FINAL REPORT

Enhancing the capability and efficiency of DoD land management by using commercial unmanned aerial vehicles to assess the impacts of fires and coastal storms

ESTCP Project RC18-5187

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14. ABSTRACT

Introduction and Objectives- Department of Defense (DoD) land management benefits from having the capability to collect, process, and interpret on-demand high-resolution remotely-sensed data. These data are critical in DoD coastal-zone and forest management because of frequent impacts by severe storms, inundation, or management activities, such as prescribed burns. The main goal of this project was to implement reliable Unoccupied Aerial Systems (UAS) in Marine Corps Base Camp Lejeune environmental management, thereby increasing the speed, ease, and safety of obtaining useful, highly accurate, and detailed monitoring products for a fraction of the cost of manned operations. The three primary objectives included: 1. Train environmental management personnel to conduct UAS operations legally and safely in DoD airspace, 2. Equip the base with a standardized UAS kit containing all of the equipment and supplies necessary for conducting operations, and 3. Demonstrate UAS applications for managing barrier island beaches and forests by generating proof-of-concept data sets and provide frequent opportunities for communication with Environmental Management Division and Marine Corps personnel. **Technology Description-** State-of-the-art aircraft (multirotor Parrot Anafi and fixed wing eBee X), sensors (Red-Green-Blue and thermal infrared), and photogrammetric software (Pix4Dmapper version 4.6.4) were used for this project. We piloted the eBee X for coastal- and forest-management demonstrations and the Parrot Anafi for demonstrating increased safety and productivity during prescribed burns. **Performance and Cost Assessment-** We used both quantitative and qualitative approaches for assessing UAS performance as a tool for coastal-zone and forest management. To demonstrate improved efficiency, accuracy, resolution and cost of coastal mapping using a UAS versus ground-based and manned-aircraft methods we compared beach volume measured using the UAS with ground surveying, terrestrial Light Detection and Ranging (LiDAR), and airplane LiDAR. Beach volume measured using the UAS was the same as terrestrial LiDAR and more accurate than airplane LiDAR and ground surveys. The reduced time needed to collect UAS data made pre- and post-storm surveys of a barrier island easier to obtain and the high-resolution images allowed 100% detection of potential sea turtle nest areas. While integrating UAS in forest management activities, we developed a pathway for quantitatively assessing burn efficacy that was previously unachievable including live visual feed for area assessment, geospatial analyses of images obtained before and after fires, accurate detection of hot spots and increased situational awareness. The costs associated with fire and coastal monitoring (US$/hour) were less for UAS than occupied systems (air and ground). UAS are most beneficial in smaller survey areas (< ~200 ha) where high resolution orthomosaics, detailed digital elevation models, and real-time data are needed. **Implementation Issues-** Cybersecurity concerns, international relations, and trade wars made transferring a UAS to end-users difficult. Due to numerous changes in DoD cyber-security policy, the mission kit aircraft became prohibited several times. The final policy bans all Chinese components, which forced the project team to continue searching for an acceptable replacement that meets the natural resources management mission set. **Publication-**Products include three peer-reviewed articles, five abstracts, two white papers, course materials and standard operating procedures for operating a UAS in DoD airspace.

15. SUBJECT TERMS
DoD land management, commercial unmanned aerial vehicles, impacts of fire, coastal storms

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ACRONYMS AND ABBREVIATIONS

BUQ	Basic UAS Qualification
CNF	Croatan National Forest
COTS	Commercial off-the-shelf
DoD	Department of Defense
DOI	Department of Interior
DSM	Digital surface model
DUML	Duke University Marine Lab
EMD	Environmental Management Division
EO	Electro-optical
EOD	Explosives Ordnance Division
FAA	Federal Aviation Administration
FL	Florida
FLIR	Forward Looking Infrared
GCP	Ground control point
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global positioning system
IR	Infrared
LiDAR	Light detection and ranging
MaRRS	Marine Robotics and Remote Sensing Lab
MCBCL	Marine Corps Base Camp Lejeune
MCIEAST	Marine Corps Installations EAST
MEF	Marine Expeditionary Forces
NASA	National Air and Space Agency
NC	North Carolina
NDAA	National Defense Authorization Act
PPK	Post-process kinematic
REDDIE	Regional Drones – Installations and Environment
RGB	Red-Green-Blue
RTK	Real-time Kinematic
SfM	Structure from Motion
SSI	Special Security Instructions

T&E	Threatened and Endangered
TNC	The Nature Conservancy
TTRS	Tall Timbers Research Station
UAS	Unoccupied Aircraft Systems
UXO	Unexploded Ordnance

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ABSTRACT

INTRODUCTION AND OBJECTIVES

Department of Defense (DoD) land management benefits from having the capability to collect, process, and interpret on-demand high-resolution remotely-sensed data. These data are critical in DoD coastal-zone and forest management because of frequent impacts by severe storms, inundation, or management activities, such as prescribed burns. The main goal of this project was to implement reliable Unoccupied Aircraft Systems (UAS) in Marine Corps Base Camp Lejeune environmental management, thereby increasing the speed, ease, and safety of obtaining useful, highly accurate, and detailed monitoring products for a fraction of the cost of manned operations. The three primary objectives included: 1. Train environmental management personnel to conduct UAS operations legally and safely in DoD airspace, 2. Equip the base with a standardized UAS kit containing all of the equipment and supplies necessary for conducting operations, and 3. Demonstrate UAS applications for managing barrier island beaches and forests by generating proof-of-concept data sets and provide frequent opportunities for communication with Environmental Management Division and Marine Corps personnel.

TECHNOLOGY DESCRIPTION

State-of-the-art aircraft (multirotor Parrot Anafi and fixed wing eBee X), sensors (Red-Green-Blue and thermal infrared), and photogrammetric software (Pix4Dmapper version 4.6.4) were used for this project. We piloted the eBee X for coastal- and forest-management demonstrations and the Parrot Anafi for demonstrating increased safety and productivity during prescribed burns.

PERFORMANCE AND COST ASSESSMENT

We used both quantitative and qualitative approaches for assessing UAS performance as a tool for coastal-zone and forest management. To demonstrate improved efficiency, accuracy, resolution and cost of coastal mapping using a UAS versus ground-based and manned-aircraft methods we compared beach volume measured using the UAS with ground surveying, terrestrial Light Detection and Ranging (LiDAR), and airplane LiDAR. Beach volume measured using the UAS was the same as terrestrial LiDAR and more accurate than airplane LiDAR and ground surveys. The reduced time needed to collect UAS data made pre- and post-storm surveys of a barrier island easier to obtain and the high-resolution images allowed 100% detection of potential sea turtle nest areas. While integrating UAS in forest management activities, we developed a pathway for quantitatively assessing burn efficacy that was previously unachievable including live visual feed for area assessment, geospatial analyses of images obtained before and after fires, accurate detection of hot spots and increased situational awareness. The costs associated with fire and coastal monitoring (US$/hour) were less for UAS than occupied systems (air and ground). UAS are most beneficial in smaller survey areas (< ~200 ha) where high resolution orthomosaics, detailed digital elevation models, and real-time data are needed.

IMPLEMENTATION ISSUES

Cybersecurity concerns, international relations, and trade wars made transferring a UAS to end-users difficult. Due to numerous changes in DoD cyber-security policy, the mission kit aircraft became prohibited several times. The final policy bans all Chinese components, which forced the project team to continue searching for an acceptable replacement that meets the natural resources management mission set.

PUBLICATION

Products include three peer-reviewed articles, five abstracts, two white papers, course materials and standard operating procedures for operating a UAS in DoD airspace.

EXECUTIVE SUMMARY

INTRODUCTION

Department of Defense (DoD) land management would benefit greatly from having the capability to collect, process and interpret on-demand high-resolution, and remotely-sensed data. These data provide the latest information for optimizing decision-making processes, which is critical in areas frequently impacted by severe storms, that change state rapidly due to erosion, inundation, or management activities such as prescribed burns, and that are persistently impacted by rising sea level and a warming atmosphere. Many DoD installations are strategically located in areas best suited for specific training purposes, such as the four installations used for Marine Expeditionary Forces (MEFs) are located in coastal areas to provide proper training grounds for amphibious assaults. It is imperative that these DoD installations remain persistently functional to not impede the readiness of our MEFs and that depends on sound management of the environment. Incorporating unoccupied aircraft systems (UAS) into the existing environmental management activities of Marine Corps Base Camp Lejeune (MCBCL) will advance the Marine Corps training mission by increasing efficiency, reducing cost, and decreasing response time to environmental changes from both natural and human impacts.

Anticipating and addressing the effects of coastal storms, wildfires or controlled burns requires high-resolution habitat information and real-time and/or rapid assessment of events, which are often difficult to achieve on the ground due to safety concerns, lack of access from unexploded ordnance (UXO), and/or the large spatial scale of affected areas. Employing remotely-sensed data is the solution; however, traditional sensor platforms, such as satellites and airplanes, are expensive, require significant coordination efforts, and may not be available during necessary event periods. The use of UAS can overcome some of these issues and can reduce the risk of injury or death to personnel conducting airborne monitoring, especially around fires that are often associated with unstable smoky air, and in the Southeastern US coastal plain occur in areas with low-gradient topography limiting natural vantage points for monitoring fire progression. Working directly with DoD range control and land managers we applied commercial unoccupied aircraft system (UAS) technology to enhance both coastal zone and fire management on DoD lands by assessing impacts from storms, persistent seasonal shoreline alterations, and sea turtle nesting (coastal zone), and through integrated planning, pre-prescribed burn forest assessments, real-time monitoring of fire progression, and post-prescribed burn activities (fire management; Figure 1).

Figure 1- Demonstrations focused on coastal-zone and forest management. The application of unmanned aerial systems to barrier island monitoring (A) and prescribed burns (B) were used as proof-of-concept case studies.

OBJECTIVES

The main goal of this project is to implement reliable UAS activities in DoD forest and coastal-zone management, thereby increasing the speed, ease, and safety of obtaining useful, highly accurate, and detailed monitoring products for a fraction of the cost of manned operations. The three primary objectives include: 1. Train MCBCL Environmental Management Division (EMD) personnel to conduct UAS operations legally and safely in DoD airspace, 2. Equip EMD with a standardized UAS kit containing all of the equipment and supplies necessary for conducting operations, and 3. Demonstrate UAS applications for managing barrier island beaches and forests by generating proof-of-concept data sets and provide frequent opportunities for communication with EMD and Marine Corps personnel. Additionally, to ensure that the MCBCL UAS program remains productive and persists past this project's end date, we wanted to produce and disseminate key products to EMD, including training materials, standard protocols and requirements needed to conduct UAS operations in DoD airspace, and white papers outlining the demonstration test cases.

We demonstrated the application of commercial UAS technology to enhance coastal-zone management on ocean facing shorelines of MCBCL and nearby Bird Island. Initially, we compared beach volumes based on UAS derived data, with more traditional mapping methods, including global positioning system surveys, terrestrial Light Detection and Ranging (LiDAR), and occupied airborne LiDAR. Coastal-zone management demonstrations focused on assessing impacts from storms and persistent changes due to sea-level rise, human modifications to sediment budgets, and beach use (e.g., recreational use and military training). These impacts include erosion, increased inundation, and reduction in elevation including supratidal island area, all of which may restrict the military's use of the beach for training. Specifically, these assessments defined and monitored shoreline position, as well as providing near real-time decision support for field personnel responsible for managing these habitats and endangered species (e.g., loggerhead sea turtle).

Working directly with range control and DoD land managers, we applied commercial UAS technology to enhance fire management on DoD and adjacent managed lands. This included: 1) providing methods to assess habitats in regions where wildfires may occur or at locations subject to prescribed burns; 2) providing increased situational awareness through the deployment of a compact, personal drone to ensure safety; 3) demonstrating cost reductions using UAS versus manned aircraft methods, and 4) improving the monitoring of the prescribed fire impact zones to provide better risk assessment, real-time information on the progression of a controlled burn, and ensure proper extinguishment and recovery.

TECHNOLOGY DESCRIPTION

State-of-the-art aircraft (both multirotor and fixed wing), sensors, and photogrammetric software were used for this project. We used the eBee X, a fixed-wing unoccupied aircraft with a high-resolution AeriaX (Red-Green-Blue, RGB), SODA (RGB), SODA 3D (RGB) and Red Edge (multispectral) sensor for the coastal management demonstration. For the forest management demonstration we used the Parrot Anafi multirotor aircraft fitted with electro optical and Infra-Red sensors for both situational awareness and mapping, and the eBee X with the Aeria X sensor for pre- and post-prescribed burn forest mapping. UAS obtain high-resolution imagery, finer than what airplanes or satellites can achieve, but are limited to mapping relatively small areas (<10 km^2) due to battery technology and/or line-of-sight regulatory restrictions. Currently, the commercial UAS niche is high-resolution, highly precise and accurate, versatile, on-demand, affordable, and safer data collection than using an aircraft with an onboard pilot and technicians. 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. Additionally, the amount of data we can extract from various imaging sensors is rapidly developing. Structure from Motion (SfM) techniques have extended UAS-derived data products to include high-resolution (seamless) 2D orthomosaics and 3D models from overlapping imagery and these products were created by post-processing images with Pix4Dmapper version 4.6.4. The evolution of camera sensors, compactness, UAS extended flight capability, and integration of real-time kinematic GPS has increased the possibilities of obtaining precise 3D measurements and landscape delineation over larger areas (square kilometers).

PERFORMANCE ASSESSMENT

We used both quantitative and qualitative approaches for assessing UAS performance as a tool for coastal-zone and forest management. Barrier island management is commonly centered around monitoring sand volumes because if sand volume persistently decreases through time, restoration such as the installation of sand fences, planting dune grasses, and beach nourishment needs to be considered as options to maintain elevation and protect infrastructure. To demonstrate improved efficiency, accuracy, resolution and cost of coastal mapping using a UAS versus ground-based and manned-aircraft methods we compared the various methods of beach surveying by calculating beach volume at Onslow Beach using data from two GPS survey transects, images from the eBee X, terrestrial LiDAR, and airplane LiDAR (Figure 2A). Beach volume measured using the UAS was the same (within error) as beach volume measured using the terrestrial LiDAR; however, the time and cost savings clearly makes mapping with a UAS superior to terrestrial LiDAR. The UAS also outperformed airplane LiDAR and ground GPS surveys, achieving twice as accurate beach-volume measurements. In addition, the resolution of the UAS orthomosaic (2.54 cm) is an order of magnitude higher than the airplane (30.0 cm).

Assessing storm impacts along barrier islands is always a challenge because storm paths are difficult to predict, which results in a lack of pre-storm data. We demonstrated that pre- and post-storm surveys of a barrier island are easy to obtain using a UAS and it followed that regular monitoring of beach morphology was also achieved easily, as demonstrated at multiple sites along Onslow Beach and communicated to base personnel through a white paper and a half-day demonstration event (Figure 2B). Monitoring and managing nesting sea turtles are challenging along the northeastern end of Onslow Beach and adjacent Browns Island due to unexploded ordnance. Current methods include weekly airplane flights with a visual observer noting the presence of crawl marks, which may miss crawl marks and nests created between flights. We achieved 100% detection of nine turtle crawls up to 24 hours after they were created using images obtained from the eBee X (Figure 2C). Turtle monitoring with a UAS can be done frequently and results can be confirmed by the images, and archived for better threatened and endangered species monitoring.

While integrating UAS in forest management activities, we learned that few quantitative metrics are traditionally used to assess prescribed burns and post-burn monitoring occurs over a very limited area, based on visual sweeps of the burned-forest perimeter. In working with project partners, we developed a pathway for quantitatively assessing burn efficacy that was previously unachievable. This includes using both live visual feed for area assessment as well as geospatial analyses of post-processed overlapping imagery from before and after fires (Figure 3). Accurate detection of active hot spots was also demonstrated over a broad area much more rapidly and thoroughly than perimeter scans from the ground. The additional aerial perspective provides better context for the danger these hotspots may or may not pose given nearby unburned vegetation. Trained DoD firefighters demonstrated the ease of using UAS technology and supplied positive feedback on the increased situational awareness UAS provide.

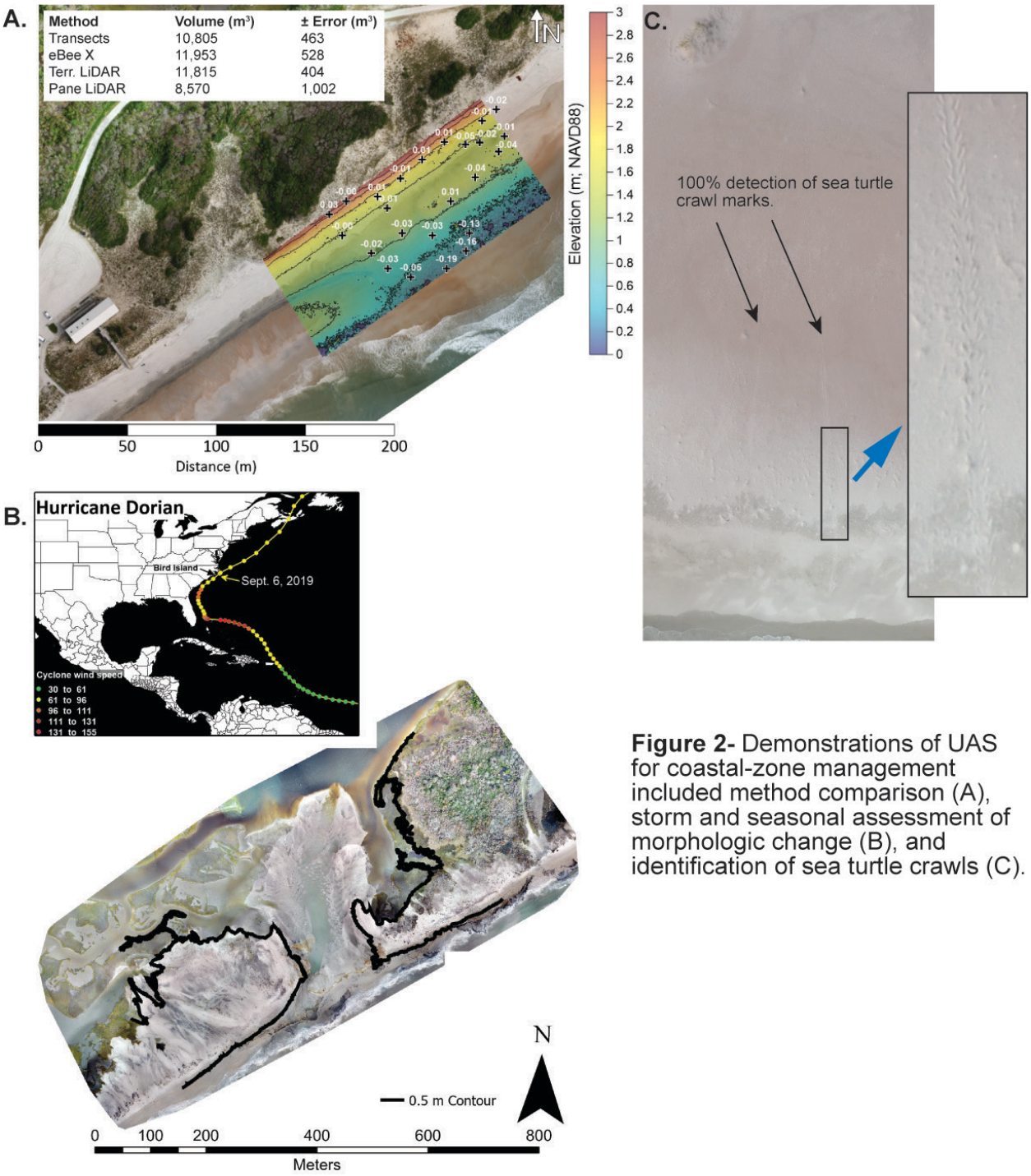


Figure 2- Demonstrations of UAS for coastal-zone management included method comparison (A), storm and seasonal assessment of morphologic change (B), and identification of sea turtle crawls (C).

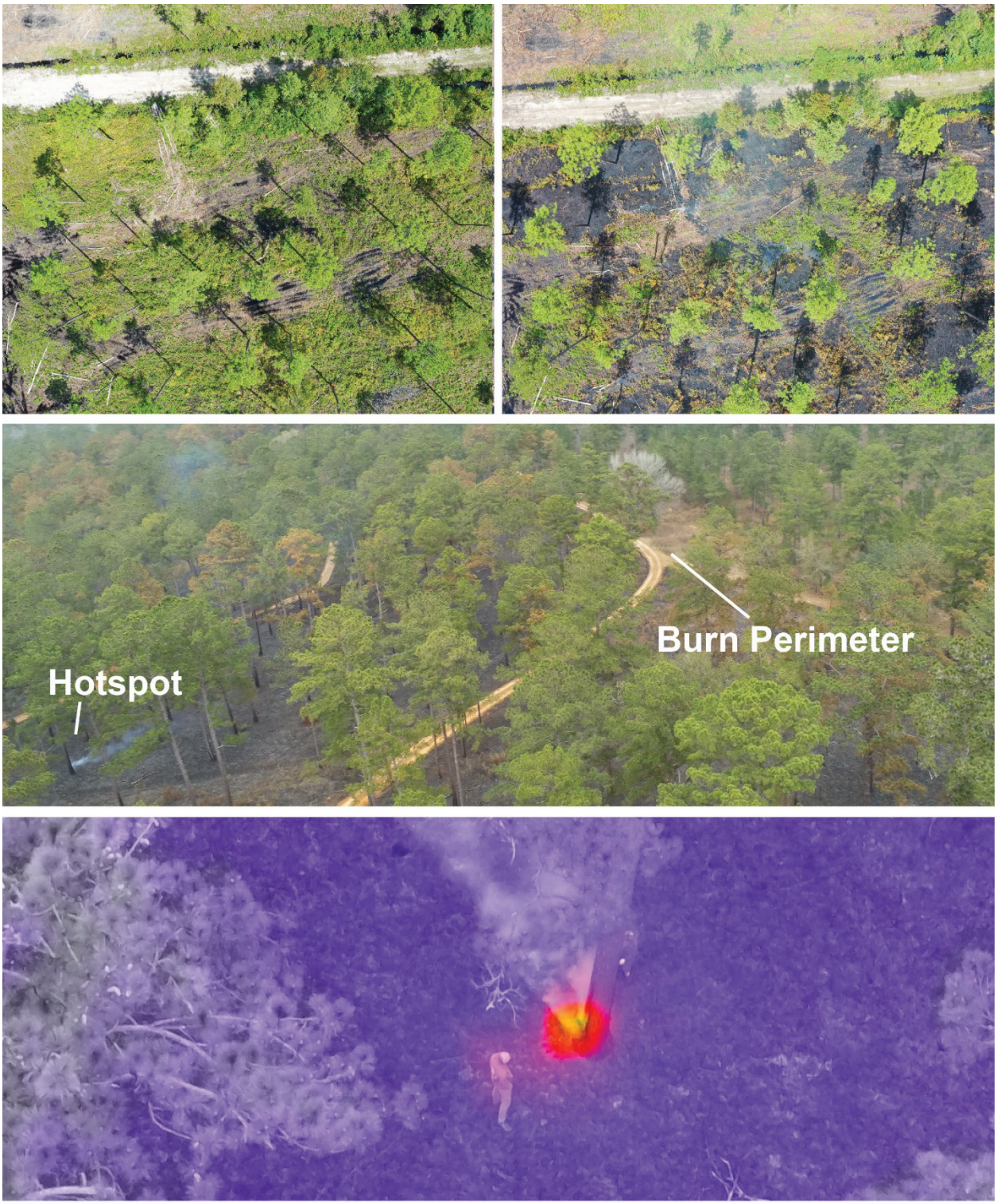


Figure 3. Examples of UAS Use for Fire Management.

