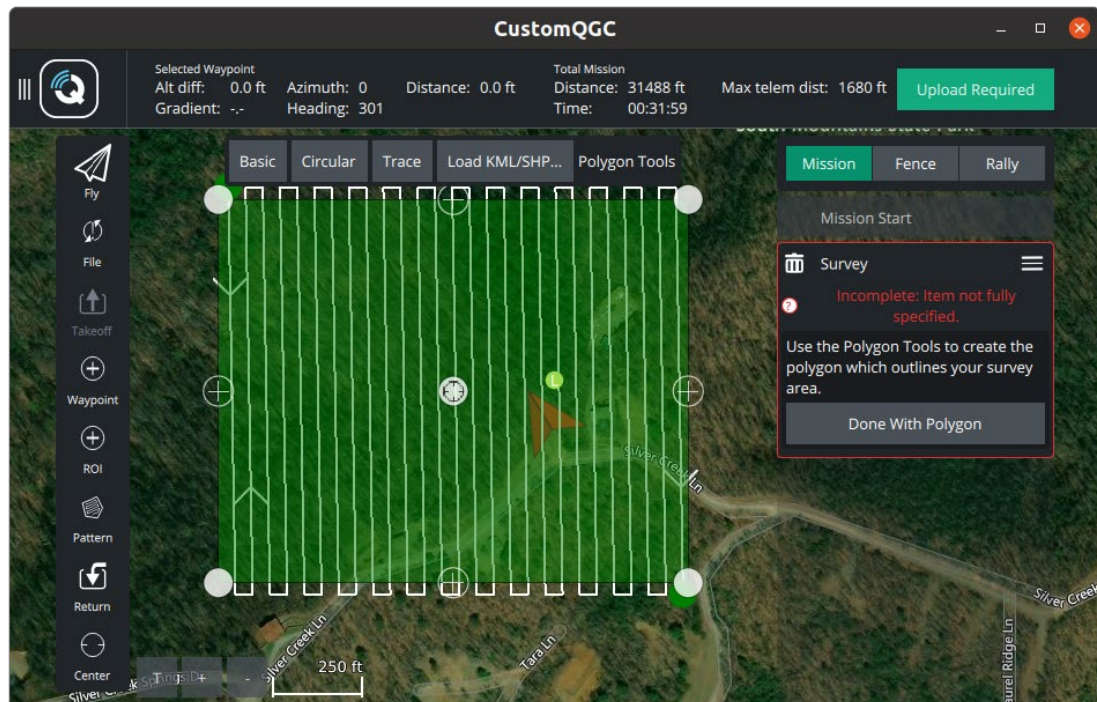
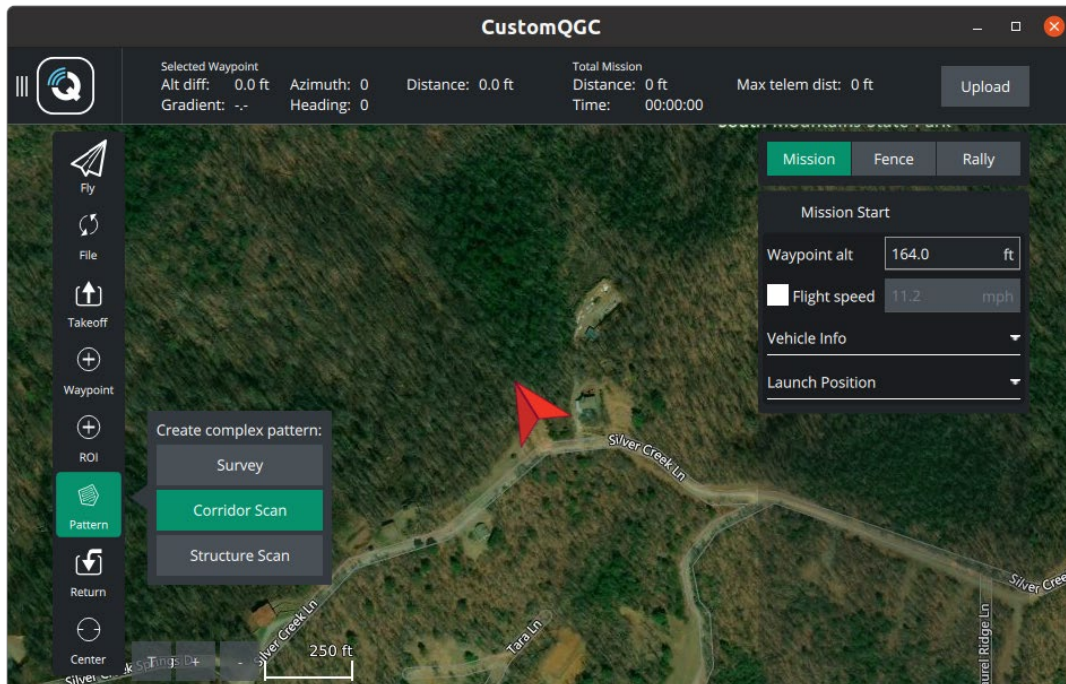
Color Pulse Pattern	Cyan	Cobalt Blue	Green
Blinking/ Breathing	Booting...	No GPS fix, unarmed	GPS lock OK, unarmed
Solid	Booting...	No GPS fix, armed for takeoff	GPS lock OK, armed for takeoff

Mapping Missions

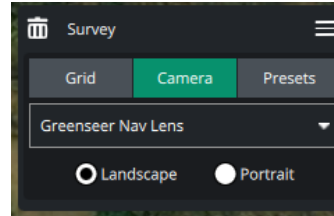
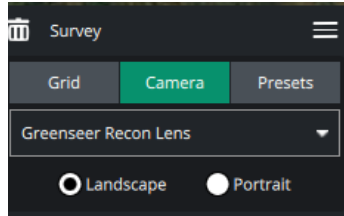
1. Select “Plan” icon on the action panel
2. Add a waypoint near the beginning of the mission block
 - a. Set camera angle to 90°.
 - i. This will automatically fly the mission at nadir. Failure to add a waypoint with this camera setting will result in forward-facing pictures.
3. In “Mission Start” box, ensure waypoint altitude is set higher than all obstacles in the area. Set flight speed of 12 mph for best results.