Before (top left panel) and after (top right panel) prescribed burn images. Using UAS for situational awareness (middle panel) to see the burn perimeter and identify areas that are still aflame (hotspots). UAS thermal data can be overlain on the live video feed to help further identify hotspots (bottom panel).

COST ASSESSMENT

The costs associated with fire and coastal monitoring (US$/hour) were generated for both UAS and occupied systems (air and ground). Costs of contracting a manned operation (including aircraft, personnel, and fuel over multiple seasons) were compared to the costs involved with purchasing and operating a UAS (including aircraft, sensors and accessories, training, and personnel time to operate the UAS that will be available through multiple years). UAS operations proved significantly more cost effective; UAS are most beneficial in smaller survey areas (< ~200 ha), which are generally too small to require manned aircraft support. However, in larger survey areas, UAS proved to be a highly useful tool supplementing manned operations, enhancing the capacity to monitor forest and coastal systems and respond to unpredictable events. While hourly monetary cost savings were most pronounced when comparing UAS operations to occupied aircraft, the time/area efficiency was significant when compared to the ground assessment methods. Spatial coverage efficiency equates to dramatic monetary cost reductions using UAS compared to ground assessments when relative to the area surveyed.

IMPLEMENTATION ISSUES

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. The most frequent initial concerns expressed by MCIEAST users and leadership included: 1. financial (i.e. initial affordability and future budgeting), 2. time (i.e. demand of new technology use on people's schedules) and 3. bureaucracy (i.e. strong leadership framework necessary to move paperwork through the system). After conducting the Remote Pilot Course, we documented a complete reversal of those reservations and course reviews provided positive feedback about the high confidence of land managers to successfully employ drones in their work and the vast benefits of the technology when compared to the traditional, more costly, and less efficient means of conducting operations. The formalization of the program through combined work with RC19-5218 (Regional Drones – Installations and Environment, REDDIE) has resulted in a MCIEAST order that provides a pathway for the program to continue and grow as each installation wants and other installation groups (e.g., Installation Development and Design, Range Control) have expressed a desire to use drones in their work.

The drone commercial market is constantly evolving due to complex issues like cybersecurity concerns, international relations, and trade wars. At the time of purchase, the UAS in the mission kit, US-1 (made by Impossible Aerospace) was a revolutionary aircraft advertising a flight time of 1 hr+ and was anticipated to perform an array of mission sets related to coastal and forestry management. The company struggled during the pandemic and ceased operations in 2020. As a result, we opted to replace the US-1 in the mission kit with the Anafi USA. This replacement drone is manufactured by Parrot SA, a mature UAS company with headquarters in Paris, France. The above replacement was short-lived as the flight controller is prohibited due to Chinese components, and the team is finalizing an additional replacement of the Anafi USA. 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 low supply ballooning costs (8-fold increase). This cost shift may prove to be too much for early, unfunded programs to sustain. However, 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.

1.0 INTRODUCTION

1.1 BACKGROUND

Having the capability to collect, process and interpret on-demand high-resolution remotely-sensed data will transform Department of Defense (DoD) land management by providing the latest information for optimizing decision-making processes. Many DoD installations are strategically located in areas best suited for specific training purposes. For example, the four installations used for Marine Expeditionary Forces (MEFs) are so located to provide proper training grounds for amphibious assaults. As coastal real estate is not easy to obtain in large swaths of land, it is imperative that these DoD installations remain persistently functional to not impede the readiness of our MEFs. Anticipating and addressing the effects of coastal storms, wildfires or controlled burns requires high resolution habitat information and real-time and/or rapid assessment of events, which are often difficult to achieve on the ground due to safety concerns, lack of access, and/or the large spatial scale of affected areas. Employing remotely-sensed data is the solution; however, traditional sensor platforms, such as satellites and airplanes, are often not well suited for these tasks because they are expensive, require significant coordination efforts, and may not be available during critical event periods. The use of unoccupied aircraft systems (UAS) can overcome some of these issues and can reduce the risk of injury or death to personnel conducting airborne monitoring (Butler et al. 2015), especially around fires, where air can become unstable and smoke can obstruct visibility. This is further exacerbated in areas with low-gradient topography, like the coastal plain of the Southeastern US, that offer limited or no vantage points in which to monitor fires. The use of UAS can provide many benefits for fire management teams including assessing habitat conditions and providing situational awareness during and after fire management activities are completed. While UAS use in fire management has been successfully incorporated into several federal and state programs and across several locations, implementation has been highly localized and the DoD is not utilizing this technology to its potential. In project-team discussions with DoD regulation departments, we identified the need for protocol development in collaboration with installation regulators to help facilitate the incorporation of UAS technology into base management, including for uses associated with wildfires and controlled burns. Working directly with DoD range control and land managers, we applied commercial UAS technology to enhance both coastal zone and fire management on DoD lands by assessing impacts from storm and long-term shoreline alterations (coastal zone), and through integrated planning, pre-burn habitat assessments, and real-time monitoring of burn and post-burn activities (fire management).

1.2 OBJECTIVE OF THE DEMONSTRATION

This project aims to implement reliable UAS in DoD fire and coastal zone management, thereby increasing the speed, ease, and safety of obtaining useful monitoring products for a fraction of the cost of manned operations. This demonstration also included the development and dissemination of training materials for the use of UAS technology, the development of a standardized UAS kit for conducting operations, and the creation of standard protocols and requirements needed to conduct UAS operations legally and safely in DoD airspace for coastal natural resource management purposes. State-of-the-art aircraft (both multirotor and fixed wing), sensors, and photogrammetric software were used for this project. Multispectral imaging was conducted using a combination of visible (Red-Green-Blue, RGB) and longwave infrared (i.e., thermal) sensors.

COAST: Working directly with range control and DoD land managers, we demonstrated the application of commercial UAS technology to enhance coastal-zone management on DoD and adjacent federal lands. This focused on assessing ongoing impacts from storms and beach use (e.g., recreational use and military training) on ocean facing shorelines of Marine Corps Base Camp Lejeune (MCBCL) and elsewhere. These impacts include erosion, increased inundation, and reduction in elevation including supratidal island area, all of which may restrict the military's use of the beach for training. Specifically, these assessments defined and monitored shoreline position, and where possible, beach sand volumes, as well as providing near real-time decision support for field personnel responsible for managing these habitats and endangered species (e.g., loggerhead sea turtle).

FIRE: Working directly with range control and DoD land managers, we applied commercial UAS technology to enhance fire management on DoD and adjacent managed lands. This included: 1) providing methods to assess habitats in regions where wildfires may occur or at locations subject to controlled burns; 2) providing increased situational awareness through the deployment of a compact, personal drone to ensure safety; 3) demonstrating cost reductions using UAS versus manned aircraft methods, and 4) improving the monitoring of the fire impact zones to provide better risk assessment, real-time information on the progression of a controlled burn, and ensure proper extinguishment and recovery. In addition, this project publicized, communicated and delivered the UAS demonstrations across DoD installations.

1.3 REGULATORY DRIVERS

Existing UAS that encompass all necessary hardware and software, technologies and applications, are not widely included in DoD land management because there are no existing or anticipated federal, state, or local regulations or DoD directives that have resulted in a mandate. Integrating UAS in DoD environmental management, however, will enhance existing activities and concerns by providing the means to monitor and assess the state of the environment, both built and natural, from an aerial perspective. Data sets generated from UAS are more accurate, extensive, and deployable and are less costly than existing methods.

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

Detailed specifications on technology and methods are provided in relevant sections of 5.0 (Test Design).

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

UASs obtain high-resolution imagery, finer than what airplanes or satellites can achieve, but are limited to mapping relatively small areas (<10 km^2) due to battery technology and/or line-of-sight regulatory restrictions. Technology and policy is constantly improving and in the future, UASs 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 UASs the ideal tool for examining landscape changes that occur rapidly, unpredictably and are difficult, hazardous and/or expensive to assess on the ground. Additionally, the amount of data we can extract from various imaging sensors is rapidly developing. Structure from Motion (SfM) techniques have revolutionized data collection, where high-resolution 2D maps and 3D models are created from overlapping imagery (Shin et al. 2018). The evolution of camera sensors, compactness, UAS extended flight capability, and integration of real-time kinematic Global Positioning System (GPS) has increased the possibilities of obtaining precise 3D measurements and landscape delineation over larger areas (square kilometers) (Hugenholtz et al. 2013). Small consumer drones are now available with both standard electro-optical (EO) 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). With higher sampling resolution and greater stability, multirotor aircraft have already been used to achieve highly precise measurements and digital surface models (DSM) in coastal environments (Mancini et al. 2013). With new iterations of sensors, aircraft, and software, it is important to assess improvements to accuracy and precision. UASs have been used for environmental monitoring since the early 2000s (Klemas 2015). The US Geological Survey started the National Unmanned Aircraft Systems Project in 2008 to help incorporate UAS in Department of Interior (DOI) operations, but this is still in development and refinement currently run by DOI Aviation Management Directorate.

This project centered around two demonstrations as they relate to incorporating UAS into DoD environmental management. The first demonstration addressed monitoring barrier island morphological change and utilization as sea turtle nesting grounds (Figure 2.1), and the second demonstration addressed forest management, specifically prescribed burning (Figure 2.2). We applied UAS technology to barrier island management and demonstrated that high-resolution optical aerial images provide data necessary for monitoring seasonal shoreline change in amphibious training zones, assessing before and after storm impacts of DoD property along with recovery from disturbance such as training exercises, and monitoring sea turtle nesting in areas with UXO. Forest management also benefits from including UAS technology in activities and we demonstrated the use of infrared sensors at identifying “hot spots” that remained smoldering after the burn event and real-time progression of the fire line. We also demonstrated the use of optical sensors for mapping pre- and post-burn vegetation cover, and situational awareness as it pertains to forestry personnel and the

progression of the prescribed burn event. Finally, we addressed the cost savings and increased safety associated with using UAS in DoD land management as compared with traditional methods.

Figure 2.1. Flow Diagram Illustrating the Demonstration of UAS for Coastal Applications.

Figure 2.2. Flow Diagram Illustrating the Demonstration of UAS for Forest Management.

2.2 TECHNOLOGY/METHODOLOGY DEVELOPMENT

The Marine Robotics and Remote Sensing (MaRRS) Lab (PI Johnston and Co-PI Ridge) at Duke University Marine Lab (DUML) has been operating since 2015. It is the only marine conservation facility with a focus on UASs, and is funded by the National Science Foundation, amongst other agencies. Attollo LLC (Co-PI's Putney and Walton) have been operating since 2016 with extensive DoD experience in military aviation, range regulation development, and unoccupied aircraft systems integration. We employed the general TED methodology for this project - Train, Equip, and Demonstrate. A two-week training class was developed to teach DoD environmental management personnel how to safely pilot, recover, and collect data with the eBee X (fixed wing) and Anafi Thermal (quadcopter), process data into usable products with Pix4D mapper, and plan UAS missions to solve pressing environmental problems. The training and protocol development methodology was an integration between MaRRS Lab applied sciences with DoD flight training standards, practices and requirements. After an initial test-run of the training class with students from Duke Marine Lab, the University of North Carolina at Chapel Hill, and MCBCL, the syllabus was modified, and the revised class was taught at MCBCL. A UAS kit was given to the Environmental Management Division (EMD), containing all of the equipment necessary for data collection and processing. This equipped the class with all necessary materials to form the foundation of a drone mapping program. At the end of the class we spent two years demonstrating to MCBCL the use of UAS for environmental management in a variety of ways including: 1) having base personnel participate in every drone mission we conducted on DoD property, 2) hosting a workshop for forest management personnel at DUML aimed at optimizing the application of UAS for prescribed burns, 3) conducting two formal demonstrations at the base focusing on applications of UAS for coastal and fire management, 4) developing and distributing two white papers that outlines how to collect, process and interpret UAS data for coastal monitoring and managing prescribed burns (see Appendix B and C), and 5) conducting a one-day refresh course at the end of the project to provide an opportunity for UAS users to ask questions after they ran missions independently.

Demonstrating the application of UAS for coastal monitoring and fire management to DoD personnel required us to develop proof-of-concept data sets. To show that drone data is more cost effective and is as accurate (in most cases, more accurate) than traditional beach-mapping methods, we directly compared beach sand volume derived from optical images, to GPS surveys, terrestrial laser scanning, and airborne Light Detection And Ranging (LiDAR). Pre- and post-storm monitoring is particularly important for beach management but difficult to conduct with traditional methods that require weeks to deploy; however, we mapped changes in beach morphology that occurred over a three-day period from Hurricane Dorian that impacted the site on day two. Seasonal monitoring at Onslow Beach, MCBCL, was also demonstrated and we used those monitoring trips to supplement the training of base personnel by having them participate as visual observers and field assistants. Enumerating sea turtle nests and false crawls requires identifying their tracks as they traverse the beach to nest in supratidal backshore areas. This is difficult and expensive in areas of Onslow Beach and adjacent Browns Island because of UXO and we showed 100% turtle track identification from imagery obtained using the eBee X.

Proof of concept data for demonstrating the application of UAS for prescribed burns built on that initial workshop with MCBCL forestry personnel. During that workshop we identified pre-and post-burn mapping, situational awareness, fire-line progression, and post-burn identification of hot spots as demonstration targets. Data sets addressing those four demonstration targets were

obtained in coordination with The Nature Conservancy (TNC) in southwestern North Carolina (NC) and North Central Florida (FL) from southern pine forests, identical to the forest landscapes managed at MCBCL. We used those data to develop the instructional white paper (Appendix C) and a formal presentation given to MCBCL personnel during the demonstration event, held at an outdoor location adjacent to a recently burned forest.

2.3 ADVANTAGES & LIMITATIONS OF THE TECHNOLOGY/METHODOLOGY

Beach erosion is currently assessed by mapping the shoreline, defined as the wet-dry line from aerial photography, or the mean high-water line using surveying techniques like real-time kinematic global positioning, terrestrial laser scanning, or airborne LiDAR. Changes in the position of the shoreline are assumed to approximate volume change, with displacement landward and seaward indicating erosion and accretion, respectively. Airborne photographic methods work best over decadal time scales because they assume a constant cross-shore beach morphology and ground-based surveying is precise at the point scale but can lead to large errors when data is scaled up and extrapolated along the shoreline (100-m scale; Theuerkauf and Rodriguez, 2012; Theuerkauf and Rodriguez, 2014). Airborne LiDAR data provides detailed topographic maps at a resolution of ~20 cm and is currently the most accurate method for examining changes in the volume of sand and spatial distribution of beach environments (intertidal zone, dunes, etc.). Airborne LiDAR data is expensive to collect and process and requires time-consuming planning and coordination. Evaluating impacts from coastal storms require real-time and/or rapid assessment, which is difficult to achieve on the ground due to safety concerns with access (e.g., washed-out roads, downed power lines, and flooding) and the large spatial scale of impact areas and is difficult to achieve using airplanes due to funding constraints and time-consuming logistical complications. Similarly, inventories of turtle nesting are conducted twice/week during nesting season by foot and/or vehicle in accessible areas and by manned aircraft over impact areas (locations with unexploded ordnance).

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 designed for on-demand utilization because they require a high-level of funding, coordination, and specialized training. Furthermore, use of UAS would reduce the risk of injury or death to personnel conducting airborne monitoring (Butler et al. 2015). The use of UAS provides a mobile watch tower, allowing for daily monitoring and near real-time support of field personnel charged with assessing the viability of the beach for amphibious training, and vastly increasing the speed and decreasing the cost to oversee impact areas. The main limitation of UAS for monitoring beach morphology is the smaller spatial area they can map, as compared to traditional planes, but differences in spatial areas will likely converge as battery technology improves.

Fire monitoring by UAS has been demonstrated by several groups since the mid-2000s (Ambrosia et al. 2003, Casbeer et al. 2005, Merino et al. 2012, and reviews in Ollero et al. 2006 and Ambrosia and Zajkowski 2015), where the combination of imaging sensors and automated software processing can quickly map and report fire intensity and movement. Over the past decade, the National Air and Space Agency (NASA) has been working with the US Forest Service to integrate UAS in fire management with the Wildfire Research and Application Partnership (Hinkley and Zajkowski 2011, Ambrosia and Zajkowski 2015); however, implementation has

not been widespread, and access to these resources has only begun to trickle into various branches of federal land management. Similarly, the US Geological Survey started the National Unmanned Aircraft Systems Project in 2008 to help incorporate UAS in DOI operations, but this is still in development and refinement currently run by DOI Aviation Management Directorate. Recent cost analysis considering UAS functionality have indicated that small area fire management could highly benefit from small UAS operations (Ambrosia and Zajkowski 2015). For example, Christensen (2015) estimated that using drones in wildfire management could provide a 31% cost savings for fire-suppression activities compared to traditional helicopter-only approaches. Fuel conditions are an important factor for managing controlled burns and understanding and predicting the behavior of wildfires. Drones are now used to estimate fuel conditions through multispectral methods and 3D modeling using SfM techniques (Shin et al. 2018). Drone-derived 3D models have achieved accuracies on par with other methods for measuring the 3D environment, including LiDAR (Seymour et al. 2018). This approach requires less time spent on the ground doing in-situ assessments and provides an archive of the ecological context useful for future assessments of these areas. Small consumer drones equipped with standard EO and thermal IR sensors can be easily applied to assess extent of burn, detect lingering hotspots, and provide significant advantages for personal situational awareness. Despite the advantages provided by UAS for fire management, there are some drawbacks that can, for the most part, be categorized into three different aspects: regulatory lag, the immaturity of the technology, and the scalability of applications. 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. As with any rapidly developing technology, there are issues associated with maturity. In the case of UAS, basic long-term information on reliability and efficiency are lacking. Small consumer-grade UAS are subject to reliability issues and are constrained by low-performance battery technology. These issues are partially offset by the low cost of acquiring the technology, and they remain extremely attractive for natural resource managers that have small budgets or are seeking to reduce risk to personnel and the environment. Finally, both regulatory lag and technology maturity contribute to scalability of deployment for UAS. Line-of-sight regulatory restrictions and immaturity of fuel systems reduce the spatial and temporal scales over which UAS can be used effectively. Fortunately, in the case of most fire management programs, scalability is not a major issue.

3.0 PERFORMANCE OBJECTIVES

This project covered two distinct demonstrations, a coastal application and a fire application. In an effort to make the results as clear and easily understood as possible, we have addressed sections 3 – 6 in two distinct sections, the first covering the coastal component, the second covering the fire component.

3.1 PERFORMANCE OBJECTIVES (COAST)

Table 3.1. Coastal Performance Objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
1. Demonstrate improved efficiency, accuracy, resolution and cost of coastal mapping using an UAS versus ground-based and manned-aircraft methods.	The efficiency of mapping measured in area per unit time (m^2 mapped/hour). Cost of mapping measured in currency per unit area (US$ /m^2 mapped). Mapping accuracy measured as the root-mean-squared horizontal and vertical positioning error. Image resolution measured in cm/pixel.	Simultaneous mapping of beach topography using GPS transects, terrestrial lidar and UAS aircraft. Orthomosaics of Onslow Beach obtained from manned and UAS aircraft. Manned aircraft obtained information will be gathered from other efforts by Camp Lejeune, NOAA, USGS, and/or the State.	Achieve at least 25% increase in UAS mapping efficiency and cost over ground-based methods of mapping beach topography. Achieve comparable or better UAS accuracy and resolution over traditional manned aircraft (for comparison of orthomosaics) and ground-based methods (for comparison of topographic maps).	Achieved > 25% increase in mapping efficiency and cost.
2. Demonstrate application of UAS for quantifying island impacts from seasonal or event-driven (storms, training) forcing, such as increased waves, wind, and water level.	Ecotone displacement (m). Beach environment elevation (m) and area (m^2) changes.	Pre/Post event survey flights. Seasonal surveys. Base utilization of coastal area.	Identify and measure impacts to coastal zone from events and communicate results to Camp Lejeune personnel.	Collected pre and post Hurricane Dorian beach surveys, monitored Onslow Beach, and communicated results.
3. Demonstrate application of UAS for monitoring species of special interest in areas with UXO.	UAS-measured number and location (UTM coordinate along the beach) of turtle crawls above high tide elevation (TUAS) as compared with the same metric from ground-based assessments (TGBA; % detection= (TUAS/TGBA)*100.	Ground-based assessment of turtle crawls in a non UXO area at the same time imagery of sea turtle crawls from UAS flights are acquired.	100% detection of turtle crawls above high tide.	Achieved 100% detection of turtle crawls above high tide.

1. *Demonstrate improved efficiency, accuracy, resolution and cost of coastal mapping using an UAS versus ground-based and manned-aircraft methods.*

   - Relevance: One of the major goals for this project was to provide military installation environmental managers a method to rapidly map the coastal environment. Currently, MCBCL land managers use satellite and manned aerial imagery/lidar data sets collected infrequently (once a year to once every five years) to monitor Onslow Beach. We demonstrated that a commercial UAS, the senseFly eBee X, can obtain high-resolution, georeferenced baseline data across the island for seasonal and annual evaluations. This is critical for specialized training areas, such as amphibious training zones, which are reliant upon the dynamic coastal setting. The ability to rapidly map the coastal environment allows installation land managers to more easily assess beach access, elevation, resistance to inundation, and recovery from storms, increases in water level, and vehicle use.
   - Metric Description: The metrics we derived included 1. efficiency of mapping (m^2 mapped/ hour), 2. cost of mapping (US$ /m^2 mapped), 3. mapping accuracy (root-mean-squared horizontal and vertical positioning error), and 4. resolution (cm/pixel). We compared metrics among four methods, including: 1. the eBee X, a fixed-wing unoccupied aircraft with high-resolution sensors (both senseFly's S.O.D.A. 3D and AeriaX), 2. a Riegl LMSZ210ii terrestrial laser scanner, 3. a Trimble R8s survey-grade GPS receiver for collecting beach profiles, and 4. public USGS aerial photos collected from a manned aircraft. Costs included personnel and resources necessary for mission planning, implementation, and data-processing.
   - Data Required: To meet the objective, we obtained data using the four methods outlined above from a common area on Onslow Beach, MCBCL. Data included: 1. georeferenced UAS imagery to create detailed orthomosaics and digital elevation models using the Pix4D software, 2. georeferenced digital elevation models based on data collected with the terrestrial laser scanner, 3. beach profiles collected using the GPS receiver, 4. aerial photos from a manned aircraft, and 5. the time and cost necessary to create maps from UAS imagery, terrestrial laser scanning, beach surveying, and aerial photos from a manned aircraft platform. Additionally, the accuracy of each method was tested using horizontal and vertical checkpoints.
   - Success Criteria: We considered the objective met if using UAS reduced the time and cost to survey an area by at least 25% while still achieving sub-decimeter vertical accuracy, on par with traditional benchmark methods.

2. *Demonstrate application of UAS for quantifying island impacts from seasonal or event-driven (storms, training) forcing, such as increased waves, wind, and water level.*

   - Relevance: A major reason for developing faster, cheaper, more reliable, and more accessible methods for coastal monitoring is to give land managers control to decide when changes to the coastal landscape need to be measured. Rapid assessment will minimize loss of training time and will optimize the quality of amphibious exercises and recreational activities on the barrier island. Effective management of this valuable dynamic landscape requires monitoring erosion, accretion and displacement of environments, which displays large spatial variability in the direction and magnitude of change. Monitoring Onslow Beach at a fine temporal scale will allow land managers to pinpoint and potentially respond to areas experiencing the most deleterious changes, such as erosional hotspots.

- Metric Description: The metrics, shoreline displacement (m), beach environment elevation (m) and beach environment area (m^2) were derived from maps obtained before and after Hurricane Dorian on Bird Island, a surrogate for Onslow Beach. In addition, seasonal mapping missions of Onslow Beach were used to track metrics across longer time scales. The metrics were derived from successive maps, compared using a Geographic Information System (GIS).
- Data Required: UAS imagery was gathered across Bird Island pre- and post-Hurricane Dorian and Onslow Beach seasonally. These images were processed to provide digital elevation models, extract the shoreline position (mean high water), and beach area defined here as extending from mean sea level to the dune toe using GIS.
- Success Criteria: We considered the objective met if the project team provided the Environmental Management Division and Range Management with geo-rectified maps and surface models of Onslow Beach seasonally and demonstrated to those end users that pre/post event data can be collected by individuals whose personal and work lives are affected by the storm, similar to most base personnel who would be collecting these data at Onslow Beach.

3. *Demonstrate application of UAS for monitoring species of special interest in areas with UXO.*

- Relevance: The north side of Onslow Beach is considered a buffer zone near an active firing area, where there is potential for UXO. Turtle-nest monitoring within this zone is limited to manned aerial surveys twice per week during nesting season. This provides a unique opportunity to demonstrate the use of UAS for remote monitoring of species of special interest in hard to reach or dangerous areas.
- Metric Description: The metric is percent detection of sea-turtle tracks. We also imaged sea-turtle tracks over a 2-day period to assess detection limitations as wind displaces sand and removes evidence of nesting over time defined as percent detection of sea-turtle tracks post 5 days.
- Data Required: The eBee X fixed-wing UAS was used to collect RGB images over the Bird Island surrogate site to identify turtle tracks. Simulated turtle tracks were created and geolocated by one research group and identified using UAS-based imagery by a second research group. Counts based on the UAS imagery were compared to the number and location of tracks created on the island.
- Success Criteria: Objective was met if turtle-track counts from drone imagery matched the on-the-ground measures of sea-turtle activity.

3.2 PERFORMANCE OBJECTIVES (FIRE)

Table 3.2. Fire Performance Objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
1. Demonstrate efficiency in measuring % area burned of target stand and crown scorch using a UAS versus ground-based methods	The efficiency of assessment measured in area per unit time (acres/hour)	Time required for ground-based assessment of a given area Time required for UAS assessment of a given area	Achieve at least 50% increase in UAS assessment efficiency compared to ground-based method	Success criteria modified. See findings in section 6.0.
2. Demonstrate accurate ID of fire hotspots (flaming and/or smoldering) using UAS in longleaf pine forest.	Positive identification of fire hotspot using UAS, validated through ground sampling	IR imaging capabilities on UAS Ground-based geolocation and verification	Achieve >95% correct ID of fire hotspot locations identified as compared to ground-based methods.	Success criteria modified. See findings in section 6.0.
3. Demonstrate cost reductions using UAS versus manned aircraft methods	Cost of effort per time ($/hr)	Cost required to contract manned aircraft for burn monitoring and costs associated with operating a drone for same area	Achieve at least 50% decrease in price from manned aircraft	Significant cost reduction by using drones, but see conditional comments in section 6.2.3.
Qualitative Performance Objectives				
4. Demonstrate ease of use of UAS during prescribed fires	Ability of a firefighter to use UAS technology in addition to their mandated tasks associated with the prescribed fire	Feedback from firefighter on the usability of the UAS technology and time required to use, collected via a combination of post-operation interviews and online surveys.	A single firefighter who effectively used a drone to get a bearing to a rally point and navigated UAS to that point	Demonstrated ease of use
5. Demonstrate improvement in situational awareness with UAS use	Quality of assessing personnel situational awareness with a small UAS versus traditional methods, including assessment of fire progression and firefighter location relative to the burn line	Feedback from firefighters about personnel situational awareness* with aerial feed vs. ground visuals Live visual feed during IR imaging	Responses that indicate positive feedback of UAS use as compared to ground-based methods.	Documented improved situational awareness

**Situational awareness aspects include location of fire personnel, ground crew, heavy equip. operators; location of flaming front; fire escape/ fire line containment.*

One of the major goals for this project is to provide military installation managers a better method to monitor and improve their fire management activities before, during, and after prescribed fires. The DoD manages vast acreage with prescribed fire as well as managing for wildfires (both natural and from training events). Prescribed fire management can be critical to an installation's management of ecosystems - oftentimes in support of a regulatory driver to manage for a federally listed, Threatened and Endangered Species (T&E), like the red-cockaded woodpecker (RCW) at MCBCL. Equally important is that prescribed fire supports military training by providing open forest lands for maneuvers and supports the use of munitions that tend to be incendiary; controlling the fuels and above ground biomass allows for incendiary training with less risk of wildfire and supports realistic training. For natural resource managers charged with managing fires, UAS provide the advantage of both real-time, situational awareness to monitor fire infrastructure (e.g., fire lines, escape routes, flaming front) and fire crews, as well as post-fire surveillance for hot spots and excessive smolder, and finally of mapping post- fire effectiveness, severity, and recovery.

1. *Demonstrate efficiency in measuring percent area burned of target stand and crown scorch using a UAS versus ground-based methods.*

    - Relevance: The ability to accurately measure area burned and severity allows managers to evaluate the effectiveness of their prescribed burns in meeting their land management objectives. Important fire planning techniques, like ignition patterns, fuel loading, and fuel moisture assessments, used for decision making in burning can be evaluated in the context of percent area burned. Detecting crown scorch is a measure of severity and can be telling of future tree decline and/or infestations, like from the southern pine beetle. All of these metrics and measures communicate to managers both how much acreage burned, the completeness of those burns, and the severity.
    - Metric Description: The metrics are efficiency of mapping (m^2 mapped/hour) and data resolution (cm/pixel) generated from flights using fixed wing and multirotor unoccupied aircraft with high-resolution sensors (RGB and thermal) and on-the-ground observers. The effort expended by MCBCL fire managers to map percent area burned was communicated during team interactions.
    - Data Required: To meet the objective, we compared time required for current methods employed by MCBCL fire managers and additional ground-based assessments of a given area to time required for a UAS assessment of the same area.
    - Success Criteria: We considered the objective met if we could achieve at least a 50% increase in efficiency of UAS as compared to the ground-based method, including aircraft staging time and labor required for each method.

2. *Demonstrate accurate identification of fire hotspots (flaming and/or smoldering) using UAS in longleaf pine forest.*

    - Relevance: At the end of the active phase of a prescribed burn, it is common to have larger fuels that continue to smolder and need to be evaluated, and depending on location, extinguished. Ensuring the site of a prescribed fire is contained post-fire prevents potential re-ignition which can create dangerous wildfire conditions. Locating hot spots is typically accomplished by hiking through a stand and looking for smoke, but UAS may provide both a safer and faster resource for locating persistent fire areas and access areas too challenging on foot, but accuracy needs to be compared against traditional methods.

- Metric Description: This metric was the positive identification of fire hotspots using UAS, validated through ground sampling.
- Data Required: To meet the objective, we obtained thermal imaging data using IR imaging capabilities on a UAS and ground-based geolocation and verification.
- Success Criteria: We considered the objective met if we could achieve a >95% correct identification of fire hotspot locations via imagery as compared to ground-based methods.

3. Demonstrate cost reductions using UAS versus manned aircraft methods.

- Relevance: Accessibility to a more comprehensive view of a fire from the air, particularly when line of sight from the ground is obscured, can lead to better and safer decision making. The use of occupied aircraft for fire monitoring and burn management can not only be risky but also costly when fire managers have to contract pilots and aircraft for extended periods of time due to unreliable burn windows depending on weather. Depending on scale of the fire, UAS offer a usable and on-site tool for a host of real-time decision making.
- Metric Description: This metric is cost of effort per time ($/hr) for real-time monitoring.
- Data Required: To meet the objective, we obtained cost data required to contract manned aircraft for burn monitoring and compared drone operation cost for the same area. Costs of contracting a manned operation included aircraft, personnel, and fuel over multiple burn seasons. Costs of UAS involved purchasing an aircraft, sensors and accessories, training, and personnel time to operate the UAS through multiple burn seasons.
- Success Criteria: We considered the objective met if cost comparisons resulted in at least 50% decrease in price from manned aircraft to drone operation.

4. Demonstrate ease of use of UAS during prescribed fires.

- Relevance: UAS have a lower barrier to entry than integrating traditional platforms for small fires or traditionally unaffordable aerial support scenarios. Small UAS can be deployed quickly, in a matter of minutes, and offer a vantage point that takes in a much greater view than eyes on the ground. After a short training period, fire managers should be confident in their ability to use UAS during active prescribed fires for a variety of uses such as checking fire lines and escape routes, assessing the flaming front and the progress of the fire, and locating crew members.
- Metric Description: This metric captured the ability of a firefighter to use UAS technology in addition to their mandated tasks associated with prescribed fire. Interactions with MCBCL fire managers communicated ease of use.
- Data Required: To meet the objective, we obtained qualitative data from firefighters on the usability of the UAS technology and time required to use, collected via a combination of post-operation interviews and online surveys.
- Success Criteria: We considered the objective met if a single firefighter could effectively use a drone to get a bearing to a rally point and navigate the UAS to that point.

5. Demonstrate improvement in situational awareness with UAS use

- Relevance: While objective 4 focuses on ease of use, it is linked to objective 5 which demonstrates that employing UAS during fires improves the situational awareness of fire managers and their crews. During a burn, observations of personnel activity and burn progression are normally conducted from the perimeter or, when available, from an occupied aircraft. Perimeter monitoring provides a limited view of how a stand is burning. UAS can provide a mobile watchtower for gaining situational awareness with relative ease during the course of a burn.
- Metric Description: This metric captured the quality of assessing personnel situational awareness using a UAS versus traditional methods, including assessment of fire progression and firefighter location relative to the burn line. The impression of MCBCL fire managers for improved situational awareness was communicated during interactions.
- Data Required: To meet the objective, we obtained qualitative data in the form of feedback from firefighters about personnel situation awareness with aerial feed versus ground visuals.
- Success Criteria: We considered the objective met if responses indicated improved situational awareness using UAS compared to ground-based methods.

4.0 SITE DESCRIPTION

4.1 SITE DESCRIPTION (COAST)

4.1.1 SITE LOCATION AND HISTORY

The objectives related to coastal issues were conducted along Onslow Beach and Bird Island, two barrier islands in North Carolina (Figure 4.1). The island of Onslow Beach has four main use areas from the southwest to the northeast, including a zone used mainly for off-road recreation vehicles (access to fishing spots near the New River Inlet when training is not taking place), a zone used for military training (hovercraft, large-wheel vehicles and track vehicles), a recreational zone, and a buffer zone ("no-go-zone") between the northeastern end of Onslow Beach and ordinance testing on Brown's Island (Figure 4.2). There used to be an access road (unpaved) behind the dune line and egress points connecting this road to the beach but over the past two years the shoreline moved to a position landward of that road. Onslow Beach was used to demonstrate Performance Objectives 1 (methods comparison) and 2 (seasonal monitoring).

Bird Island, is located in Back Sound, NC across from the Beaufort Inlet (Figure 4.3). It is an anthropogenically-modified inlet barrier island and is part of the Rachel Carson National Estuarine Research Reserve. Bird Island was a salt marsh and tidal flat in the late 19th century but was converted into an island during the 20th century by the disposal of dredge spoil along its western end (Evans, 1988; Seymour et al., 2019). The addition of sand to the west end promoted the formation of dunes along the central and eastern portions of the island as spoil material was transported by tidal currents and wind. No spoil disposal has occurred over the last two decades. This site was used to demonstrate Coast Performance Objectives 2 (storm assessment) and 3 (species monitoring).

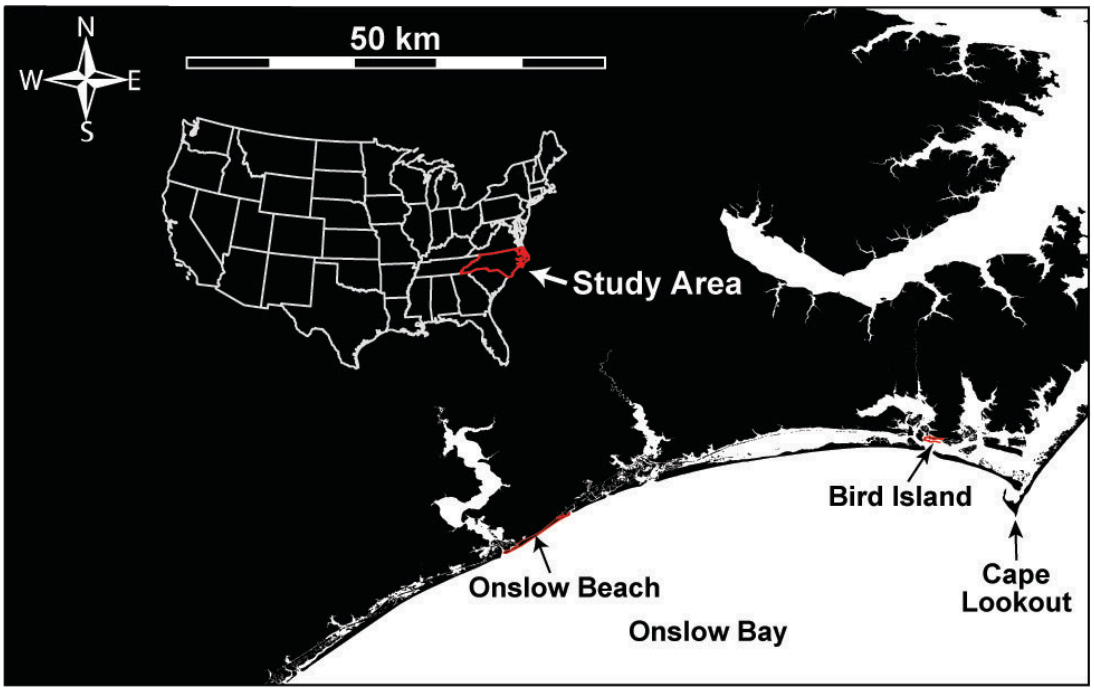


Figure 4.1. Study Area Map of Central Eastern North Carolina Highlighting Bird Island and Onslow Beach Where Coastal Objectives 1-3 Were Addressed.

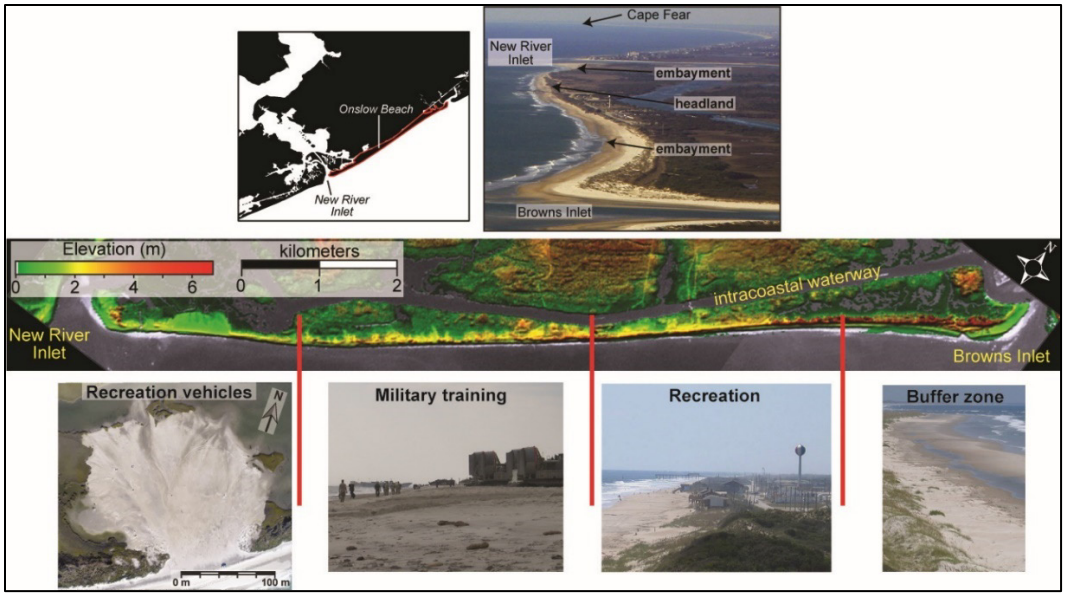


Figure 4.2. Onslow Beach Is a Barrier Island on Marine Corps Base Camp Lejeune Positioned Between Browns Inlet to the Northeast and the New River Inlet to the Southwest.

The shoreline has variable along-shore orientations with small embayments and headlands, dune elevations that are generally low in the southwest and high in the northeast, and used in different ways by Marine Corps personnel.

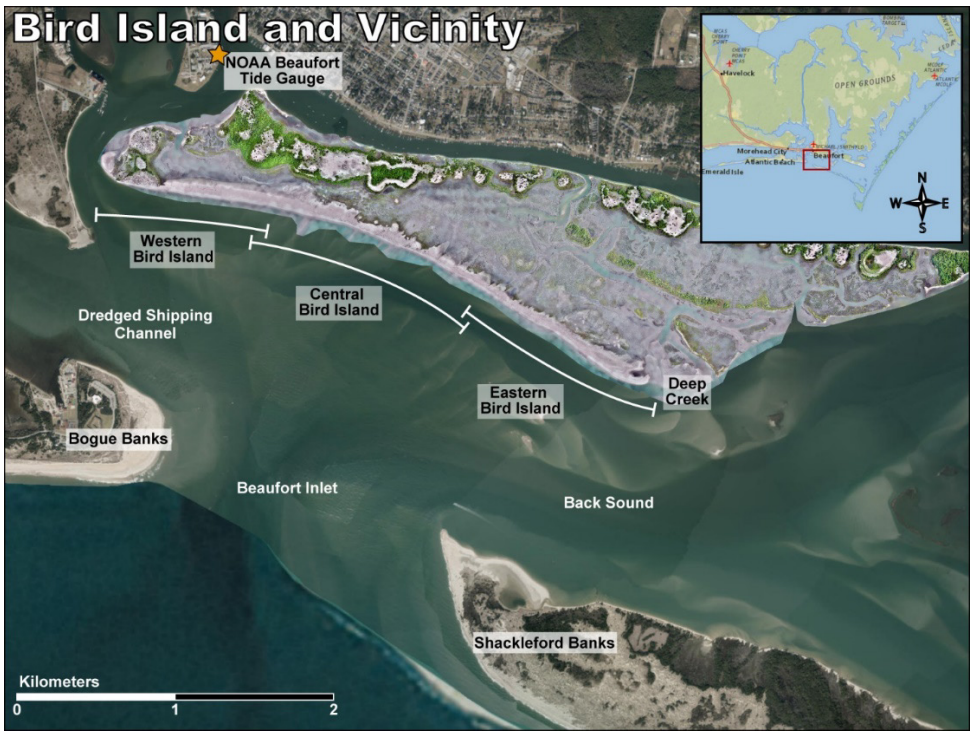


Figure 4.3. Map of Bird Island.

Bird Island is a fetch limited barrier island located behind Beaufort Tidal Inlet and is part of the Rachel Carson National Estuarine Research Reserve.

4.1.2 SITE CHARACTERISTICS

Onslow Beach is a northeast-southwest trending barrier island that is 12 km long, 90-600 m wide, and is bordered by Browns Inlet to the northeast and the New River Inlet to the southwest (Figure 4.2). It is a wave-dominated barrier with a mean wave height of 0.91 m and tidal range of 1.2 m based on National Oceanic and Atmospheric Administration's (NOAA's) tide gauge at Wrightsville Beach, NC (Station ID 8658163, located 60 km southwest of Onslow Beach). The shoreline of Onslow Beach is sinusoidal with a central headland separating two embayments. The morphology of the island also varies along its length. The northern arcuate section has a wide beach (approximately 80-m wide) with multiple well-developed dune ridges (7–9 m in height). Landward of the dune ridges a narrow (less than 100–m wide) maritime forest abuts the backbarrier saltmarsh. This northern section of the barrier has low net decadal rates of accretion of approximately 0.25 m/yr (Figure 4.4). The central headland area has a narrow beach (approximately 20-m wide) with a single discontinuous dune ridge less than 4 m in height that is currently being re-formed by bulldozers after Hurricane Florence (2018) removed the dunes. The beach widens significantly along the southern embayment from 20 m in the northeast to 80 m in the southwest. The discontinuous dunes are less than 2 m in height and washover fans can be extensive (>250-m wide) and extend across backbarrier marshes. This southern part of Onslow Beach has a net erosion rate of approximately 2 m/yr and erosion rates decrease toward the headland where shoreline position is highly variable through time. The variable morphology of Onslow Beach reflects its central location within Onslow Bay because it defines the border between the high-elevation regressive islands with multiple beach ridges to the north and the low-elevation, narrow transgressive islands to the south. The central headland is produced by a submarine rock ridge that intersects Onslow Beach. The rock ridge is composed of the Oligocene Silverdale Formation, a sandy, molluscan-mold limestone unit. The Quaternary sediment layer is thin and patchy offshore of southern and central Onslow Beach, where more than 50% of the inner shelf is exposed limestone.

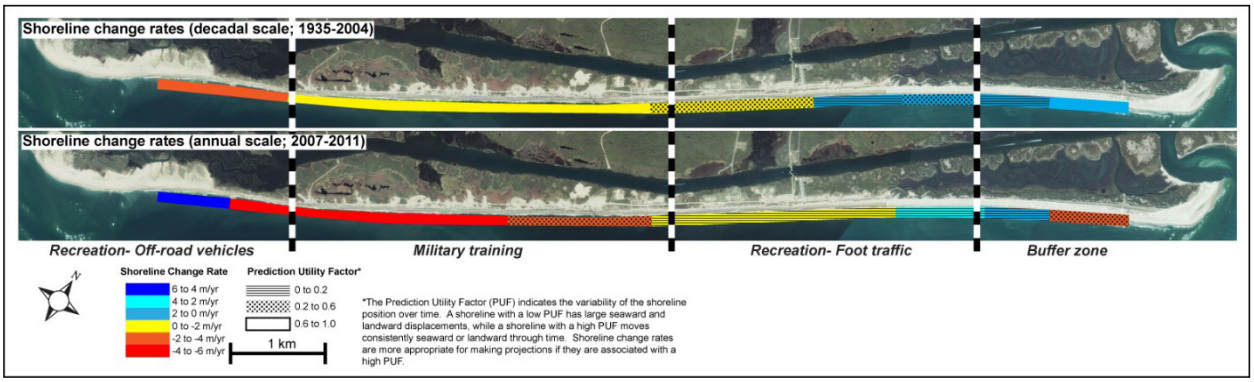


Figure 4.4. Shoreline movement along Onslow Beach. Decadal (top) and annual (bottom) rates of shoreline movement along the various zones on Onslow Beach.