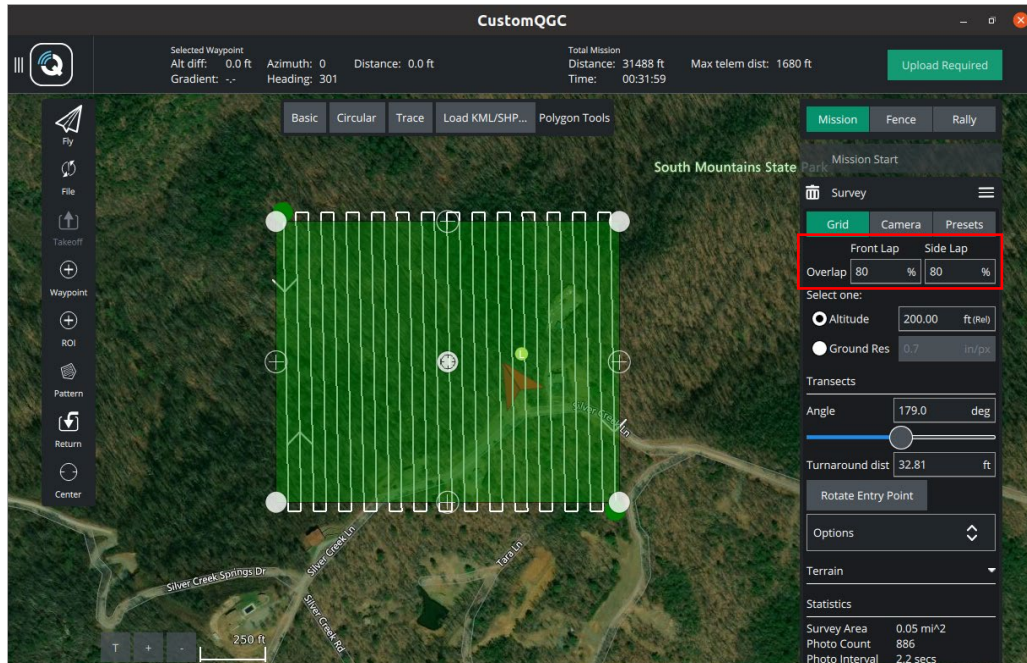
4. Select:
 - a. “Pattern”
 - b. “Survey” for a standard mapping mission
 - c. “Basic” for a square. Vertices may be added by clicking the plus symbols.
 - d. Click “Done With Polygon” once collection area is set.



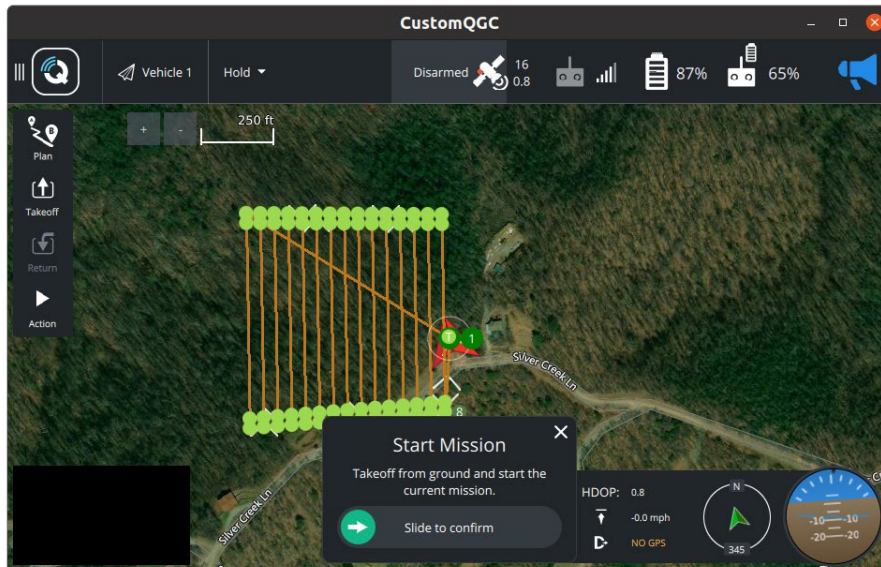
5. Select "Camera" tab and choose ReconLens or NavLens based upon mission goals. Recon Lens will have much better resolution, but ground coverage per battery is approximately $\frac{1}{4}$ of using the navigation camera.
 - a. ReconLens GSD at 400ft: $\sim 1\text{cm}$
 - b. NavLens GSD at 400ft: $\sim 6\text{cm}$



6. Set desired overlap based upon collection goals. **80%** front and **80%** side overlap are recommended for the best results.



7. Total mission distance, time, and max distance are found in the top information bar. Survey area size, photo count, photo trigger interval and distance are found in the Survey planning box.
8. Select flashing green “Upload Required” button to upload the mission to the aircraft.
 - a. Flight lines turn orange with green dots at the turn around points