The washover fans in the central and southern parts of Onslow Beach indicate storms are an important driver of geomorphologic change on the island. Hurricane Irene (Category 1, maximum sustained wind speeds 119-153 km/h) caused significant overwash at Onslow Beach. That storm made landfall in August 2011 at Cape Lookout, NC, 70 km northeast of the study area and formed washover terraces and fans along the southern and central parts of Onslow Beach.

Recently, Hurricane Florence (September 2018 Category 1), destroyed most of the infrastructure on the island and has made driving south of the training zone impossible.

Bird Island is a 4-km long fetch limited barrier island, bounded by dredged and tidal channels on the west and east ends, respectively, and experiences a 0.95 m mean tidal range. The width of Beaufort inlet, which varies through time and is currently at its historical maximum of ~2 km, the refracted ocean waves that travel through the inlet, and storms are the main drivers of morphologic change (Seymour et al., 2019). The island has three distinct components based on morphology, including, 1. A western end, consisting of a short spit, a continuous vegetated dune escarpment composed mainly of dredge spoil, and a beach with a narrow foreshore, 2. A central component that consists of a dune ridge, a washover terrace, washover fans that extend landward into a tidal flat with salt marsh, and 3. An eastern end consisting of discontinuous low lying dune fields and an elongated spit extending into a salt marsh and tidal creek (Figure 4.3).

4.2 SITE DESCRIPTION (FIRE)

To achieve the fire demonstration goals, the team took advantage of a variety of prescribed fire opportunities with various agencies and organizations to include MCBCL, Croatan National Forest (CNF), TNC, and Tall Timbers Research Station (TTRS). Numerous federal, state, and private entities manage forests with prescribed fire in the lands surrounding MCBCL. MCBCL has approximately 160,000 acres of land with a majority being managed forests and shrublands/ grasslands within and around training zones. As with much of the Southeast Atlantic Coastal Plain, the forested lands are longleaf and loblolly pine habitats that are home to a number of organisms, including the T&E Red-cockaded Woodpecker. Neighbors with large land holdings that also use prescribed fire to manage forests are the CNF and TNC. CNF comprises 160,000 acres across Carteret, Craven, and Jones counties, in eastern North Carolina, and TNC manages several parcels of land with prescribed fire within the region, including the 13,000-acre Green Swamp Preserve. While not in the Atlantic Coastal Plain, TTRS in Tallahassee, FL has similar forest types and fuels to those at MCBCL and utilizes prescribed fires in similar ways. To increase opportunities to refine our drone integration workflow into local burn operations, initial tests were planned for small parcels of land that fire managers do not normally hire helicopter operations to monitor because of prohibitive costs or to ignite the fire (aerial ignition). This was meant to reduce complexity in coordinating the immediate airspace, allowing us greater flexibility. These operations were planned in direct coordination with and participation from on-ground fire management personnel. For the demonstration at a broader scale, we demonstrated our refined workflow (from initial missions) integration into burn activities over larger land assets and in conjunction with manned aerial operations.

4.2.1 SITE LOCATION AND HISTORY

Sites were within the Southeast Atlantic Coastal Plain and Gulf Coast, including NC and FL (Figure 4.5). The CNF is NC's only coastal National Forest, and TNC manages large tracts of land in Eastern NC, including the Green Swamp Preserve (Figure 4.6) and several parcels along the coast. TTRS, in Tallahassee FL, is also managed by a land trust (Figure 4.7).

Historically, fire has been one of the primary natural disturbances to these ecosystems and prescribed fire is an important part of today's management of the forests. TTRS is actually considered the birthplace of fire ecology, helping establish prescribed burn practices.

All of the partners that the team worked with have active prescribed burn programs and share site characteristics (plant communities, fuels, and soil/moisture) and management goals for open pine stands, the absence of a mid-story, and a diverse, herbaceous, low understory. The plant communities managed on these forest lands evolved under high frequency, low intensity fire behavior and the prescribed fire programs attempt to mimic the historic fire patterns.

Figure 4.5. Map of Southeast Atlantic Coastal Plain and Study Sites as Well as Marine Corps Base Camp Lejeune.

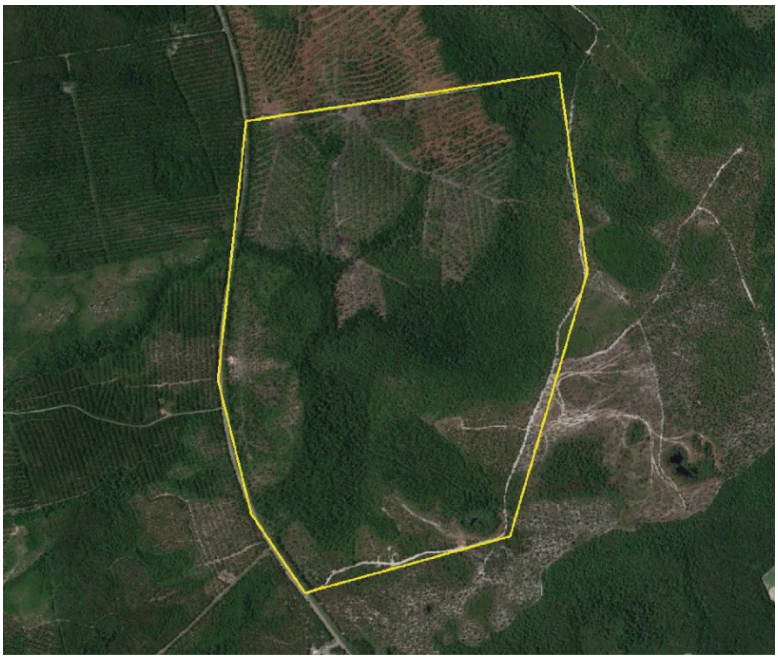


Figure 4.6. Part of the Green Swamp Preserve (TNC) Where a Prescribed Fire Was Used for This Project.

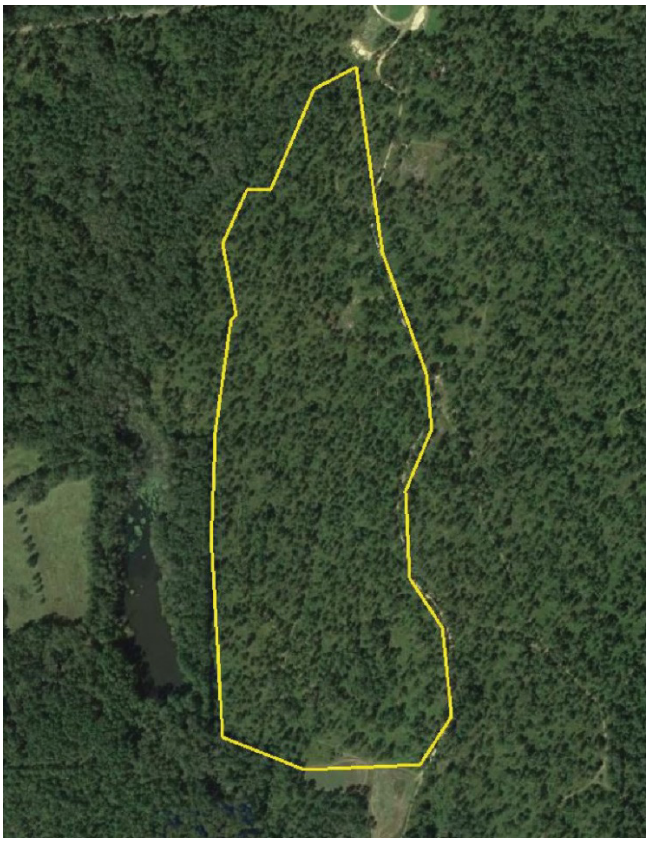


Figure 4.7. Area of Tall Timbers Research Station Where a Prescribed Fire Was Used for This Project.

4.2.2 SITE CHARACTERISTICS

MCBCL, CNF, TNC and TTRS lands consist of mixed pine savannas with open canopies and diverse understories (Figure 4.8) on a range of soil types from droughty pine sandhills to poorly-drained pine savannas and flatwoods. These more poorly drained stands are often in proximity to wetter pocosins (NC) or other wetland (FL) areas, with an intermediate ecotone that often contains both high plant diversity and numbers of endemics. In the Atlantic Coastal Plain, these areas are often home to carnivorous plants like Venus fly-traps, pitcher plants, and sundews. These are the same forest habitats present throughout much of the Southeastern Atlantic Coastal Plain. About 70 percent of these habitats are populated with loblolly and longleaf pine forests and pocosins - all managed with fire. For example, the CNF has restored approximately 15,000 acres of the original 60,000 acres of longleaf in the forest. Their goal is to burn 20,000 to 25,000 acres of forests each year and restore up to 150 acres of longleaf pine annually. Furthermore, these habitats often contain regions of peat, which can harbor smoldering fires that may be difficult to detect and can reignite fires if not accounted for.

Figure 4.8. Stills from Burn Sites at Green Swamp Preserve (Left Panel) and Tall Timbers Research Station (Right Panel).

5.0 TEST DESIGN

5.1 TEST DESIGN (COAST)

5.1.1 CONCEPTUAL TEST DESIGN

Tests to meet performance objectives 1 (methods comparison) and 2 (seasonal monitoring) were conducted at Onslow Beach, and Bird Island was used to address performance objectives 2 (storm assessment) and 3 (species monitoring; Figures 5.1 and 5.2). Limited access to Onslow Beach, forced us to include a surrogate site that is publicly accessible. Base personnel do not have the same restrictions as the research team and results from Bird Island are directly transferable to any beach along the southeast Atlantic coastline.

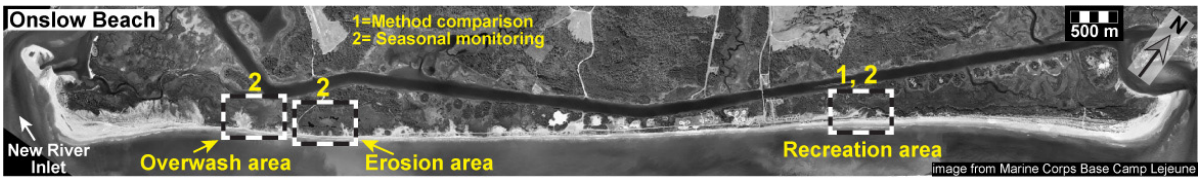


Figure 5.1. Map of Onslow Beach Showing Where Performance Objectives 1 and 2 Were Assessed.

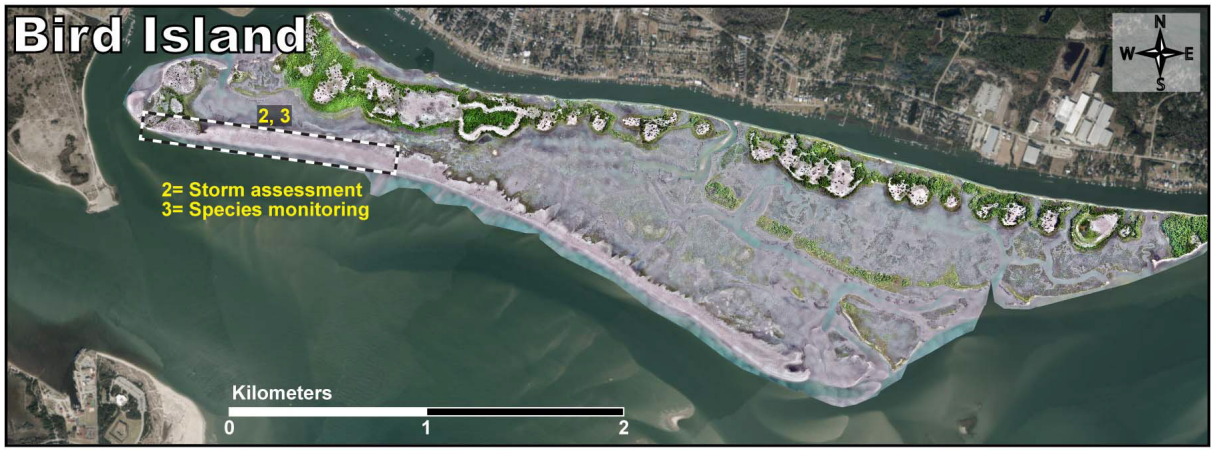


Figure 5.2. Map of Bird Island Showing Where Performance Objectives 2 and 3 Were Assessed.

5.1.1.1 OBJECTIVE 1 Survey Efficiency

We demonstrated the improved efficiency, accuracy and resolution of coastal mapping using an UAS versus ground-based and manned-aircraft methods at the northeastern end of the Onslow Beach recreation area (Figure 5.1). On May 14, 2019 we concurrently imaged the beach using a UAS, surveyed beach profiles with a GPS, and scanned beach topography with a terrestrial laser scanner during the four hours surrounding low tide. The Army Corps of Engineers in cooperation with the NOAA Office for Coastal Management collected images and LiDAR data from an airplane at the site after Hurricane Florence on October 5, 2018, and those data were obtained from https://coast.noaa.gov and included in the study. Beach volume was measured using each method and efficiency, accuracy, resolution, and cost were compared.

5.1.1.2 OBJECTIVE 2 Event monitoring

Seasonal monitoring at Onslow Beach focused on three areas including a southwestern low-elevation part of the island that is frequently overwashed (overwash area), an adjacent area to the north where the shoreline is moving landward rapidly (erosion area), and an area on the northeastern end of the island in the recreation zone where cabins and a bathhouse are positioned on the back beach (recreation area; Figure 5.1). Impacts to the geomorphology of Bird Island from Hurricane Dorian (August 2019) were constrained by collecting data immediately before and after the storm (Figure 5.2). To meet Objective 2, we used the eBee X fixed-wing UAS to collect RGB images and create highly precise 3D models. These data were analyzed to map areas of erosion and accretion and used to demonstrate the utility of UAS for preparing and responding to events.

5.1.1.3 OBJECTIVE 3 Species of special concern

Model sea turtle crawls on Bird Island were used to test the UAS/sensor/software's usefulness at detecting turtle nests in UXO areas (Figure 5.2). Using a public site and model sea turtle crawls allowed us to control for the number of turtle crawls included in the demonstration. The eBee X was used to collect RGB images immediately after model crawl marks were created and after a two-day period.

5.1.2 BASELINE CHARACTERIZATION AND PREPARATION

The coastal demonstration is generally transferable to other sandy barrier islands and preparation of the site was neither necessary nor performed prior to collecting data to address objectives 1-3. Weather conditions, however, will influence the performance of the technology. Data were collected at low tide to maximize the subaerial beach area, weather conditions were partly cloudy to clear (zero precipitation), the time of day excluded the hour before and after solar noon, and wind conditions during flights were always less than a gentle breeze (19 km hr^{-1}). We picked days when there were no people at the sites to avoid having to obtain a waiver or change the flight path of the aerial vehicle during a survey.

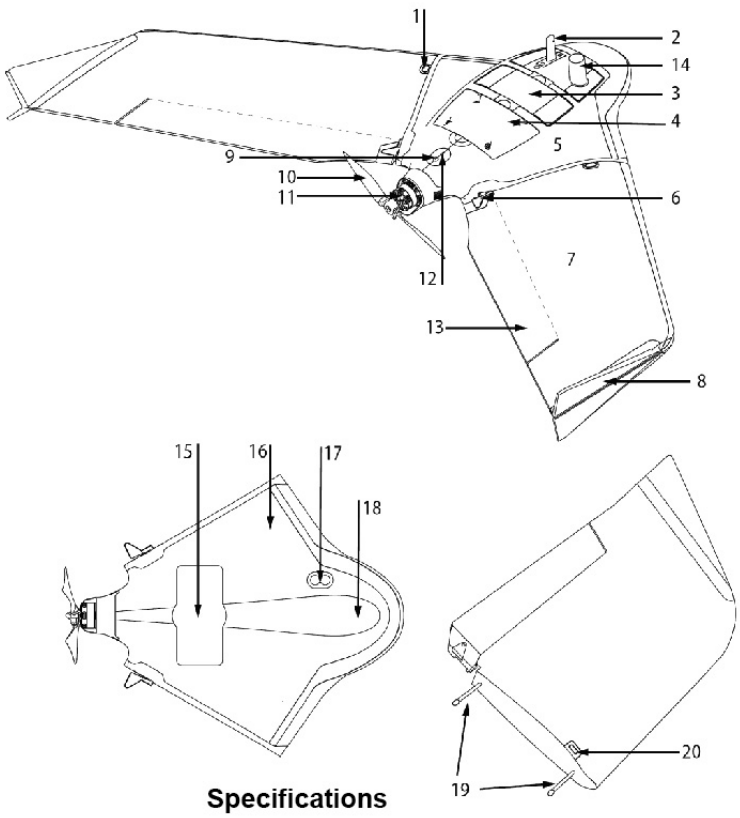
The specific locations on Onslow Beach and Bird Island that we chose for the demonstrations are based on previous monitoring aimed at measuring shoreline response to long-term processes, storms, and training (Figures 5.1 and 5.2). For objectives 1 and 2 (seasonal monitoring) we selected the northeastern recreation area and southwestern edge of the military training zone (Figure 4.2) with an adjacent active washover fan area. The shoreline at the northeastern recreation area is moving seaward (accretion) at a long-term (multi-decadal) average of <1 to 4 m/yr but shows high variability in the direction and magnitude of shoreline movement at annual and decadal time scales (Theuerkauf and Rodriguez, 2014). The southwestern military training zone has the highest long-term average shoreline retreat rate of 2–6 m per year related to the sediment supply and storage of this island compartment being low, and is highly vulnerable to overwash during storms (Rodriguez et al. 2018; Rodriguez et al., 2020). Objectives 2 (event monitoring) and 3 were tested along an area of Bird Island where the shoreline moved landward 5.6 m per year from 1984-2016 and exhibits spatial variations in erosion, accretion, and shoreline migration during and after storms over yearly time scales (Seymour et al., 2019).

5.1.3 DESIGN/LAYOUT OF TECHNOLOGY & METHODOLOGY COMPONENTS

The technology components used to address the objectives related to the coast are mobile and need to move around the demonstration areas shown on Figures 5.1 and 5.2 to capture continuous data across the sites. The project is designed around off-the-shelf equipment. Details are provided below so that tests can be repeated; however, technology in this field is constantly improving. The training we provided to environmental managers equipped them with the skills and knowledge they need to easily integrate new platforms and software into their UAS programs as the equipment we supplied them becomes outdated and needs to be replaced.

5.1.3.1 Unoccupied Aircraft System

The coastal objectives were addressed using the eBee X, a fixed-wing unoccupied aircraft with a high-resolution AeriaX, SODA, SODA 3D or Red Edge sensor (Figure 5.3; Table 5.1). For objectives 1 and 2 the UAS was flown in a double-grid pattern with inlines and cross lines perpendicular to one another. A single-grid pattern was flown to address objective 3 because only an orthomosaic, not elevation data, were needed to identify sea-turtle tracks. All flights were at an altitude of 60 m. For objectives 1 and 2, ground control points (GCP) (reference points to better geo-rectify UAS imagery) were deployed and checkpoints occupied to assess vertical error in the DSM. The eBee X is 1.5 kg, with a wingspan of 116 cm, and has a built-in survey grade Global Navigation Satellite System (GNSS). We activated the Real Time Kinematic (RTK) GNSS function or Post Processed Kinematic (PPK) GNSS data to bring the absolute positioning accuracy down to 1.5 cm (x, y, and z; both methods provide identical results). Flight planning and mission control was coordinated using the supplied eMotion 3 software package and data were post processed using Pix4Dmapper version 4.6.4.



Hardware	Specifications
1. Wing release	Wingspan: 116 cm
2. Status LED/Pitot probe	Nominal take-off weight: 1.1 kg
3. Battery compartment	Maximum take-off weight: 1.7 kg
4. Camera compartment	Propulsion: low-noise, electric brushless motor
5. Central body	Material: EPP foam, carbon structure & composite parts
6. Servo connection mechanism	Standard battery: 4-cell 3700 mAh LiHV (0.3 kg)
7. Wing	Endurance battery: 4-cell 4900 mAh LiHV (0.4 kg)
8. Winglet	Battery consumption: 15.2 V DC, 3.7/4.9 A
9. Strobe light	Nominal endurance: up to 59 minutes (standard battery)
10. Propeller	Extended endurance: up to 90 minutes (endurance extension)
11. Motor	Landing: linear landing at 20°
12. Ambient temperature sensor	Steep landing at 35°
13. Ailerons	Cruise speed: 40-110 km/h (11-30 m/s, 25-68 mph)
14. GNSS/RTK Antenna	Wind resistance: up to 46.0 km/h (12.8 m/s, 24.9 kts)
15. Camera opening	Operating temperature: -15 to 35 °C (5 to 95 °F)
16. Central body	Navigation: up to 500 waypoints
17. Ground sensor	
18. Skid plate	
19. Wing struts	
20. Wing release	

Figure 5.3. eBee X Schematic.

Table 5.1. Summary of Camera Specifications.

Sensor	RGB Lens	Shutter Speed	Resolution	ISO
Aeria X	18.5 mm (F/2.8-16)	33.3-0.25 ms	6,000 x 4,000 px	100-6400
SODA	10.6 mm F/2.8-11	33.3-0.5 ms	5,472 x 3,648 px	125-6400
SODA 3D*	10.6 mm F/2.8-11	33.3-0.5 ms	5,472 x 3,648 px	125-6400

**Changes orientation during flight to capture two oblique and 1 nadir image at every position.*

Sensor: MicaSense RedEdge-MX*					
Blue	Green	Red	Red edge	Near infrared	Band resolution
475 ±20 nm	560 ±20 nm	668 ±20 nm	717 ±20 nm	840 ±20 nm	1,280 x 960 px

**Global shutter and automatic ISO.*

5.1.3.2 Terrestrial LiDAR

The Riegl LMSZ210ii terrestrial laser scanner is designed for the rapid acquisition of high-quality three-dimensional images based on a Class 1 laser beam rang.efinder (Figure 5.4). DSMs created using this sensor were compared with the structure from motion output to address project Objective 1. The scanner has a range up to 650 m (4 m minimum range) with an accuracy of 15 mm, a measurement rate up to 10,000 points per second, and a field of view up to 80° x 360° (angular resolution = 0.005°). The raw data is converted to a global coordinate system by placing surveyed retroreflectors within the scene and various project scenes are merged into one volume using the data collection software RiSCAN PRO version 1.5.2sp2. The ground returns were classified from the point cloud using Merrick's Advanced Remote Sensing (MARS®) software version 2018.