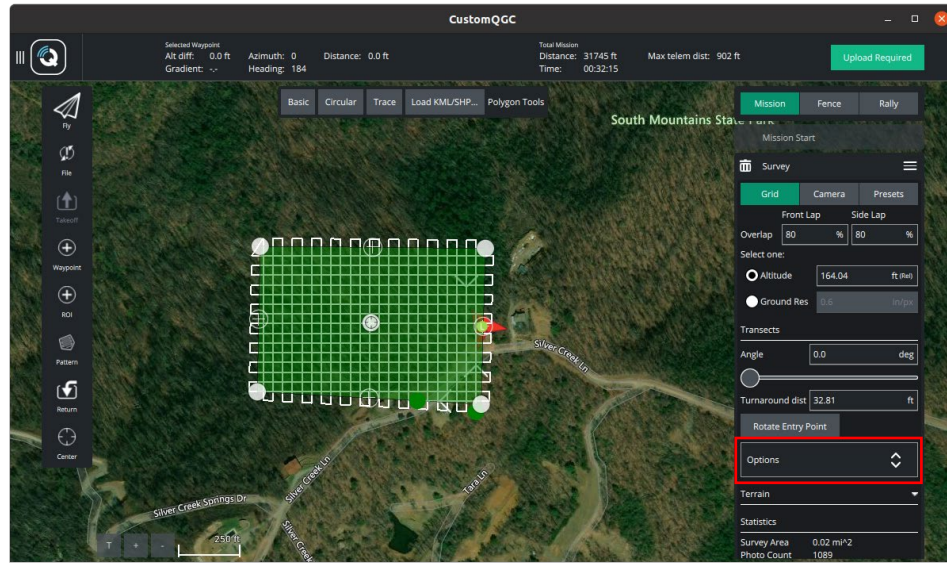
9. **Zoom to 4x** to utilize the Recon Camera (1x zoom for NavLens). Images will be captured with the low-resolution navigation camera if not zoomed to 4x.
10. When ready for takeoff, slide right on “Start Mission” box.
11. After launch, ensure camera rotated to nadir automatically upon reaching first waypoint
12. Take manual control when mission is complete by touching either joystick and return to launch location to land.
 - a. **NOTE:** Position drone 5-10 ft above the ground and select “Land.” You **cannot** hold the stick down to manually land.

3-D Missions

For best results when creating a 3-D model, it is important to fly perpendicular lines, or a “cross-hatch” pattern. This will ensure the model details all sides of the feature being captured.

Procedures

1. Plan a survey mission as detailed above
2. On the survey tab, select “Options” drop down
3. Select “Refly at 90 deg offset”



Note that this will double the flight time and number of images captured. Plan accordingly.

Best Mission Practices

- While not as important for rotary-wing drones, it is good practice to plan mapping missions for crosswind flight to maximize battery performance.
- Start at the point **farthest away** and work back towards the landing point to prevent a long transit with low battery.
 - Invert flight plan via Options tab under Survey or change flight direction by 180°
- Recommended minimum in-flight battery percentage: **25%**
- Standard overlap: 80% lateral and longitudinal.
- Ensure lost link plan is set to an altitude at least 50 ft higher than all obstacles in the operating area.

Tips and Tricks

- If QGC app crashes during flight, re-open via app “VR_QGC_QC6.a-ppimage” located in center of home screen.
- Before putting drone back in case, quickly pop battery off and on to power down.
 - Note: the drone may be placed in the case with the power on and it will self-power down after 5 minutes
- For 1.8 GHz models, leave GCS antenna down until after takeoff to avoid signal loss
- Avoid interrupting mapping missions unless there is a safety of flight issue – you must land and restart the mission to reset planned flight speed.
- Upon completion of a mapping mission, Vesper will remain at last waypoint until commanded. Utilize Return-to-Home button to easily bring aircraft back to start point.

Maintenance & Care

Conduct the following post-flight inspection steps after every flight:

1. Inspect the propellers for loose screws and damage. Replace propellers if damage is discovered.
2. Inspect the lens for dirt/debris. Following cleaning instructions as necessary.
3. Keep batteries charged at full capacity whenever possible.

Note: Only use the charging cables provided in the kit. A standard USB-C cable could damage the GCS during charging.

****Detailed care and maintenance procedures can be found in the 'Vesper and Vision GCS Manual.'**

Acronyms

ASAP - as soon as possible

AV - air vehicle

COC - command operations center

COTS - commercial-off-the-shelf

GCS - ground control station

GPS - global positioning system

KIO - knock it off

LRE - launch and recovery element

MSA - minimum safe altitude

NDVI - normalized difference vegetation index

RAW - risk assessment worksheet

Rec - recovery

RPIC - remote pilot in command

RSSI - radio signal strength indication

RTB - return to base

UAS - unoccupied aircraft systems

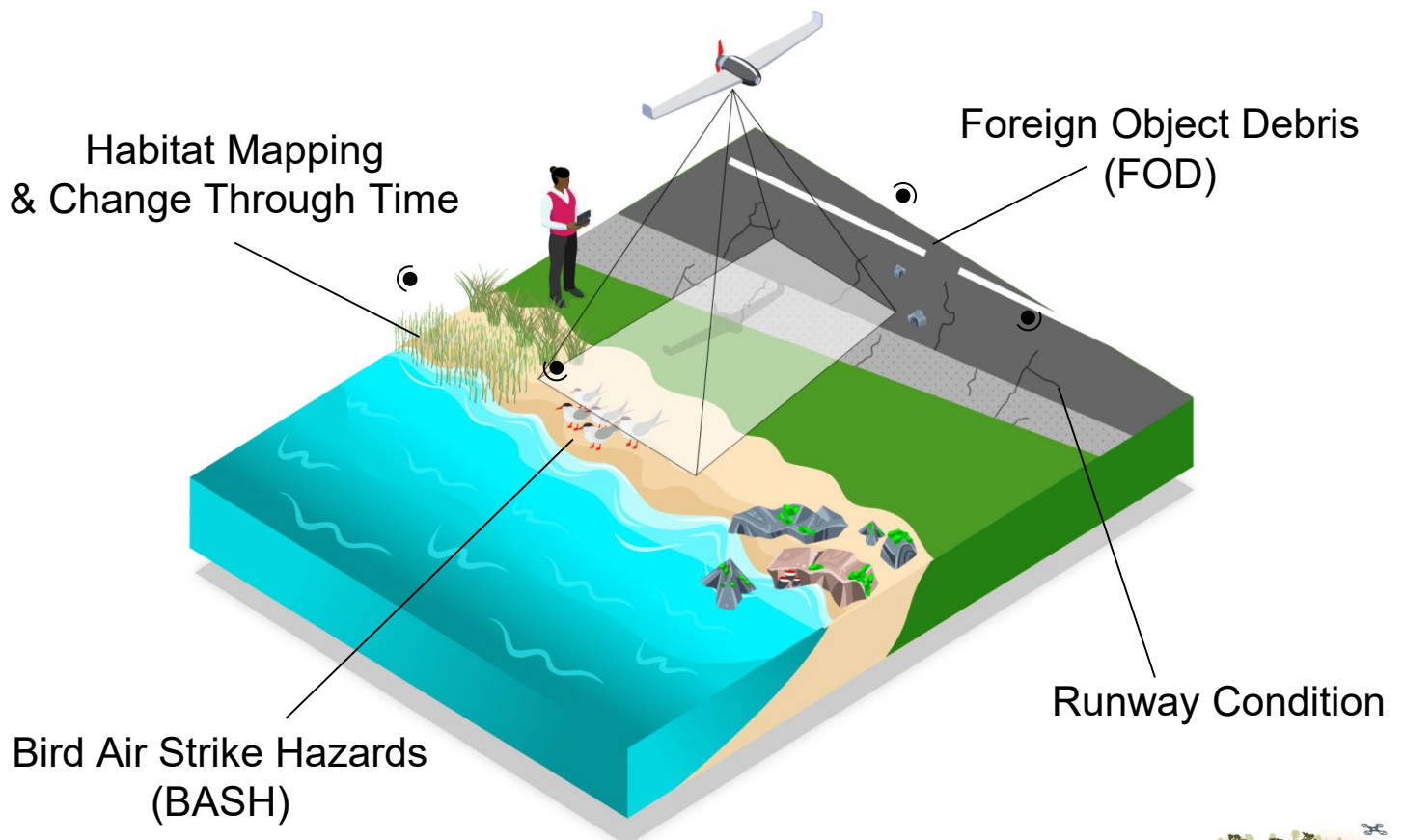
This project was funded by the Environmental Security and Technology Certification Program*. It was carried out in partnership with the University of North Carolina at Chapel Hill, Attollo LLC, and Duke University Marine Lab.

*RC19-5218; Region-wide Integration of UAS Technology into DOD Natural Resource Management through Demonstration, Coordination, Training, and Outfitting



Using Drones to Monitor Airfield Hazards and Condition

Safe airfield operations must assess hazards, such as the potential for bird air strikes, runway debris, and the condition of the runway. The current methods used for gathering these types of information is often labor intensive, through on-the-ground observational data collection. Here, we present imagery from several airports and the surrounding environments to demonstrate the utility of Unoccupied Aircraft Systems (UAS, or drones) for managing airfield hazards. UAS can help accomplish multiple objectives (e.g., habitat mapping, foreign object debris (FOD), bird air strike hazard (BASH) and runway condition) all using the same data set.



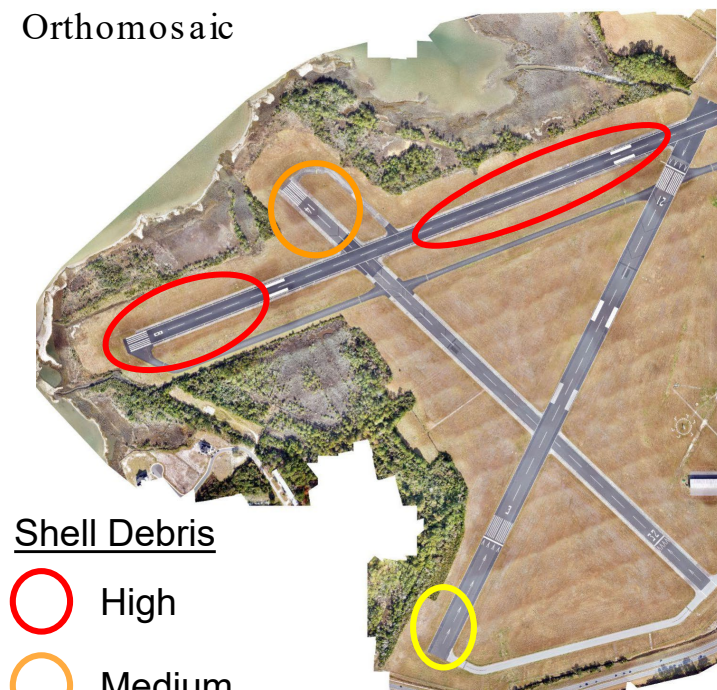
Using Drones to Monitor Airfield Hazards and Condition

Habitat Mapping

Mapping the habitat within and around an airfield can help managers better understand wildlife hazards. Birds utilize habitats adjacent to airfields in numerous ways throughout the year (e.g, nesting, foraging), introducing seasonal hazards and management challenges.

A mapping mission was flown over the Michael J. Smith Beaufort Airport (North Carolina) and surrounding environment to assess bird activity and shell-debris runway hazards (left image). Using image classification tools in ArcGIS, a high-fidelity land cover map of the airport was generated (right image). The land cover map combined with on-the-ground observations, allowed airfield managers to assess BASH risk based on surrounding habitat types. The spatial distribution of shell debris (left image) showed that bird activity was greatest on runway areas in close proximity to wetlands and water, where birds forage for shellfish.