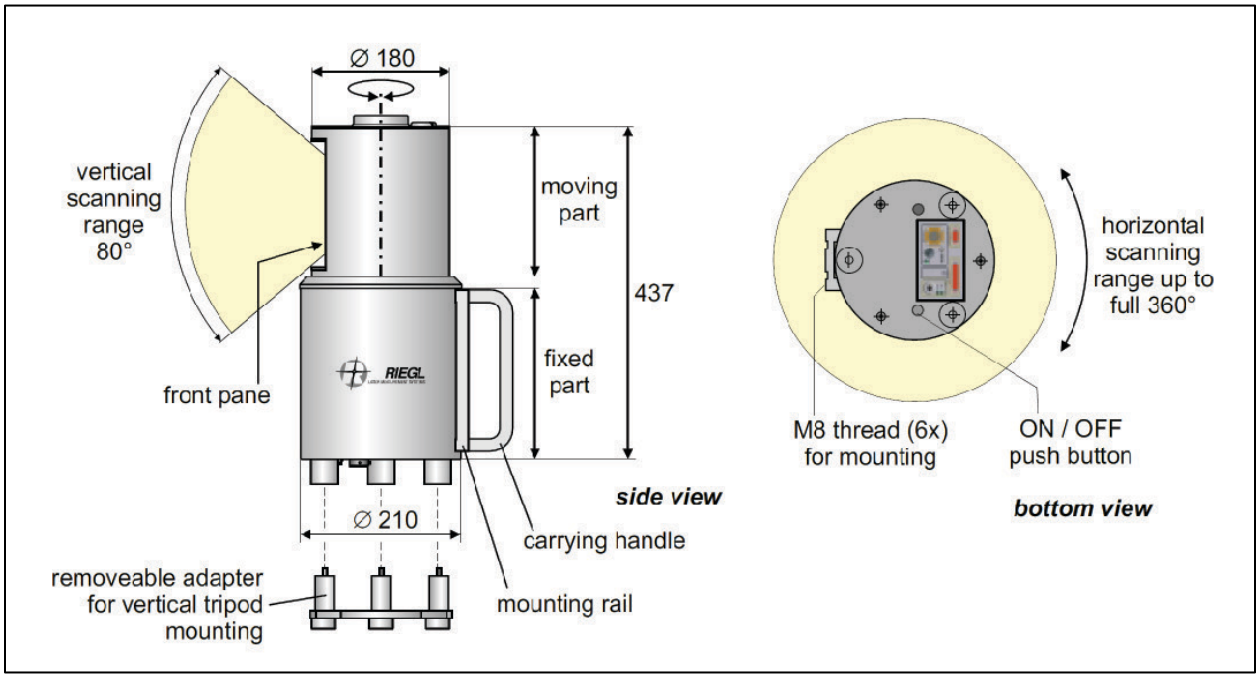


Figure 5.4. Riegle LMSZ210ii Schematic.

5.1.3.3 Survey-Grade GPS

We used a Trimble R8s survey-grade GPS receiver for measuring the elevation and coordinates of GCPs, check points, reflectors, and for collecting beach profiles (Figure 5.5). The receiver has 440 channels, is capable of tracking numerous satellite systems including GPS, GLONASS, Galileo, BeiDou, and QZSS, and has a maximum precision of 8 mm horizontal and 15 mm vertical. We always operated the unit in RTK surveying mode obtaining corrections from the North Carolina Virtual Reference System. As a result, our positioning errors were always 0.5-1 cm horizontal and 1.5-3.5 cm vertical.

1. Radio antenna connection
2. Port 2 Device, computer, external radio, DB-9 male connector that allows for full 9-pin RS-232 comms.
3. Port 1 Device, computer, external radio, power in 7-pin 0-shell Lemo connector that supports RS-232 comms and external power input.

Figure 5.5. Trimble R8s Schematic.

5.3.1.4 Manned Aircraft LiDAR

The United States Army Corps of Engineers National Coastal Mapping Program collected a LiDAR data set in October 2018 to assess elevations above and below water along the southeast US coast after Hurricane Florence. We downloaded the bare earth digital elevation model from the NOAA Office for Coastal Management to compare with the structure from motion output to address project Objective 1. Positional accuracy was compiled to meet 1 m horizontal and 19.6 cm vertical at the 95% confidence level.

5.1.4 FIELD TESTING

5.1.4.1 Unoccupied Aircraft System

The three objectives related to coastal management required collecting aerial photos using the eBee X as the acquisition platform. The eBee X was operated under parameter condition 1 to address objectives 1 and 2 and parameter condition 2 to address Objective 3. Parameter condition 1 optimizes data collection so that topographic data can be extracted from the images while parameter condition 2 is designed to produce an orthomosaic. Parameter condition 1 takes about twice the flight and computing time to map the same area as Parameter condition 2.

5.1.4.1.1 Parameter Condition 1

To address objectives 1 and 2 it was necessary to extract elevation information from the images using structure from motion (Ullman, 1979). The eBee X was configured to collect photos along a double-grid flight pattern with each photo overlapping an adjacent photo by 80%. This flight pattern consists of two series of parallel flight lines that are perpendicular to one another (inlines and crosslines). This parameter condition allows the scale invariant feature transform to match corresponding features on many images, a requirement for producing a detailed point cloud from which a digital elevation model can be derived. Prior to launching the eBee X, nine GCPs, or targets, were distributed throughout the site in a manner that would best define a plane and surveyed (Figure 5.6). GCPs were used to increase the precision of placing the surface model in a global coordinate system and serve as an important backup in case the eBee X lost connection with the GNSS during flight and the acquired images are not geotagged.

Figure 5.6. Field Photos of Surveying GCPs at Onslow Beach, NC.

These targets are black and white representations of cross hairs that are easy to identify in the aerial photos.

5.1.4.1.2 Parameter Condition 2

To address objective 3, we needed to identify sea-turtle crawl marks in areas that are potentially hazardous due to UXO. This only required producing an orthomosaic of the site and a spatial resolution <1.0 m. The eBee X was configured to collect photos of the site in a single grid pattern with each photo overlapping an adjacent photo by 50%. No GCPs were necessary.

5.1.4.2 Terrestrial LiDAR

The Riegl LMSZ210ii terrestrial laser scanner was mounted to the top of a truck and operated at three different locations within the Objective 1 site area (Figures 5.1 and 5.7). The scanner rotates 360 degrees emitting ~2 million pulses at each position, of which about 200,000 return and are registered as x, y, and z positions. The beach is relatively flat, therefore we expected ~1.8 million pulses not to return because they were sent above the horizon into the atmosphere. Prior to collecting data, we deployed nine retroreflectors across the site. The retroreflectors were distributed in a manner that would best define a plane, positioned using a rod level and a prism pole tripod, and surveyed with the Trimble R8s GPS (Figure 5.7). When the scanner is being operated, the truck is off and vacant because any movement of the scanner will adversely impact the measurements.

Field data is collected relative to the position of the scanner at coordinate 0, 0, 0 and the retroreflectors within the scan area allow conversion of the point coordinates from the scanner coordinate system into a global coordinate system using the RiSCAN PRO software.

Figure 5.7. The Terrestrial Laser Scanner Was Repositioned Throughout the Site Using a Truck (Left) and Surveyed Retroreflectors Allowed Us to Transform the Point Cloud into a Global Coordinate System.

5.1.4.3 Beach Profiles

A beach profile was collected from the western and eastern edges of the Objective 1 site using the Trimble R8s GPS receiver mounted on top of a 2.0 m long survey rod. Each profile extended from the dune toe to the seaward edge of the intertidal zone in a cross-shore orientation. The average spacing between each survey point along the profiles was 1.55 m (± 0.43 m) and each profile was 63-m long.

5.1.5 SAMPLING PROTOCOL

Samples in the context of this project consist of orthomosaics, point clouds derived from images using structure from motion, and geolocated reference checkpoints for data validation (Table 5.2).

The specific locations from where these data were collected are shown in figures 5.1 and 5.2. Orthomosaics from the overlapping images collected using the eBee X were created using Pix 4D and output as one large GeoTIFF and several smaller GeoTIFF tiles for use in a geographic information system software package (e.g., Arc or Surfer). The DSMs from the images collected using the eBee X were created using the inverse distance weighting algorithm in Pix 4D and a single GeoTiff file was generated for each mapped area. We addressed Objective 1 at a subset area of the Onslow Beach recreation site (Figure 5.8). In addition to data collected using the eBee X, samples for Objective 1 also include a point cloud collected with the terrestrial laser scanner and beach profiles (Figure 5.9). The point cloud from the terrestrial laser scanner was interpolated into a DSM using Surfer software using the inverse distance weighting algorithm. After orthomosaics and surface models were created for Objective 1, the checkpoints were used to assess the accuracy of the products following the method described by Seymour et al. (2018).

Table 5.2. Sampling Details.

Date	Location	Easting	Northing	Sensor	Objective	Ortho	DEM
Onslow Beach							
12/2018	Recreation	292994	3828659	SODA	2	X	X
12/2018	Overwash	287391	3824757	SODA	2	X	X
12/2018	Erosion	287894	3824972	SODA	2	X	X
12/2018	Erosion	287894	3824972	Sequoia	2	X	
5/2019	Recreation	292994	3828659	Aeria X	1, 2	X	X
5/2019	Recreation	292994	3828659	SODA 3D	1, 2	X	X
5/2019	Recreation	292994	3828659	LMSZ210ii	1		X
5/2019	Recreation	292994	3828659	Trimble R8s	1		X
10/2018	Recreation	292994	3828659	Plane LiDAR	1		X
12/2019	Erosion	287894	3824972	Aeria X	2	X	X
8/2020	Overwash	287391	3824757	RedEdge MX	2	X	X
8/2020	Erosion	287894	3824972	RedEdge MX	2	X	X
11/2020	Erosion	287894	3824972	Aeria X	2	X	
11/2020	Erosion	287894	3824972	SODA 3D	2	X	
Bird Island							
9/2019	PreDorian	346899	3842116	SODA	2	X	X
9/2019	PostDorian	346899	3842116	SODA	2	X	X
10/28/2019	Sea Turtle	346899	3842116	AeriaX	3	X	
10/29/2019	Sea Turtle	346899	3842116	AeriaX	3	X	

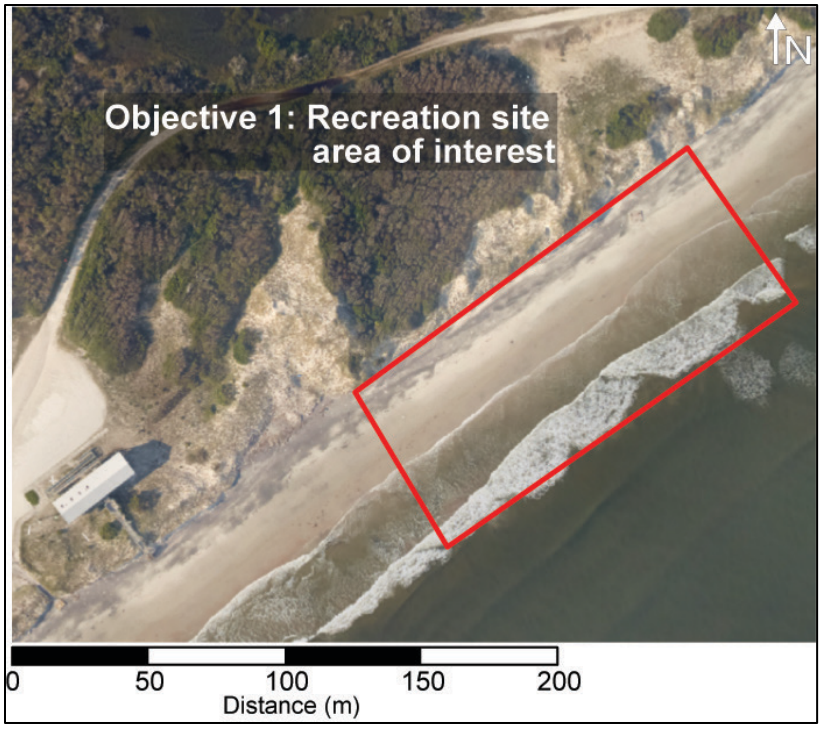


Figure 5.8. Map Showing the Subset Area of Where We Addressed Objective 1 at the Onslow Beach Recreation Site Shown in Figure 5.1.

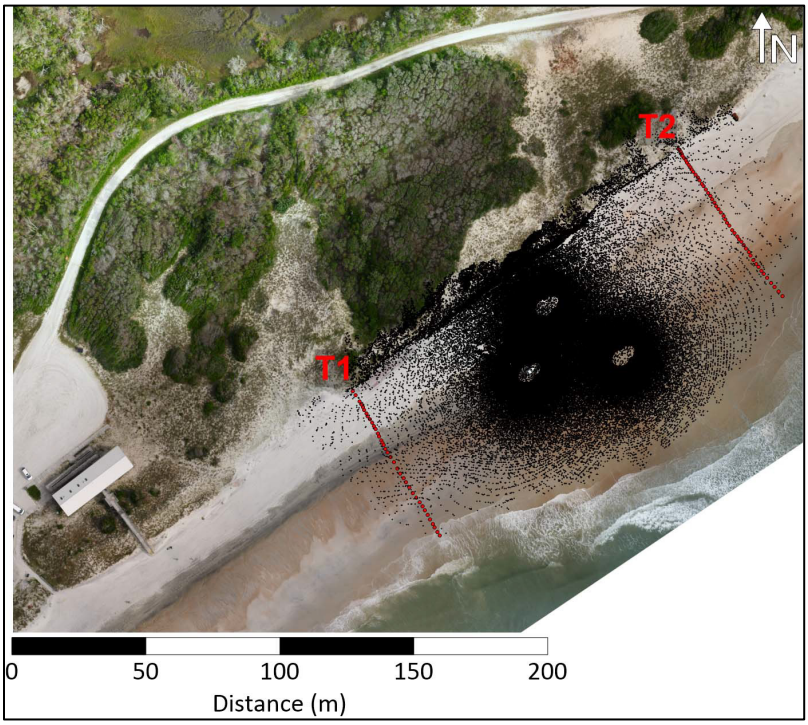


Figure 5.9. Point Cloud Obtained Using the Terrestrial Laser Scanner (Black Circles) and Samples Used for Profiling the Beach at the Southwestern and Northeastern Edges of the Study Area Shown in Figure 5.8 (Red Circles).

Bird Island was used to demonstrate the application of UAS for collecting pre-storm and post-storm data. We mapped Bird Island on September 5 and 7, 2019 one day before and after the storm made landfall (Figure 5.10). Hurricane Dorian passed by the site as a Category 1 storm with the strongest wind gust measured (96 kt at 0920 UTC 6 September) at Cedar Island about 45 km north of Bird Island. As Dorian's eye moved very near Cape Hatteras, North Carolina, the winds reached 80 kt in gusts and the pressure dropped to 959.7 mb at a NOAA National Ocean Service site there. The storm caused severe flooding north of Bird Island along the Outer Banks and in Pamlico Sound with the combined effect of surge and tide inundating up to 2.04 m above Mean Higher High Water. At Bird Island, inundation was 0.5-1 m above Mean Higher High Water. Flights were conducted with senseFly eBees with real-time kinematic positioning on images and permanent GCPs present. DEMs were generated from the before and after storm flights and subtracted to measure elevation changes to the island. A 3-cm vertical error mask was used to only display changes outside the associated precision of the products.

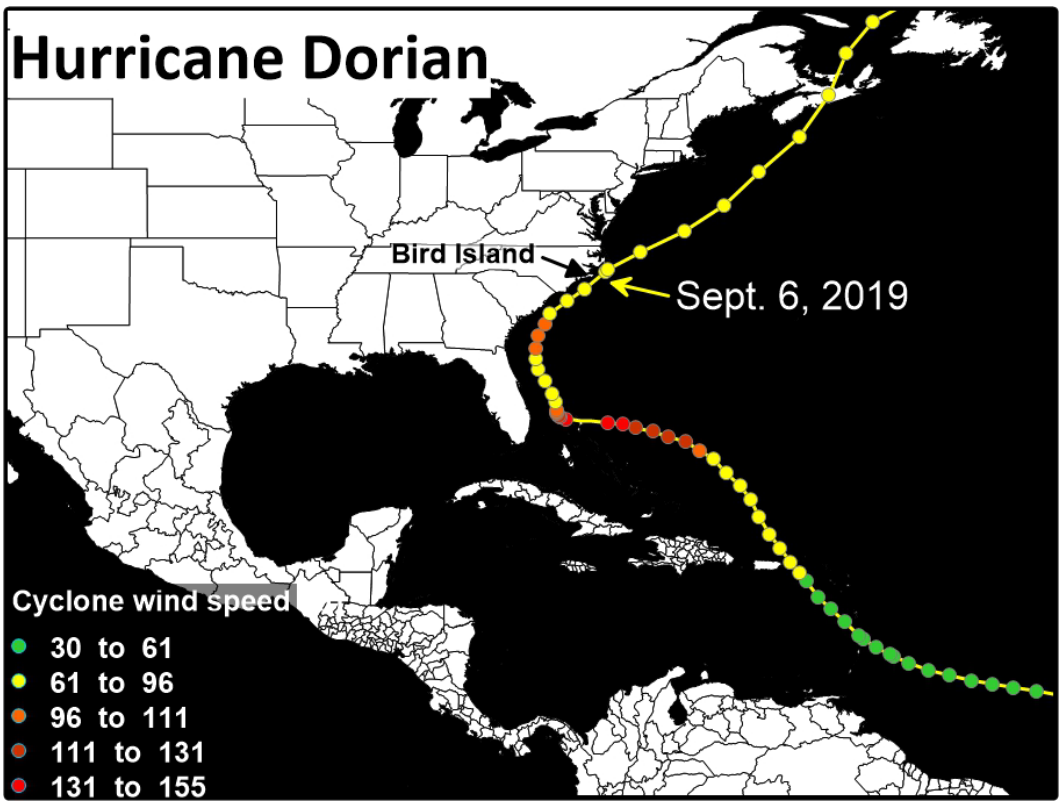


Figure 5.10. Hurricane Dorian Track.

This storm impacted Bird Island as a Category 1 hurricane on September 6, 2019.

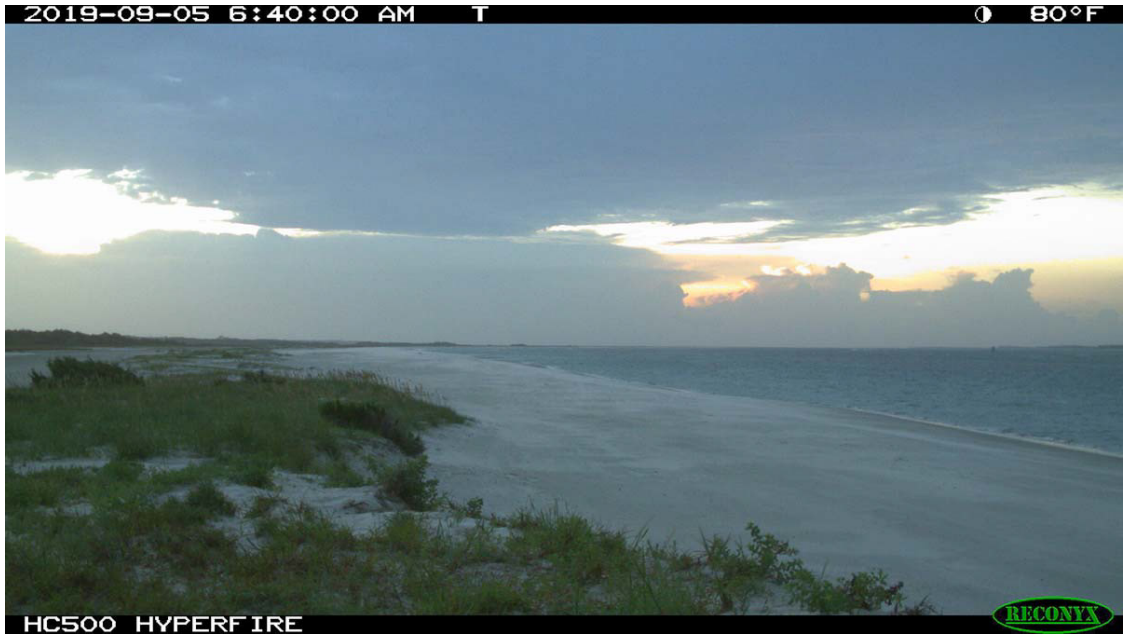


Figure 5.11. Hurricane Dorian Made Landfall During the Night.

This photo shows conditions on Bird Island during the next morning a few hours after the eye passed to the north.

Several areas of Onslow Beach were surveyed repeatedly with UAS during the project period (Table 5.3) to further address Objective 2 and demonstrate the ability to monitor changes to the island. Repeated surveys (n = 2-4) were conducted with an eBee X at approximately 110 m altitude in each of the major use zones (Figure 5.12) except for the Buffer Zone. The southwest area of the Military Training zone was chosen as the primary focus and where the most surveys were collected (n = 4). Most flights were flown with the presence of GCP targets but also implemented PPK processing to create products with centimeter-scale accuracy. Orthomosaic and DEM GeoTIFFs were generated for each of the survey time steps.

Table 5.3. Onslow Beach Survey Dates Within Each of the Specific Sites Chosen for Repeated Surveys as Indicated in Figure 5.12.

Date	Location
12/11/2018	Recreation Area
12/17/2018	Overwash Area
12/19/2018	Erosion Area
12/19/2019	Erosion Area
5/14/2019	Recreation Area
12/11/2019	Erosion Area
8/18/2020	Overwash Area
8/18/2020	Erosion Area
11/18/2020	Erosion Area

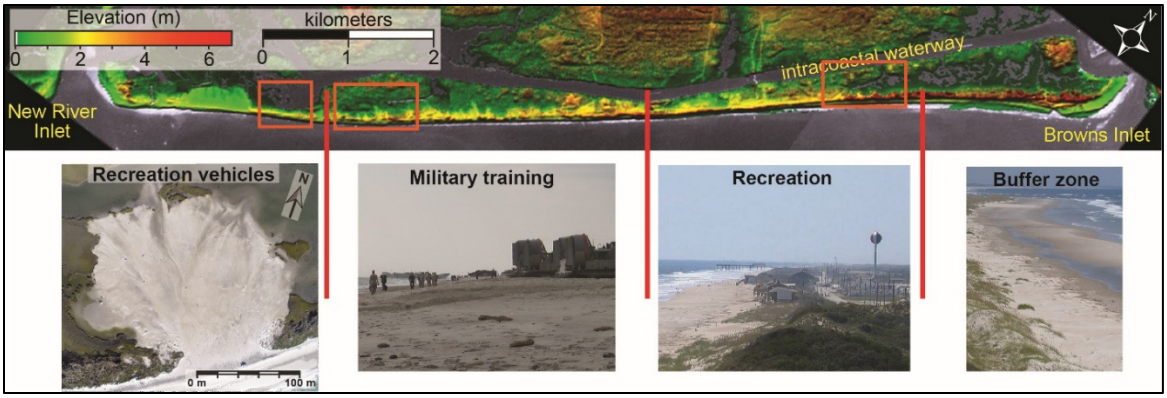


Figure 5.12. Onslow Beach Sites Selected for Repeated UAS Monitoring (Orange Boxes).