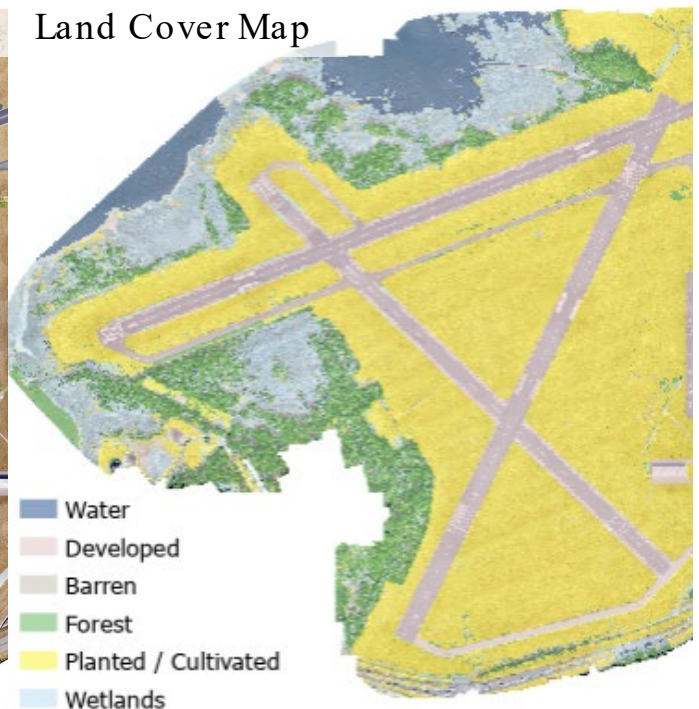
Orthomosaic



Shell Debris

- High
- Medium
- Low

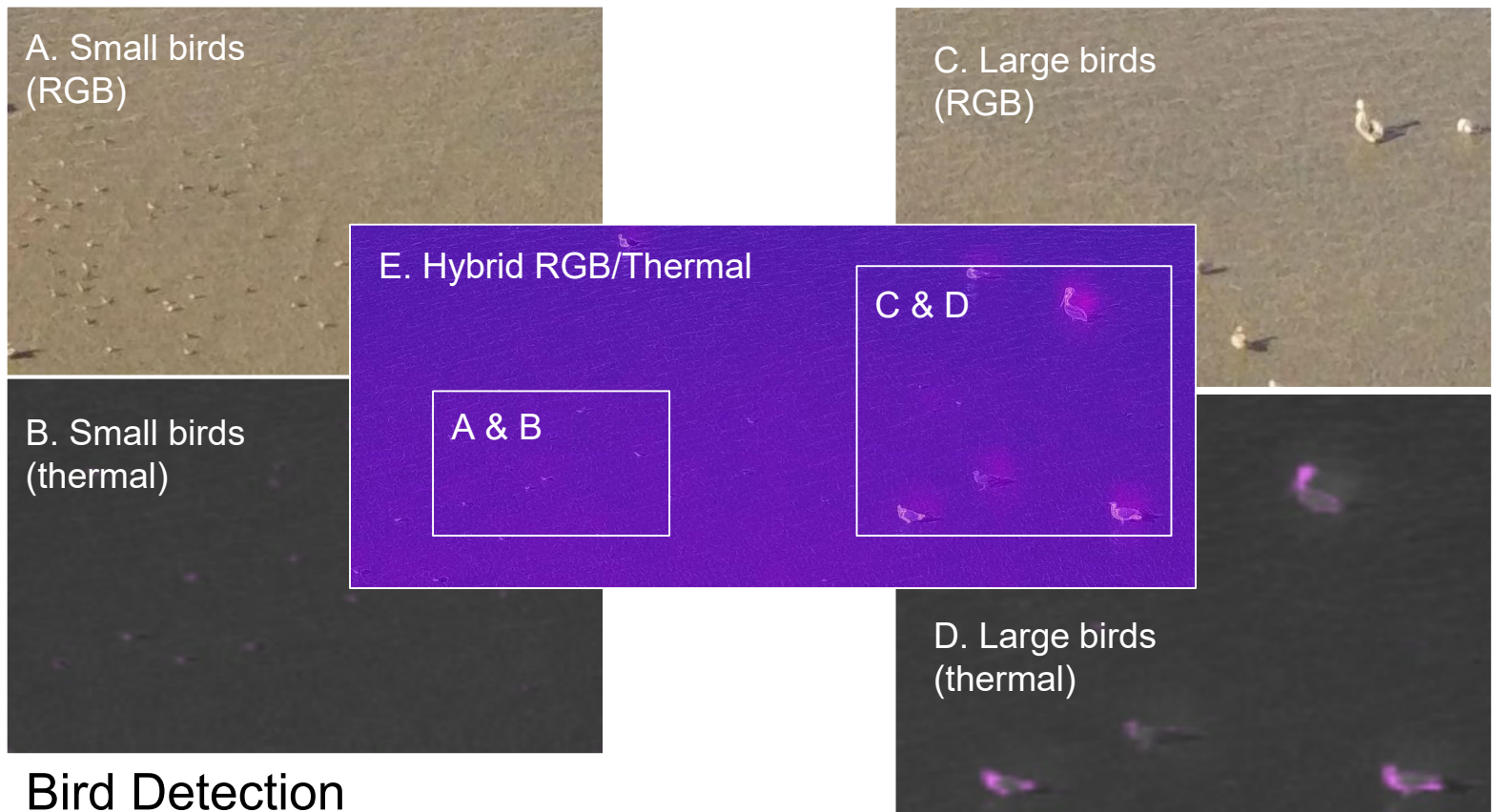
Land Cover Map



kilometers

0  1

Using Drones to Monitor Airfield Hazards and Condition



Bird Detection

Drones can be used to detect birds around airfields by providing imagery in areas that are not easily accessible on the ground. However, we have found several caveats for this particular application using RGB (Figures A & C), thermal (Figures B & D), and hybrid RGB/thermal (Figure E) imagery. While lower altitude RGB flights (using rotary-wing aircraft with live visual feed) can be used to identify the presence of birds, operating a drone too close to birds often results in birds flushing before identification or detection is possible.

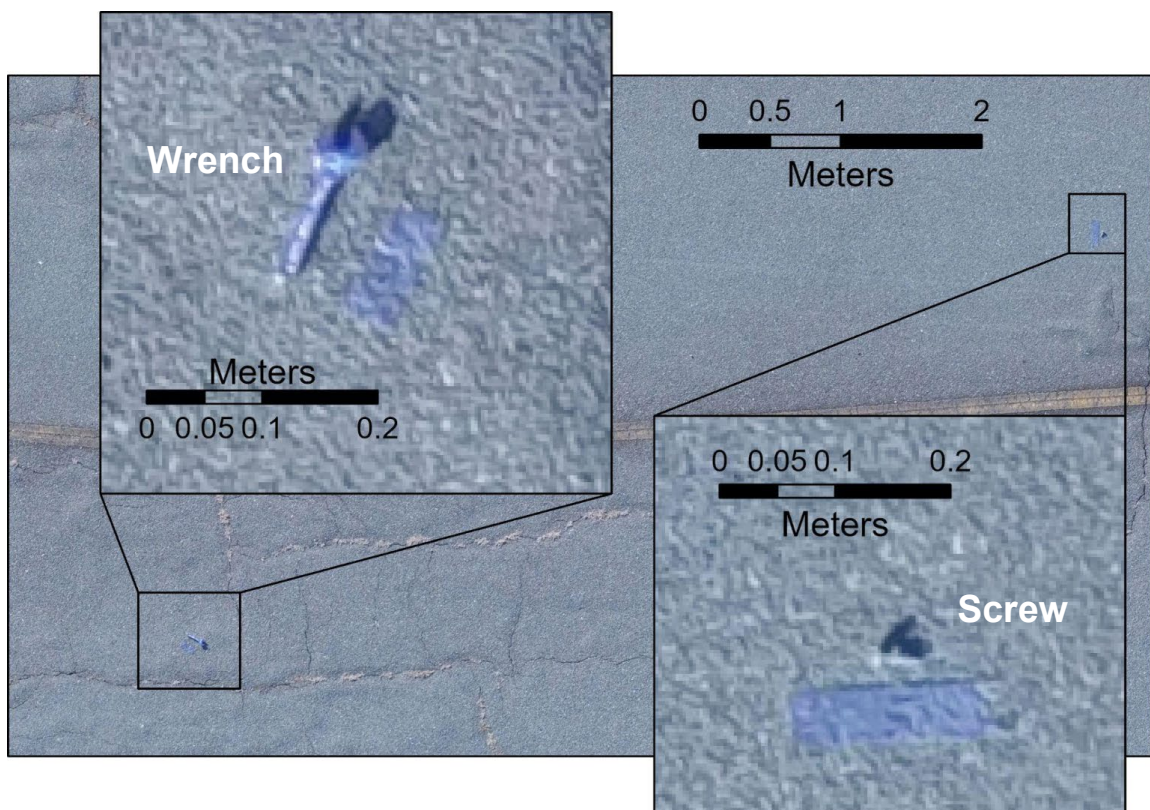
The ability of a thermal sensor to successfully detect birds depends on the temperature of the environment and size of the birds (B vs.D). Flying in early morning created a higher temperature contrast between birds and background, and birds on water were more visible in the thermal imagery than birds on land. Birds can be visualized using the Hybrid RGB/thermal live feed imagery (E) and can be further isolated through processing workflows (B and D). Bird size was the largest contributor to visibility. The panels above show small birds in both RGB (A) and thermal (B) views are barely visible, while large birds are more easily detected in both RGB (C) and thermal (D) views.

Using Drones to Monitor Airfield Hazards and Condition

Foreign Object Debris (FOD)

To ensure safe flight operations, runway debris needs to be identified and removed; ideally, these steps are accomplished concurrently. One can easily identify the location of airfield debris from drone imagery, but this takes more time than manual surveys, particularly because it does not address the most important step - physical removal. High resolution imagery can show objects as small as screws (bottom right image below), but current workflows require images to be imported to a workstation for identifying debris.

Drones could be useful as a post-removal safety sweep to ensure that no debris was missed. It is also possible that with upcoming advancements in real time detection through artificial intelligence, drones may soon become a viable tool for detecting and transmitting the locations of debris to the ground crew for removal. These are also the first steps into linked autonomous systems where the aerial drone can transmit locations of debris to a rover for debris removal.



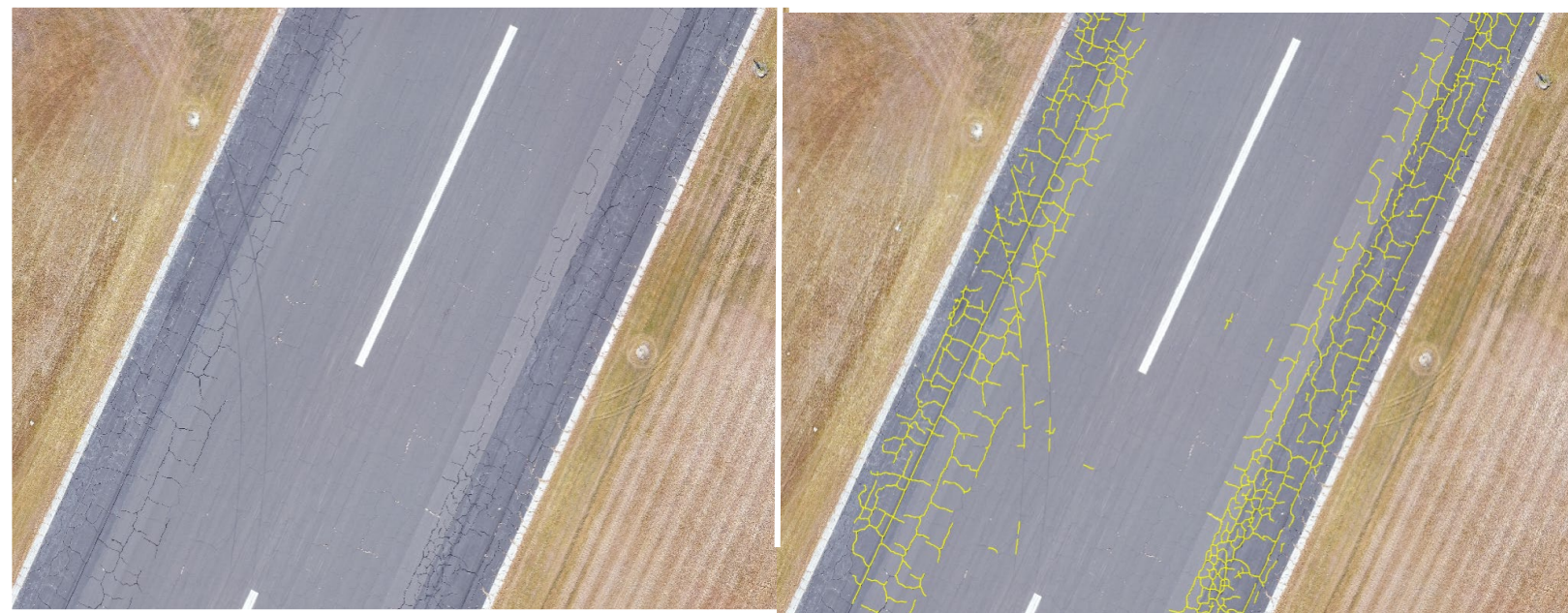
Using Drones to Monitor Airfield Hazards and Condition