To demonstrate the application of UAS for identifying the presence of nesting sea turtles on Onslow Beach, we created surrogate crawl marks on Bird Island and imaged them using the eBee X. The most common nesting sea turtle species in North Carolina is the loggerhead. In 2019 there were a total of 2293, 63, and 2 loggerhead, green turtle and Kemp's Ridley nests identified in North Carolina and Onslow Beach hosted 92 of them, including 91 loggerhead and 1 green turtle. We simulated small loggerhead sea turtle crawl marks by having one person drag a sandbag up the beach to mimic the dragging turtle shell and a second person following with wooden sled shoes (Figure 5.13) to mimic flipper marks. We created 9 crawls on October 27, 2019, obtained their coordinates using a hand-held GPS (Garmin GPSMAP 78SC; Table 5.4) and imaged them the next and following days (Table 5.2). An independent observer examined the resulting orthomosaics to identify crawl-mark coordinates and those sampled coordinates were compared with the known coordinates.

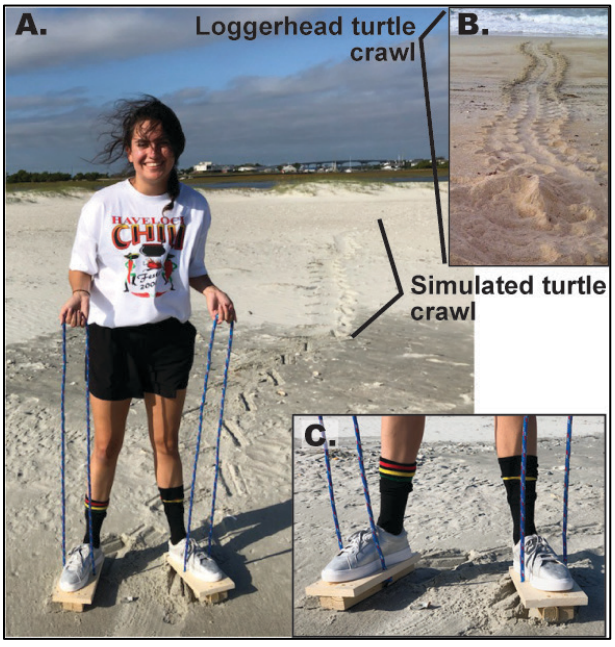


Figure 5.13. Making Simulated Turtle Crawl Marks on Bird Island (A).

To mimic a loggerhead turtle crawl (B), we dragged a sandbag up and down the beach to make shell marks (not shown) and followed that trail wearing fabricated wooden sled shoes to make flipper marks (C).

Table 5.4. Simulated Sea Turtle Crawl Marks on Bird Island.

Crawl Number	Latitude	Longitude
1	34.7087744	-76.6679969
2	34.708902	-76.6687161
3	34.7088717	-76.6683376
4	34.7089629	-76.669276
5	34.7090241	-76.6701816
6	34.7091881	-76.6711308
7	34.7091939	-76.6715381
8	34.7093168	-76.6725544
9	34.7094111	-76.6735612

5.1.6 SAMPLING RESULTS

5.1.6.1 OBJECTIVE 1 Survey efficiency

The topography of the 10,350 m^2 subset of the Onslow Beach recreation site was mapped with the eBee X, the terrestrial laser scanner, airplane LiDAR, and two beach profiles (Figure 5.8). The beach generally decreased in elevation from the dune toe at ~3 m to the swash zone at ~0.0 m NAVD88. That general shape was resolved with all methods employed (Figures 5.14, 5.15, 5.16, 5.17). A shore parallel bar in the upper intertidal zone was present in the southwestern edge of the survey area when we collected the demonstration data in May, 2019 (shown with the 1.0 m contour line) but that feature was not present in October 2018 when the airplane LiDAR data were acquired. The southwestern beach profile and the DEMs from the eBee X images and the terrestrial laser scanner all resolved that bar feature.

The accuracy of the digital elevation models created from eBee X and terrestrial laser scanning data were derived from 24 checkpoints surveyed at random locations (Table 5.5). The difference between the elevations of the checkpoints and the DEMs created from the eBee X and the terrestrial laser scanner are all low with a maximum of 19 cm and an average difference of 3.2 cm ± 3.7 cm (1 standard deviation; Table 5.6). The average residual for the eBee X and the terrestrial laser scanner is 3.3 ± 5.2 and 1.0 ± 3.1 cm, respectively (1 standard deviation) in the negative direction. These average residuals are within the average vertical accuracy of the Trimble GPS (5.0 cm at the 95% confidence interval; Tables 5.5 and 5.6).

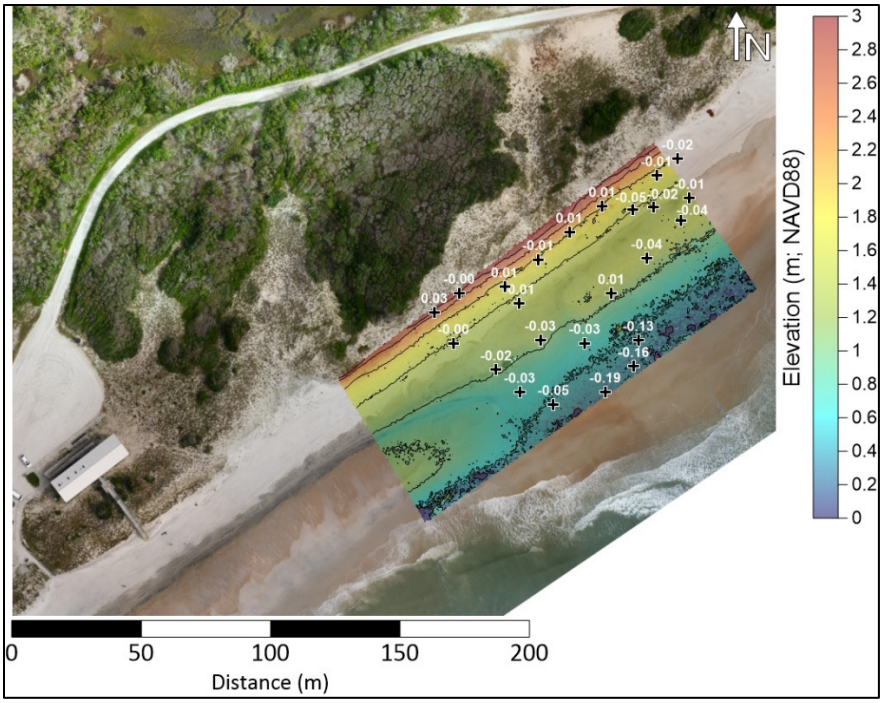


Figure 5.14. Digital Elevation Model Based on the Images Acquired Using the eBee X.

Checkpoint locations shown as crosshairs and numbers indicate difference between the map and checkpoint elevation values. Contour interval = 0.5 m. See Table 5.5 for more information.

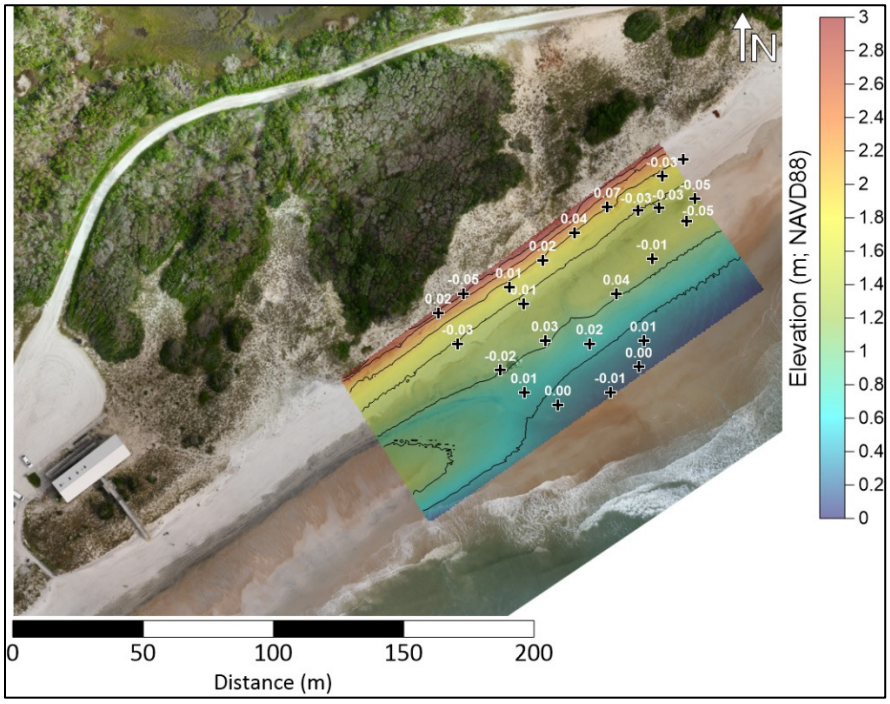


Figure 5.15. Digital Elevation Model Based on the Terrestrial Laser Scanner Point Cloud.

Checkpoint locations shown as crosshairs and numbers indicate difference between the map and checkpoint elevation values. Contour interval = 0.5 m. See Table 5.5 for more information.

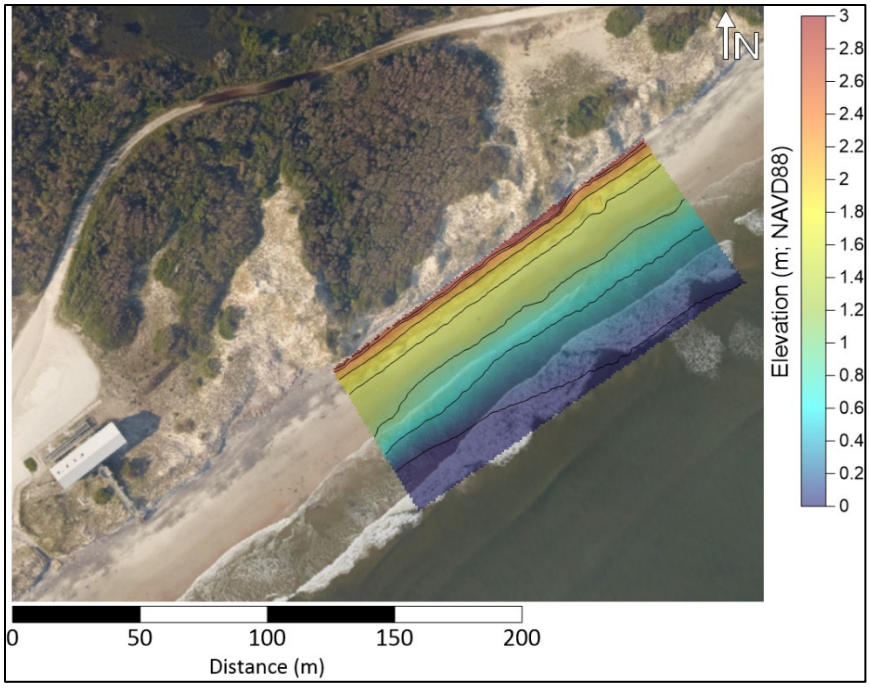


Figure 5.16. Digital Elevation Model Based on Airplane LiDAR Point Cloud Collected in October 2018.

Checkpoint locations are not available due to the temporal mismatch between UAS and occupied aircraft data collection periods. Contour interval = 0.5 m. See Table 5.5 for more information.

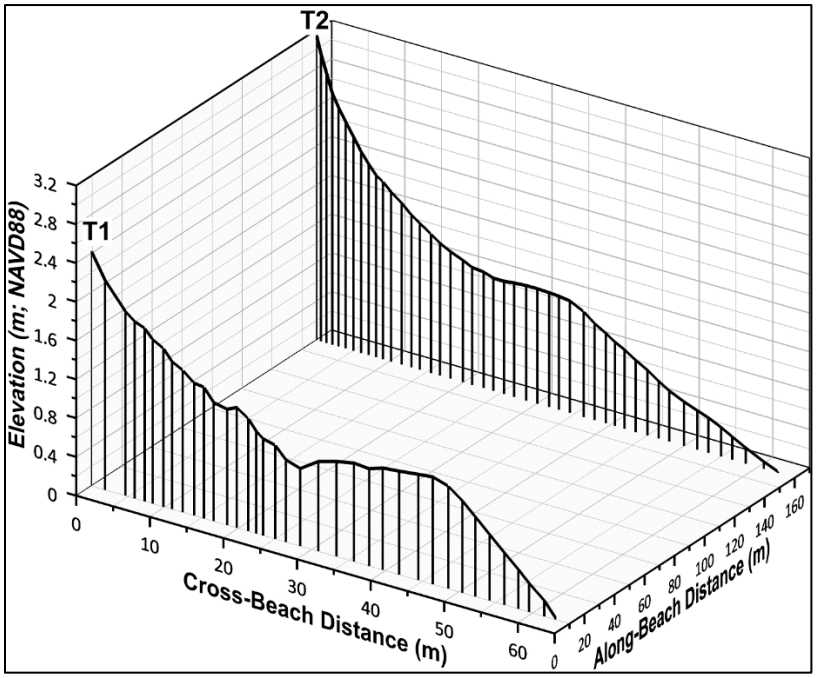


Figure 5.17. Southwestern (T1) and Northeastern (T2) Beach Profiles.

Notice the shore-parallel ridge resolved at the cross-beach distance of 20 m in T1. See Figure 5.9 for additional information.

Table 5.5. Check Points Used to Calculate Accuracy of DEMs Generated from eBee X Images and the Terrestrial Laser Scanner.

Pt name	Northing	Easting	Elevation[1]	HA[2]	VA[3]	Time	Date
cp1	3828452.023	292705.629	1.35	0.028	0.047	10:46:44	5/14/2019
cp2	3828437.986	292713.841	1.12	0.026	0.045	10:47:29	5/14/2019
cp3	3828436.789	292730.99	0.647	0.026	0.045	10:48:08	5/14/2019
cp4	3828437.962	292751.645	0.33	0.027	0.046	10:48:39	5/14/2019
cp5	3828427.9	292749.885	0.183	0.034	0.057	10:49:30	5/14/2019
cp6	3828418.155	292738.949	0.169	0.034	0.058	10:50:05	5/14/2019
cp7	3828413.365	292718.853	0.405	0.034	0.058	10:50:40	5/14/2019
cp8	3828418.072	292705.893	0.636	0.027	0.046	10:51:23	5/14/2019
cp9	3828426.622	292696.744	1.023	0.028	0.047	10:52:43	5/14/2019
cp10	3828436.755	292680.333	1.381	0.027	0.046	10:53:20	5/14/2019
cp11	3828448.559	292672.911	2.749	0.025	0.047	10:54:01	5/14/2019
cp12	3828456.046	292682.514	2.948	0.025	0.047	10:54:35	5/14/2019
cp13	3828458.455	292700.007	1.781	0.03	0.05	10:55:22	5/14/2019
cp14	3828468.882	292712.959	1.869	0.03	0.049	10:55:52	5/14/2019
cp15	3828479.367	292725.005	2.019	0.03	0.049	10:56:23	5/14/2019
cp16	3828489.198	292737.783	2.127	0.03	0.05	10:56:53	5/14/2019
cp17	3828487.904	292749.543	1.454	0.029	0.047	10:57:32	5/14/2019
cp18	3828488.881	292757.456	1.325	0.03	0.05	10:57:54	5/14/2019
cp19	3828500.984	292758.685	1.81	0.031	0.051	10:58:25	5/14/2019
cp20	3828507.36	292766.847	1.833	0.03	0.05	10:58:56	5/14/2019
cp21	3828492.356	292771.426	1.268	0.033	0.054	10:59:25	5/14/2019
cp22	3828483.803	292767.946	1.318	0.036	0.059	10:59:49	5/14/2019
cp23	3828469.314	292754.974	1.267	0.034	0.055	11:00:18	5/14/2019
cp24	3828455.853	292741.285	1.1	0.036	0.058	11:00:54	5/14/2019

[1] Measured in m relative to the NAVD88 datum.

[2] Horizontal accuracy at the 95% confidence interval.

[3]Vertical accuracy at the 95% confidence interval.

Table 5.6. Residuals Between Checkpoint Elevations and DEMs Created from eBee X Images and the Riegle LMSZ210ii Terrestrial Laser Scanner.

Checkpoint name	Checkpoint elevation	Residuals (eBee X)	Residuals (LMSZ210ii)
cp1	1.35	-0.01	0.01
cp2	1.12	-0.03	0.03
cp3	0.647	-0.03	0.02
cp4	0.33	-0.13	0.01
cp5	0.183	-0.16	0.00
cp6	0.169	-0.19	-0.01
cp7	0.405	-0.05	0.00
cp8	0.636	-0.03	0.01
cp9	1.023	-0.02	-0.02
cp10	1.381	0.00	-0.03
cp11	2.749	0.03	0.02
cp12	2.948	0.00	-0.05
cp13	1.781	0.01	0.01
cp14	1.869	-0.01	0.02
cp15	2.019	0.01	0.04
cp16	2.127	0.01	0.07
cp17	1.454	-0.05	-0.03
cp18	1.325	-0.02	-0.03
cp19	1.81	-0.01	-0.03
cp20	1.833	-0.02	N/A
cp21	1.268	-0.01	-0.05
cp22	1.318	-0.04	-0.05
cp23	1.267	-0.04	-0.01
cp24	1.1	0.01	0.04

5.1.6.2 OBJECTIVE 2 Event monitoring

The UAS-derived DEMs revealed that Bird Island experienced elevation loss of the berm crest ranging from 0.2 to 0.5 m along the island during Hurricane Dorian (Figure 5.18). Some of this sediment was redistributed on the backshore with elevation gains ranging from 5-20 cm. The small dunes along the washover terrace also experienced small losses in elevation along their crests (~10-20 cm) but remained relatively intact (Figure 5.19).

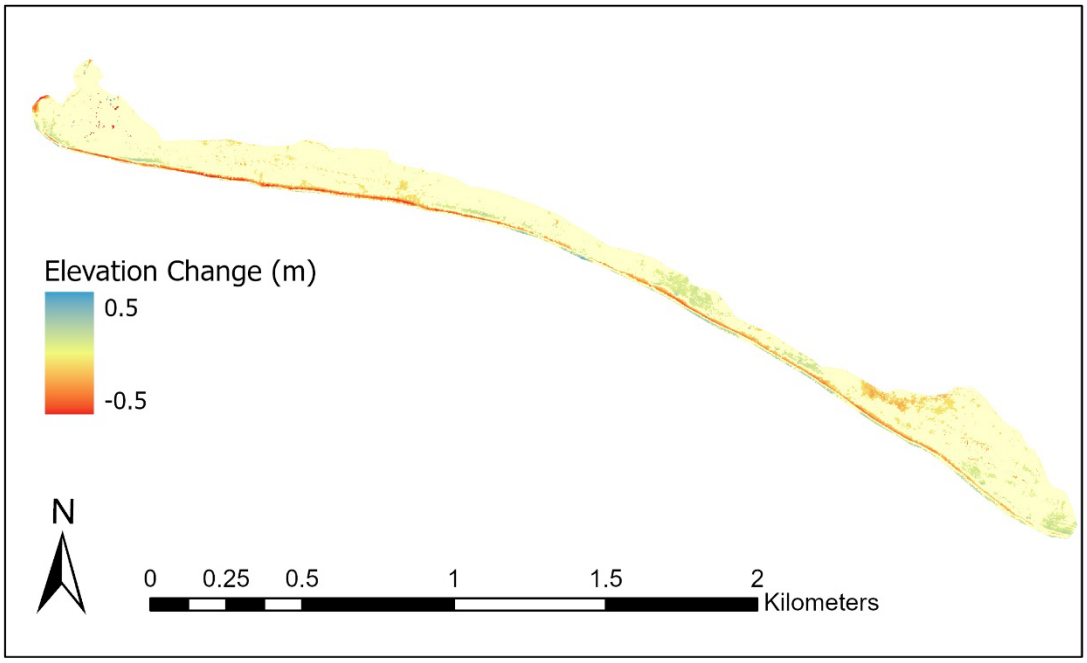


Figure 5.18. A DEM Subtraction of Bird Island Before and After Hurricane Dorian.

Red and blue represent elevation loss and gain respectively.

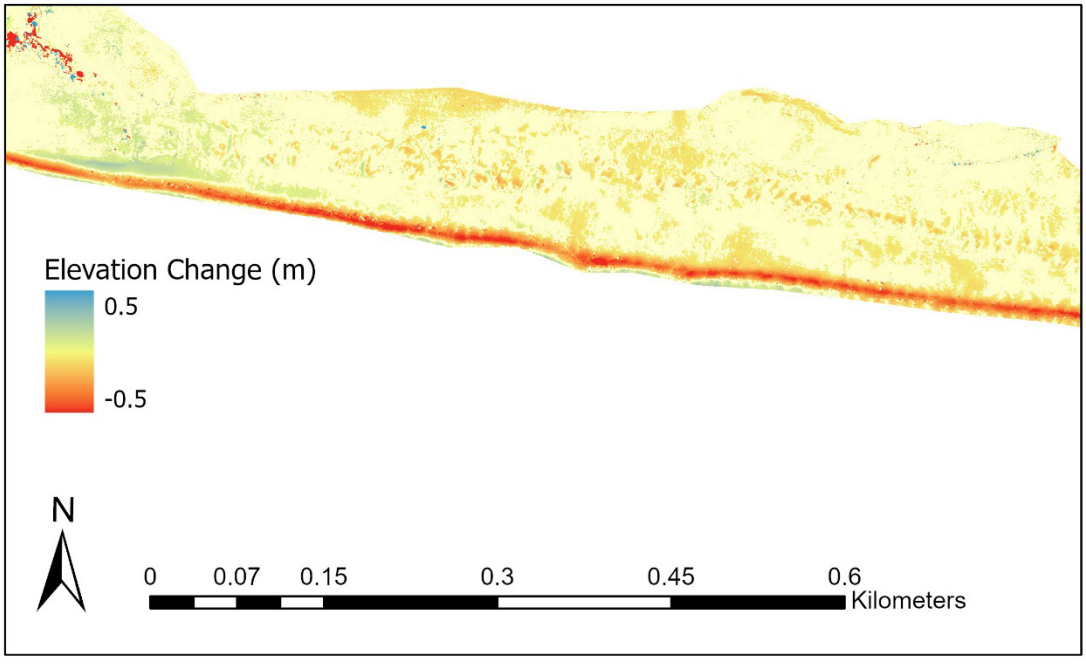


Figure 5.19. Close up of the Washover Terrace Area of the Bird Island DEM Subtraction Before and After Hurricane Dorian.

The southwest region of the military training area of Onslow Beach (Erosion Area) was relatively stable during the repeated UAS surveys from 2018 through 2020 (Figures 5.20-5.27).

Close examination shows only minor changes in backshore elevations and small washover fan expansion. The 1.5-m NAVD88 contours from each timestep further support the stability during the survey period (Figure 5.28). Similarly, the northeast recreation area had minimal changes to the beach with no natural changes occurring in the dunes and beyond (Figures 5.29-5.32) between the December 2018 and May 2019 surveys. The washover fan (Overwash Area) was the lowest lying area surveyed and experienced the most change between surveys in 2018 and 2020 (Figures 5.33-5.36). The 0.5-m NAVD88 contour from both time steps was used to examine changes in the shallow channel (active exchange of ocean and intracoastal waterway at high tide) between the time steps, showing increasing elevation on the fan and narrowing of the channel.