Runway Condition

The resolution and products provided by drone surveys and image processing allows airfield managers to assess runway condition on multiple levels. The extent of deterioration can be quantified by showing the amount and severity of cracks in the runway that form through time. This is further aided by tools provided in ArcGIS like the deep learning tool for pavement crack detections.

Cracked runway pavement is captured in high resolution RGB imagery (left image) and then identified by the ArcGIS deep learning tool in yellow (right image). This enables detection of runway damage in imagery and provides the means to quantify and monitor cumulative runway damage over time.

The 3D surface can also be constructed from Structure from Motion photogrammetry software (like Pix4D or Drone2Map). This can show how the runway surface is changing through time, where areas may need to be resurfaced, and how much volume of material will be needed for repairs.



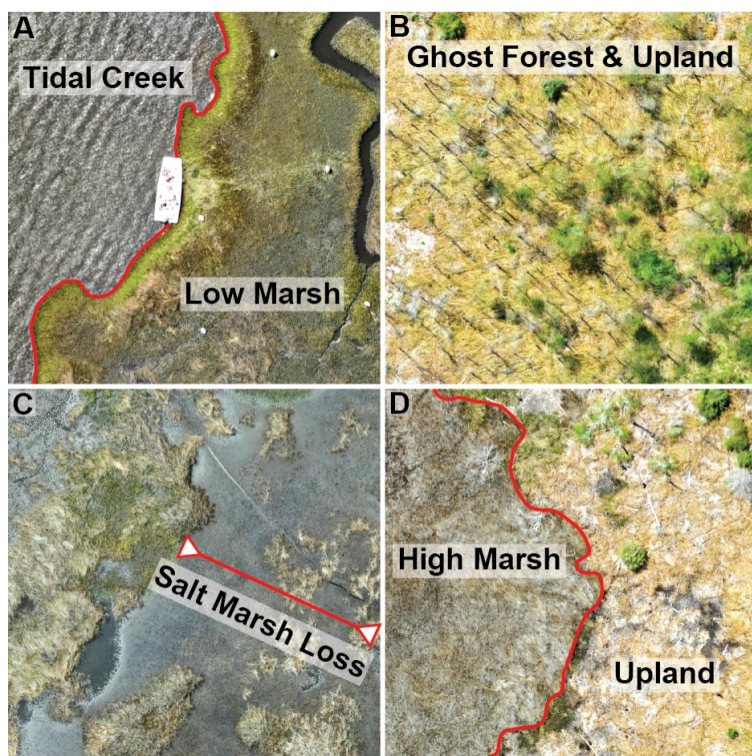


Using Drones to Monitor Salt Marsh

Background

Salt marshes provides many services to coastal military installations and surrounding communities including infrastructure protection from storms, erosion control, water purification, fish and wildlife habitat, and carbon sequestration. These services scale with the width of the salt marsh, measured as distance from the edge of forested upland or development to the shoreline. Erosion at the salt marsh shoreline and infrastructure at the upland boundary is reducing salt marsh area. Importantly, a reduction in salt marsh width decreases wave damping by grasses and the capacity of a saltmarsh to buffer a military installation from erosive wave and storm energy underscoring the importance of monitoring salt marsh extent and health.

Salt-marsh metrics extracted from remote sensing data collected using traditional piloted aircraft can be inaccurate and misleading. Unoccupied Aircraft Systems (UAS) provide superior data for mapping the salt marsh shoreline (A), health indicators (e.g., ghost forest) (B); marsh die off (C), and upland boundary (D). Figure images are insets from above banner.



Drone Products

- ❖ **RGB Orthomosaic**
UAS-Structure from motion stitched map view of salt marsh site
- ❖ **2-D Shoreline Change**
Tracking shoreline and upland boundary movement over time
- ❖ **Salt-marsh health indicators:**
Salinization of upland forest
Pond formation
Die off

Mapping Salt Marsh Shorelines

Drone flights during low tide are essential

Salt marsh shoreline erosion is persistent, mainly the result of smaller storm events that occur every month and boat wakes. During those events, wave energy is focused on the shoreline. Larger events, such as hurricanes, impact the upland boundary facilitating landward salt marsh migration. Salt marsh expansion into the estuary can also occur. This is mainly the result of estuarine sediment loading from changing land cover in coastal watersheds, such as development of forest areas.

Left image: The shoreline mapping mission was flown in 2021 over Gales Creek, NC using a DJI Mavic 2 Pro. The 2012 shoreline (white line) was positioned in the estuary, and the average retreat rate measured from 2012-2021 was 0.33 m yr^{-1} . Erosion was mainly the result of nor'easters. This 2D orthomosaic image was created using a polygon mapping mission.

Right image: Drones have the advantage over piloted aircraft in this application because images need to be collected during low tide. Salt marsh is intertidal and the shoreline edge is submerged at high tide. The 2021 shoreline (white line) is seaward of the 2012 shoreline, which was obtained during high tide from an occupied aircraft. This could incorrectly indicate salt marsh expansion, underscoring the importance of data collection at low tide.