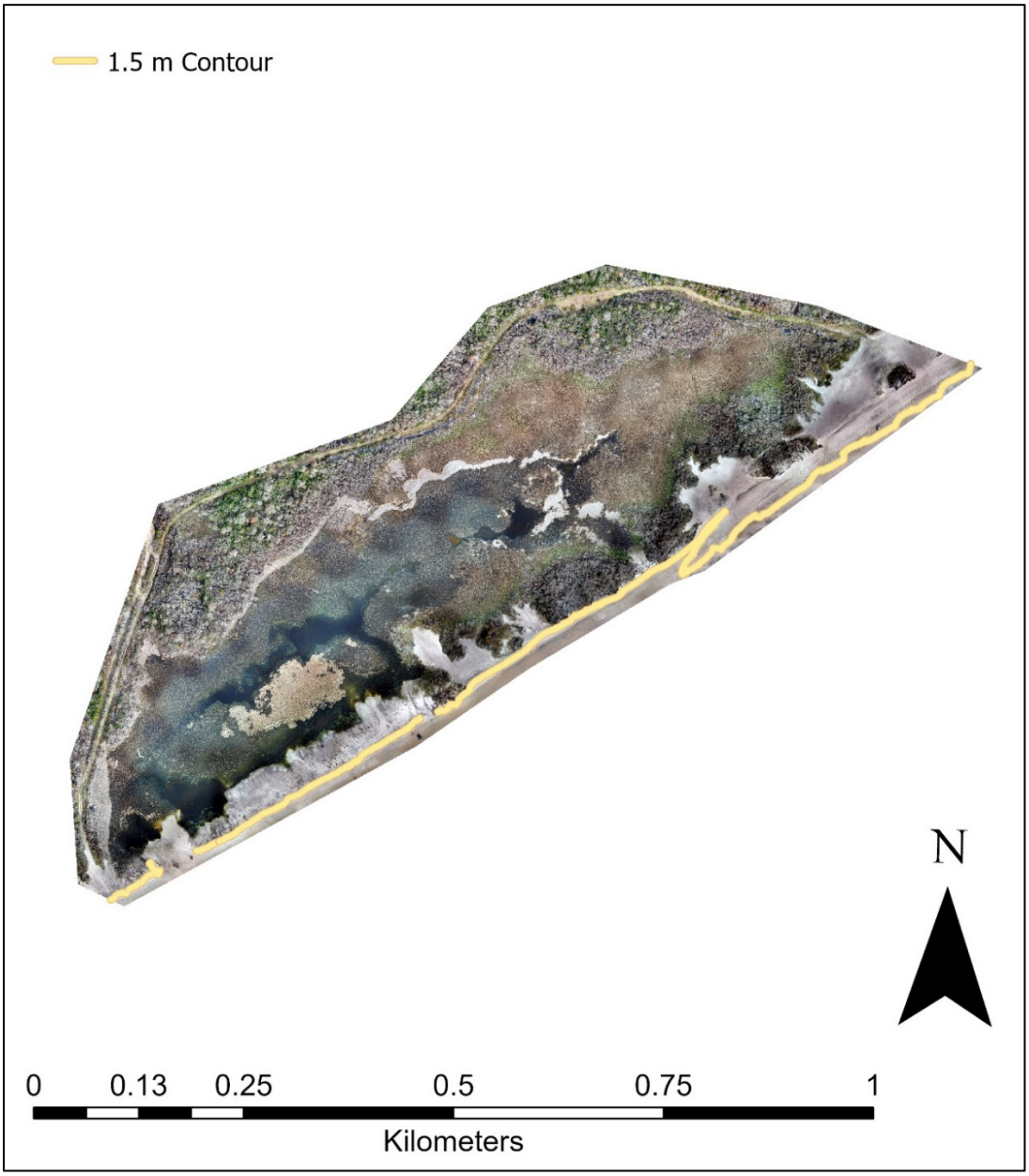


Figure 5.20. Orthomosaic of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS imagery obtained on December 19, 2018.

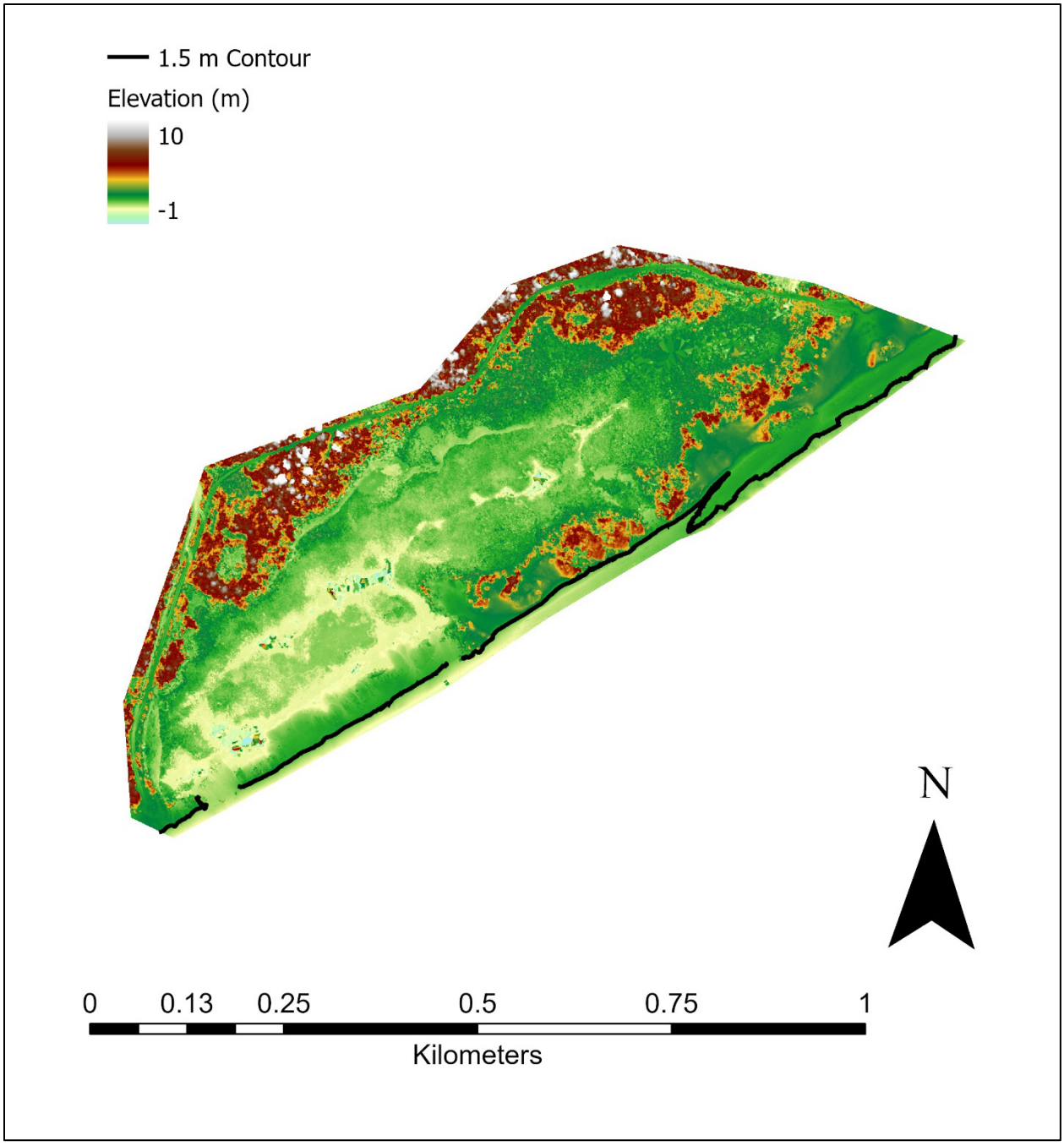


Figure 5.21. DEM of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained on December 19, 2018.

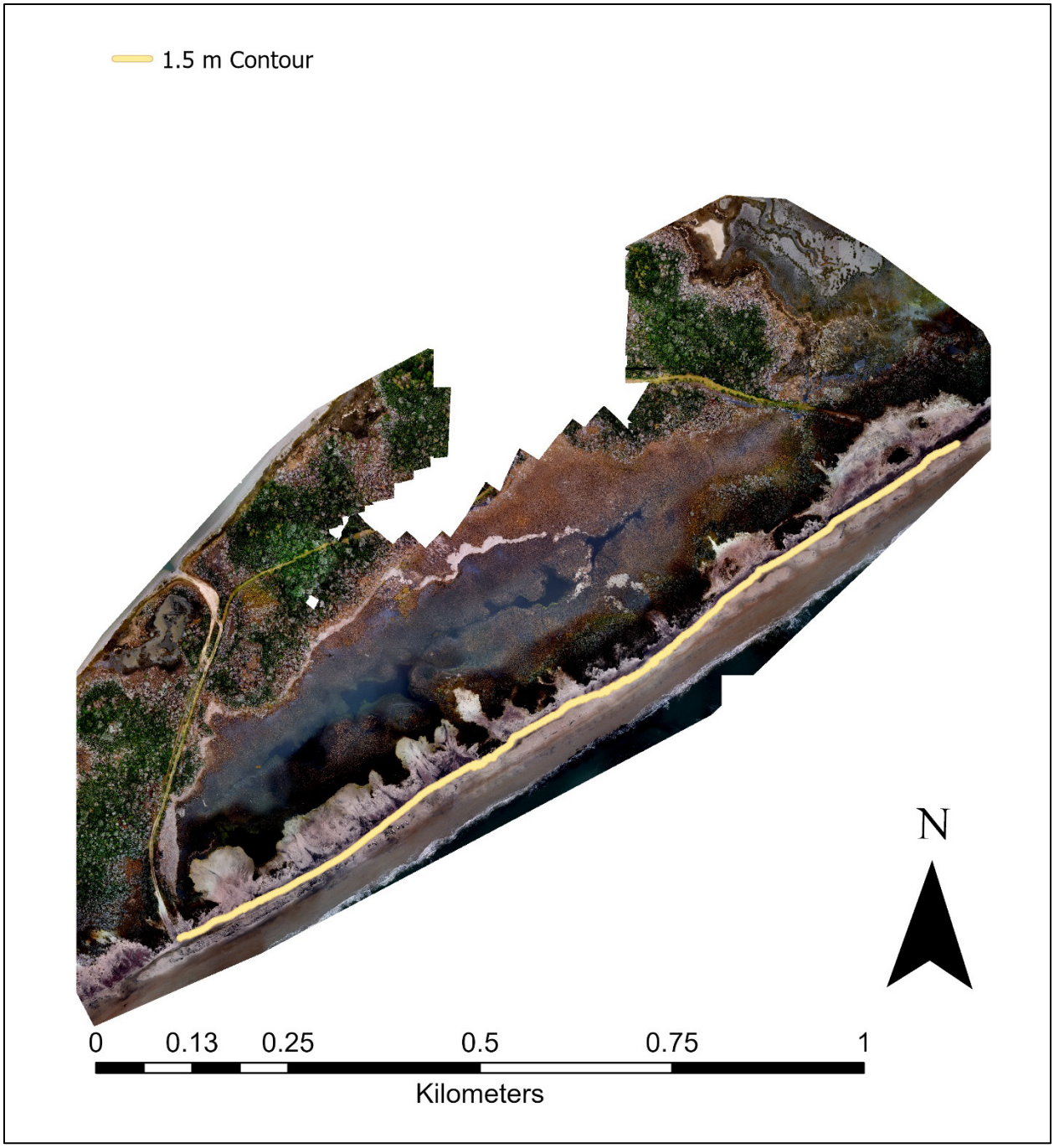


Figure 5.22. Orthomosaic of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained on December 11, 2019.

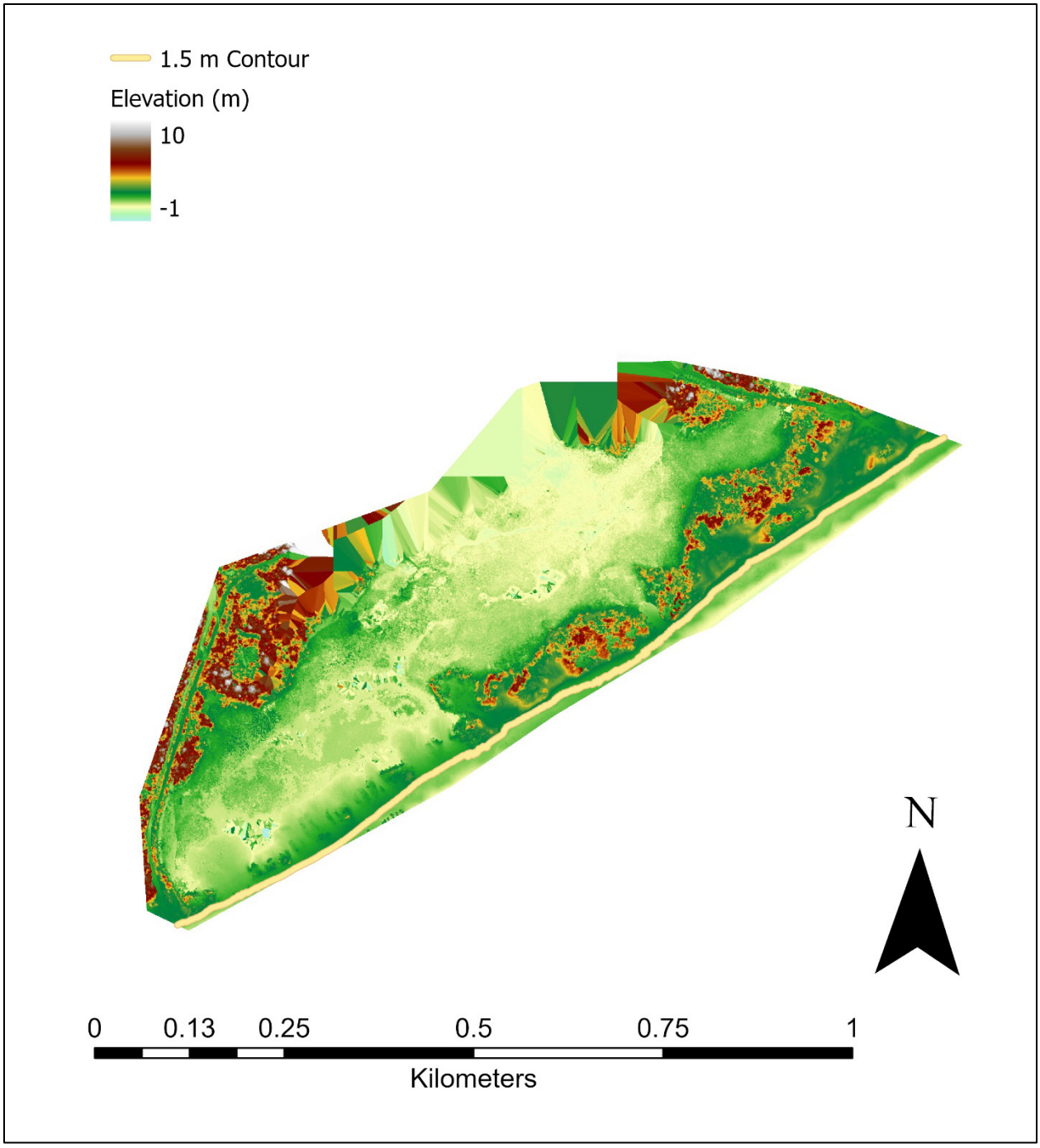


Figure 5.23. DEM of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained on December 11, 2019.

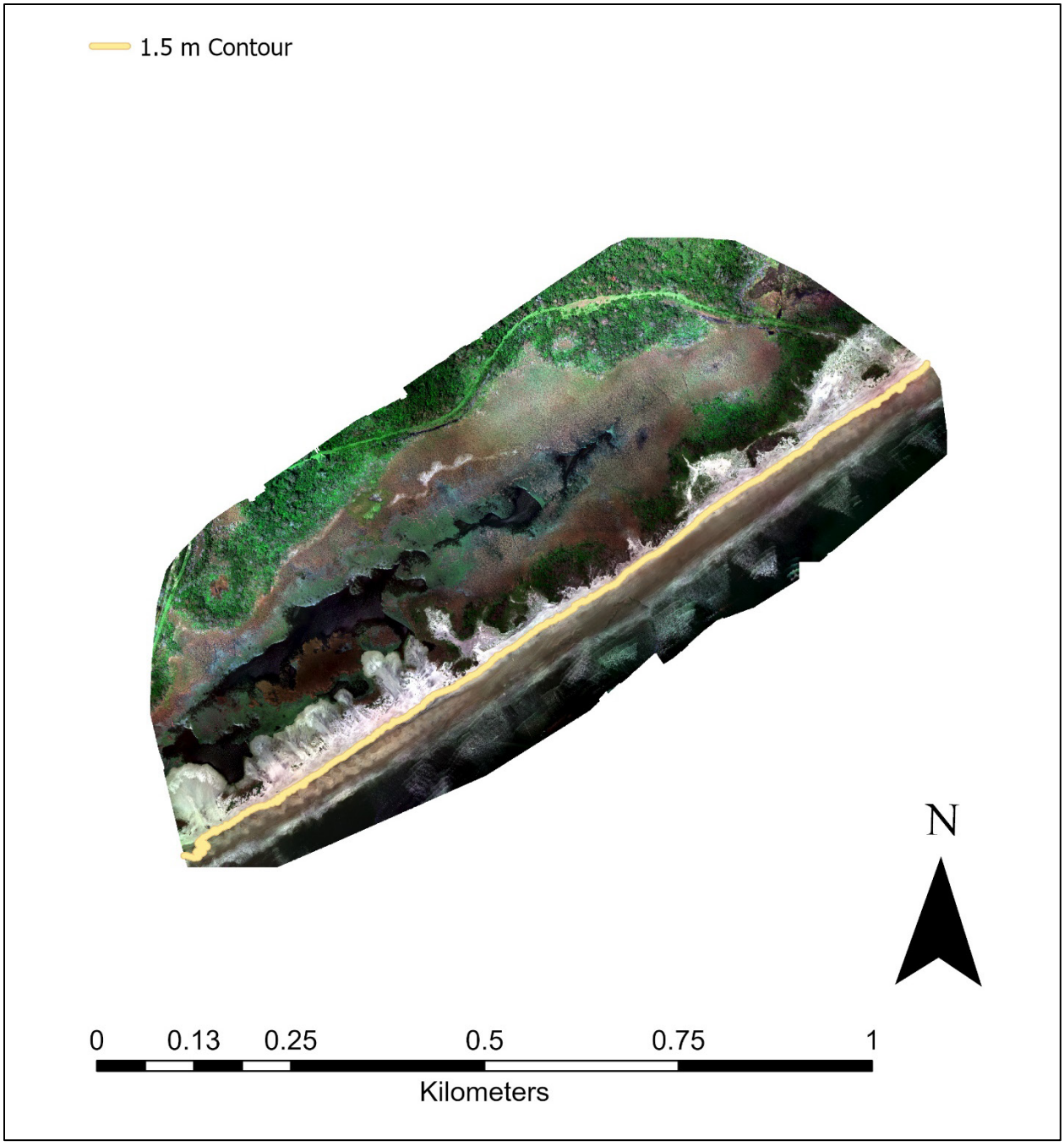


Figure 5.24. Orthomosaic of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained on August 8, 2020.

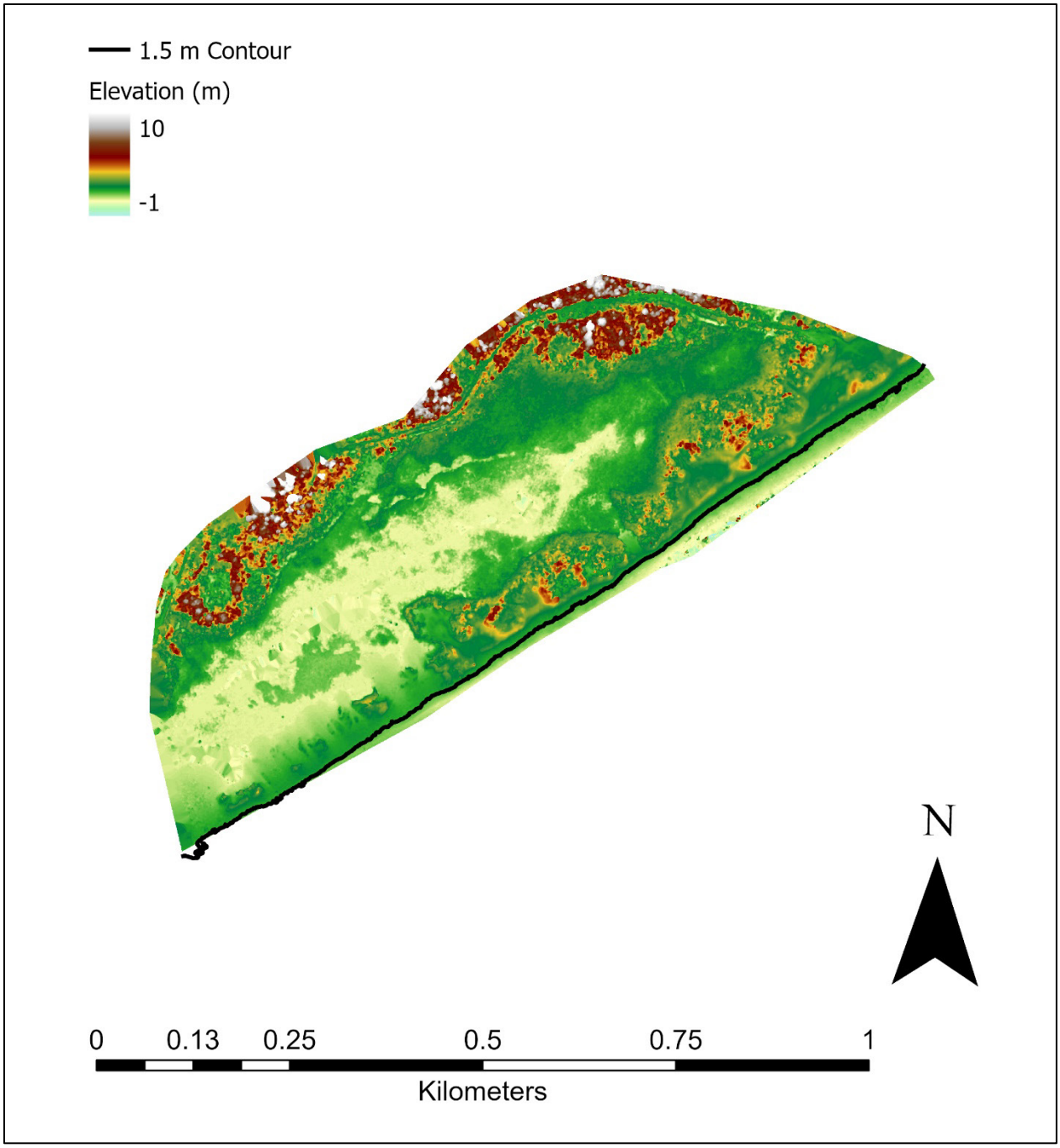


Figure 5.25. DEM of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained on August 8, 2020.