Orthomosaic from drone



Orthomosaic from piloted aircraft



Mapping Upland Boundaries and Salinization with Drones

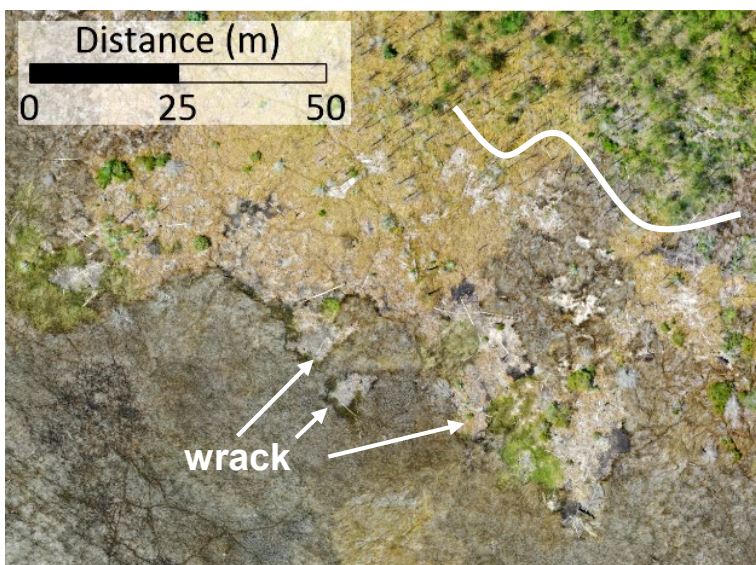
The upland edge is difficult to access on the ground

In some areas, the upland edge is marked by a rock wall or bulkhead aimed at protecting infrastructure from storm surge or sunny-day flooding. The upland edge of natural areas is difficult to access and map on the ground due to dense vegetation, muddy substrate, and hazards such as abundant poison ivy and cottonmouth snakes. A drone is a very useful tool for mapping this setting.

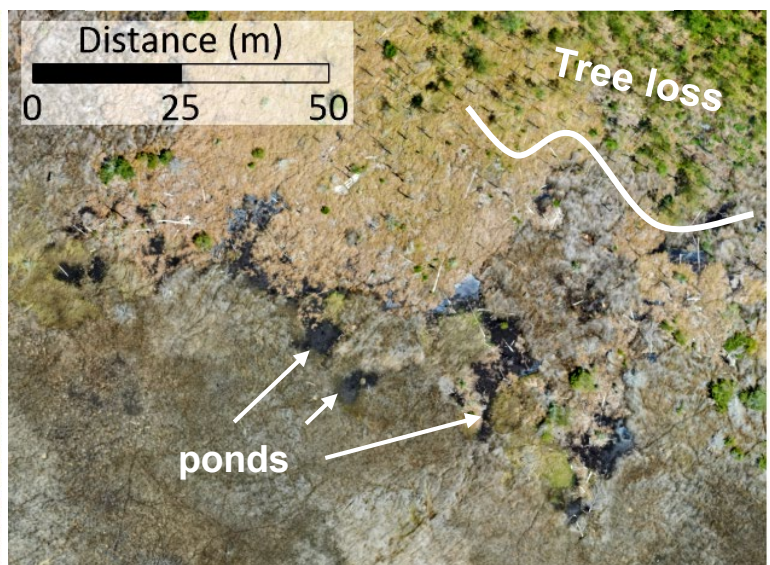
The upland edge is commonly hidden in the shadows cast from the forest canopy. This is reduced if flight times are planned during high sun angles. Including digital terrain models based on structure from motion in the data set will ensure that the forest-salt marsh boundary is clearly delineated. Salinization of upland soil from sea-level rise and storms promotes salt marsh landward expansion. This is evident over short time scales and illustrated by tree loss in Oyster Creek, NC (below).

Marsh debris (dead grass, wood, and trash) is transported landward during storm surge and accumulates on top of high-marsh vegetation (left image). This debris is called wrack, can be 1.0 m thick, and smothers the underlying vegetation. As the wrack decomposes and/or is transported away during a subsequent storm, it leaves behind a depression that forms a pond (right image), which may persist, or become recolonized with salt marsh over time. Ponds tend to increase in size during wind events that produce erosive currents, reducing marsh area.

Orthomosaic 2021



Orthomosaic 2022



Best Practices for Salt Marsh Mapping with Drones

Ground Control Points

Deploying ground control points (GCPs) within the area of interest is important if the objective is to capture shoreline changes or upland migration through time. Salt marsh edges typically move <1 m at yearly timescales a distance that cannot be resolved using standard GPS positioning methods (not survey grade). Repetitive trampling of salt marsh during the installation of GCPs should be avoided because marsh substrate is unconsolidated, vegetation is fragile, and trails can take over a decade to recover. Consider placing GCPs in the estuary (on poles) adjacent to the shoreline and at the edge of the upland, accessed by hiking through the upland. This will prevent damaging the marsh and monitoring it to death.

Mapping changes in marsh area, number of ponds, wrack, and loss of upland forest can be done precisely and accurately without using GCPs. The resolution of the orthomosaic is the same whether or not GCPs are used. The advantage of GCPs is that it allows the orthomosaic to be positioned on the planet precisely and accurately.

Structure from Motion (SfM)

Digital surface models of salt marshes based on SfM are elevation maps of the grass canopy. This information is not useful for monitoring marsh accretion, or vertical changes in the elevation of the substrate (bare Earth) through time, but is useful for mapping the tree line at the upland edge. Flying a 3D double grid mapping mission to use SfM creates more images and takes more flight time.



- Fly the mission at low tide.
- Avoid creating tracks and trails through the salt marsh as shown in the image (left). This damages vegetation and lowers surface elevation locally, which can take over a decade to recover.
- To capture salt marsh edge migration, survey annually and after major disturbances.