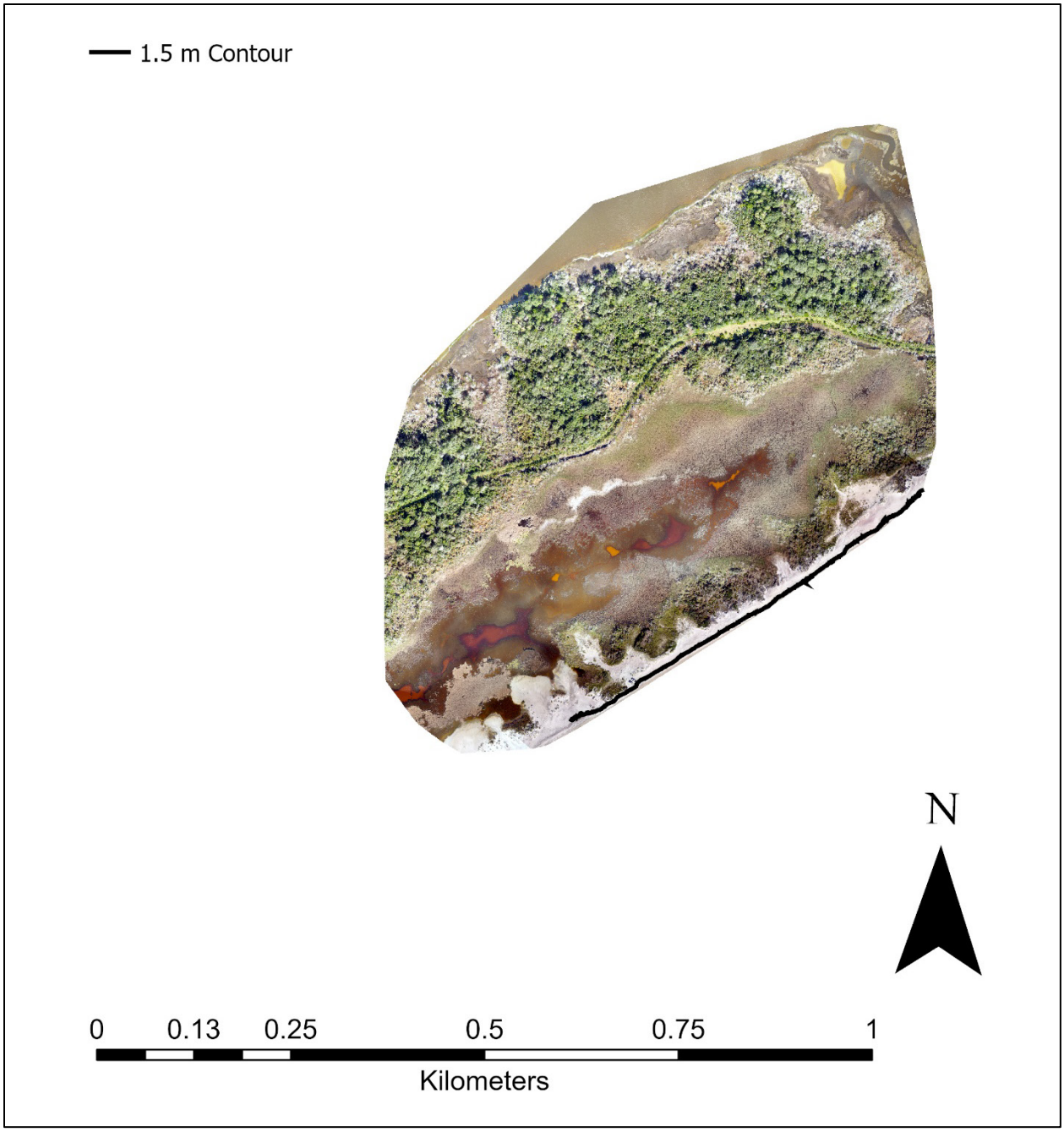


Figure 5.26. Orthomosaic of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained on November 18, 2020.

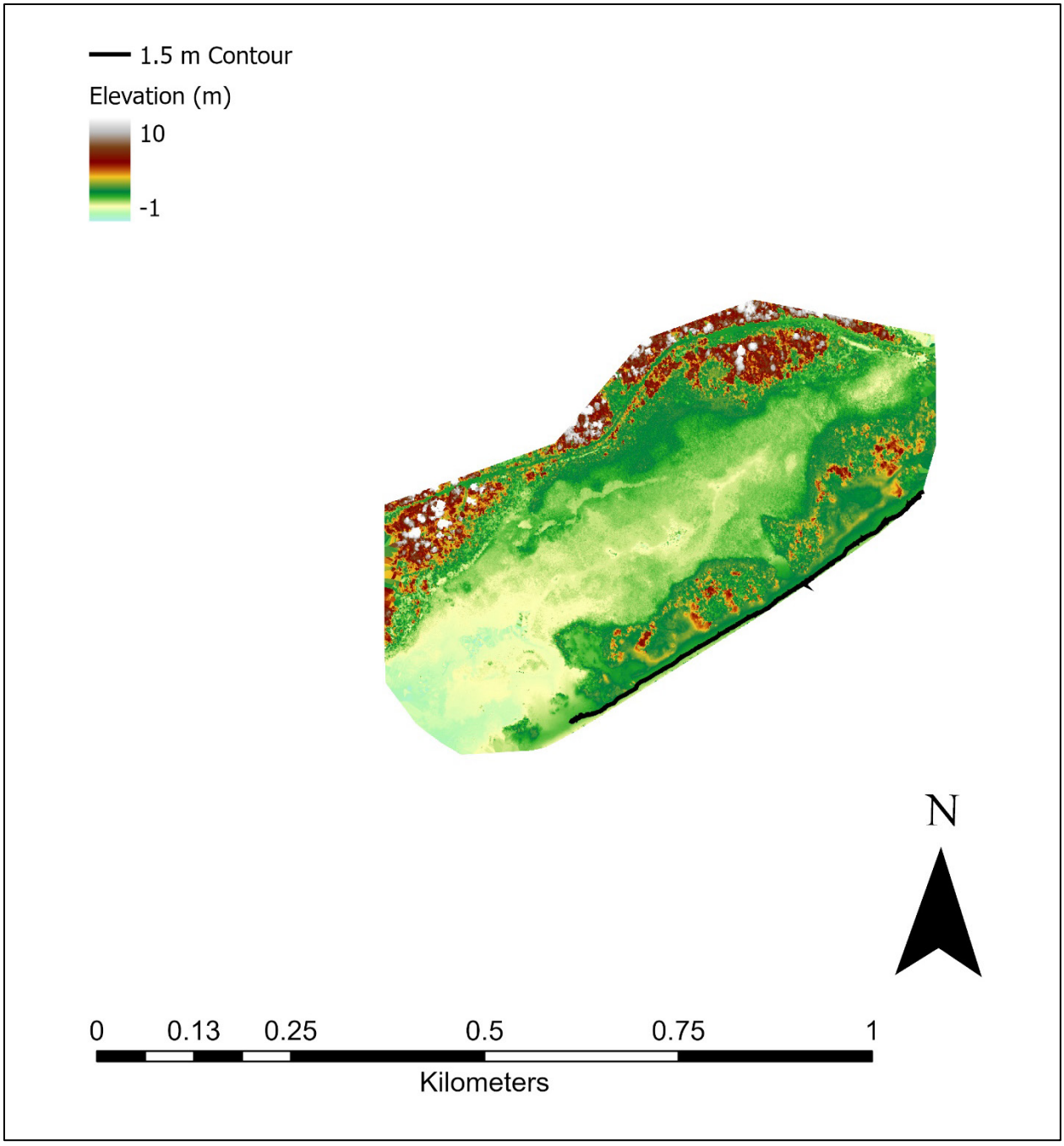


Figure 5.27. DEM of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained on November 18, 2020.

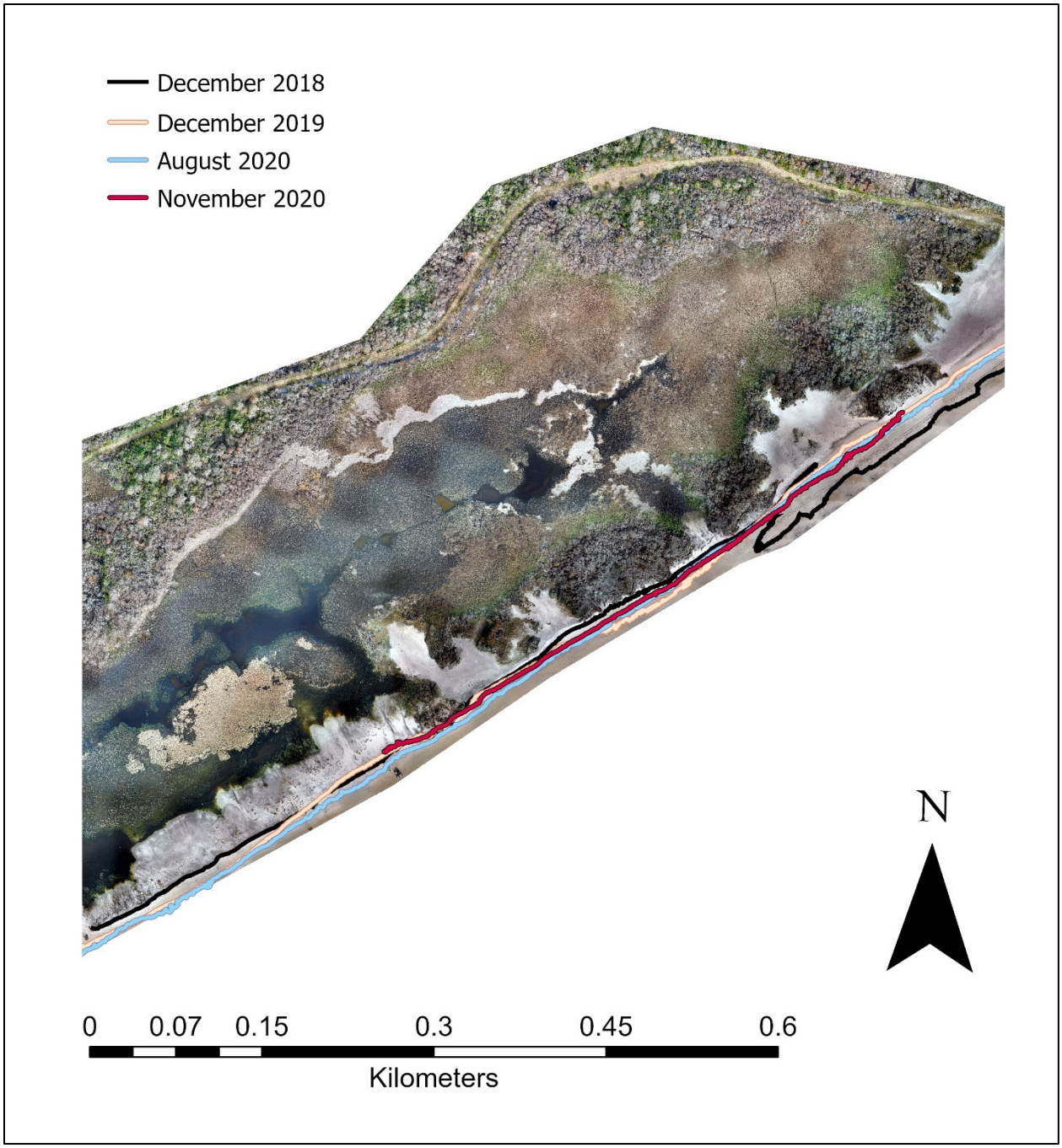


Figure 5.28. Progression of 1.5-m Contours of the Southwest Military Training Zone (Erosion Area) on Onslow Beach Created from UAS Imagery Obtained from 2018 Through 2020.

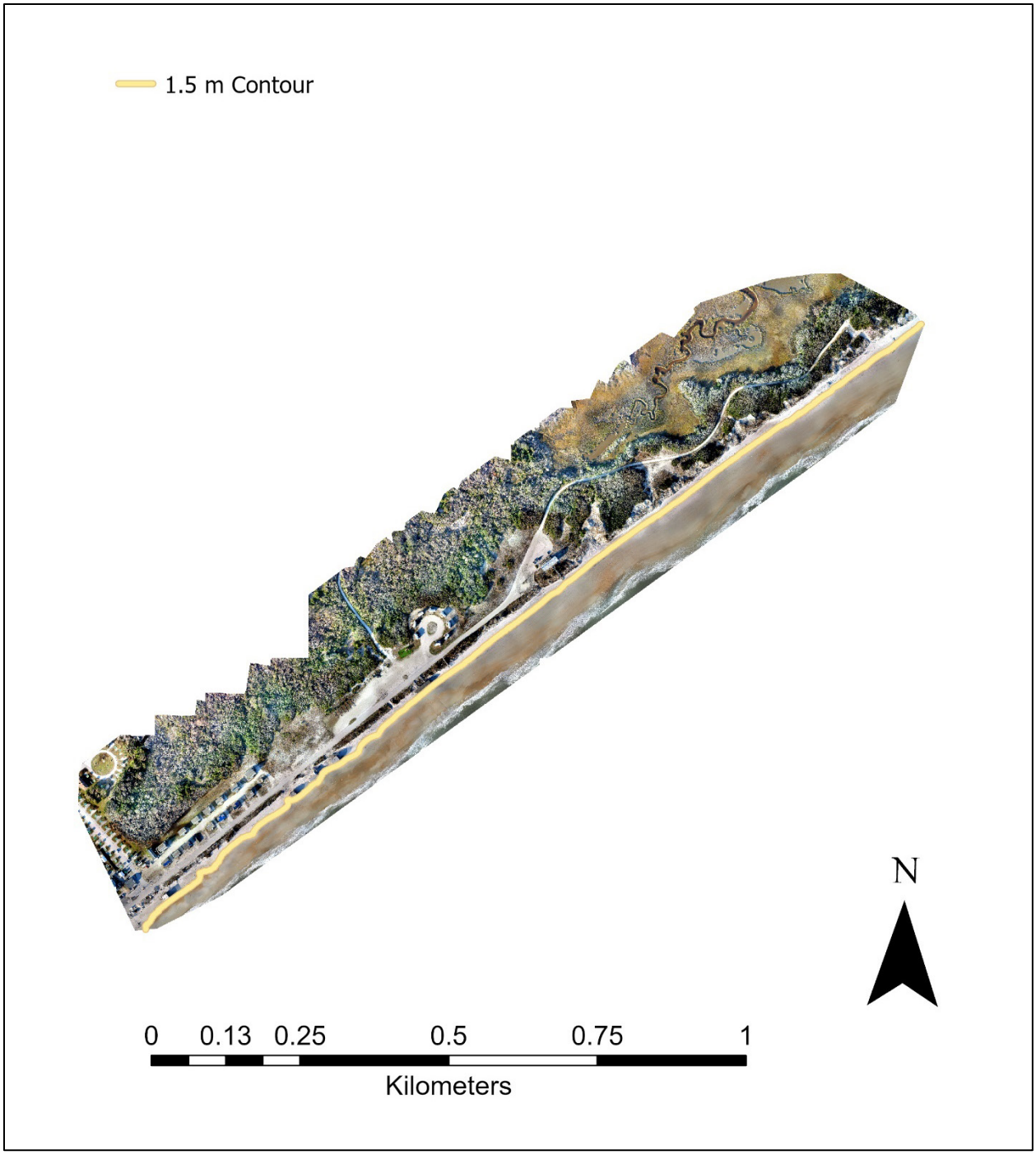


Figure 5.29. Orthomosaic of the Northeast Recreation Area on Onslow Beach Created from UAS Imagery Obtained on December 11, 2018.

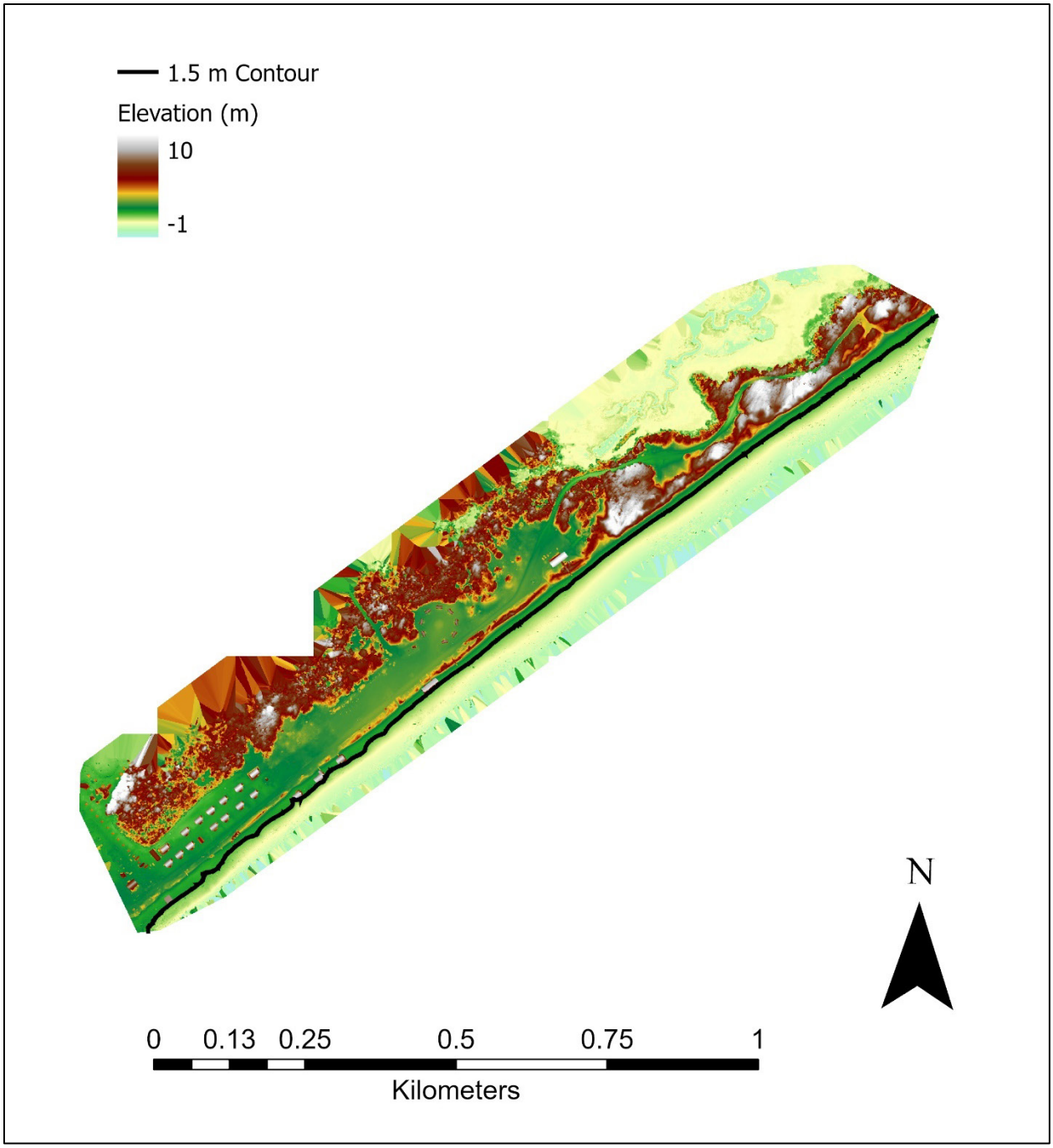


Figure 5.30. DEM of the Northeast Recreation Area on Onslow Beach Created from UAS Imagery Obtained on December 11, 2018.

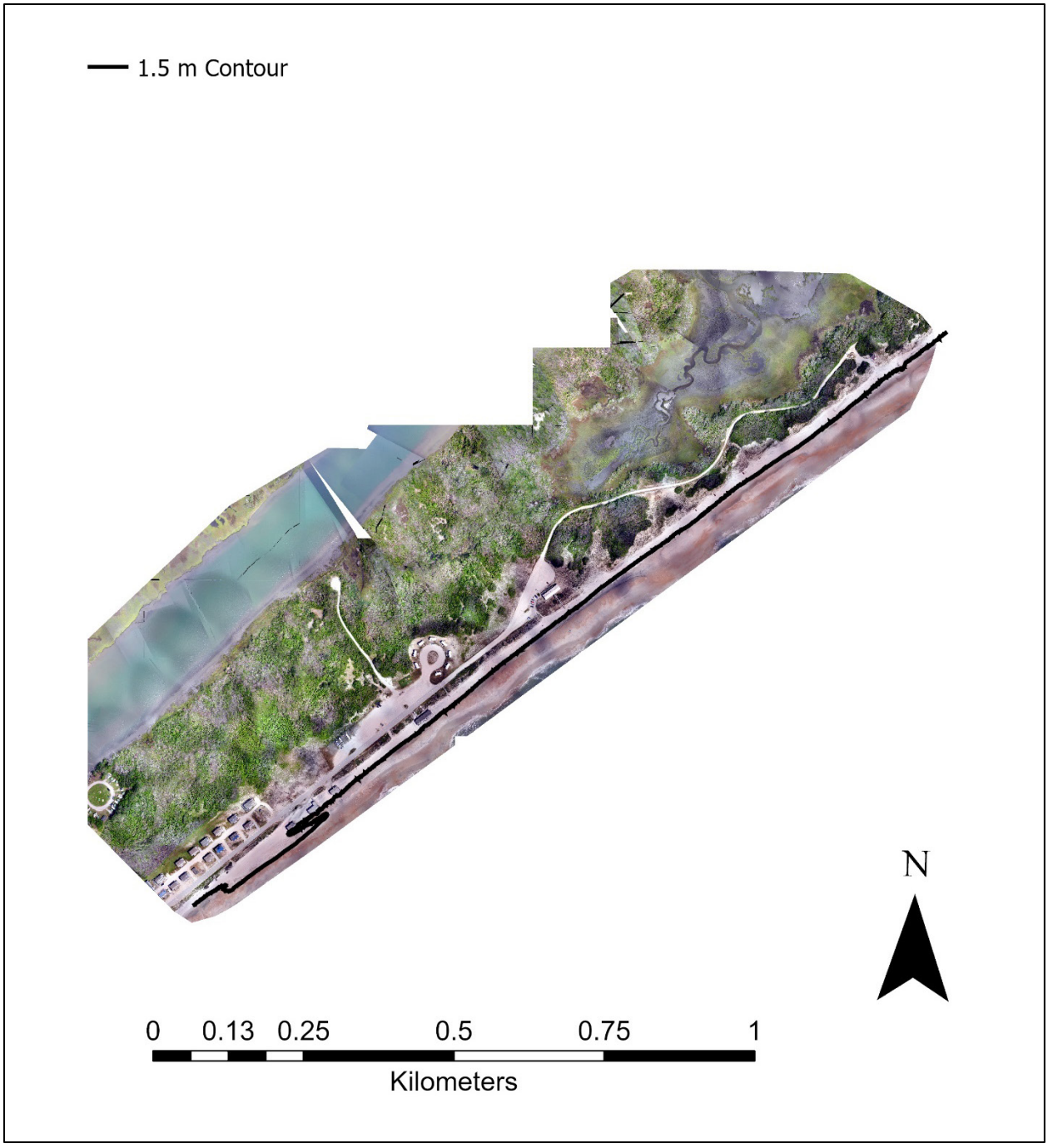


Figure 5.31. Orthomosaic of the Northeast Recreation Area on Onslow Beach Created from UAS Imagery Obtained on May 14, 2019.

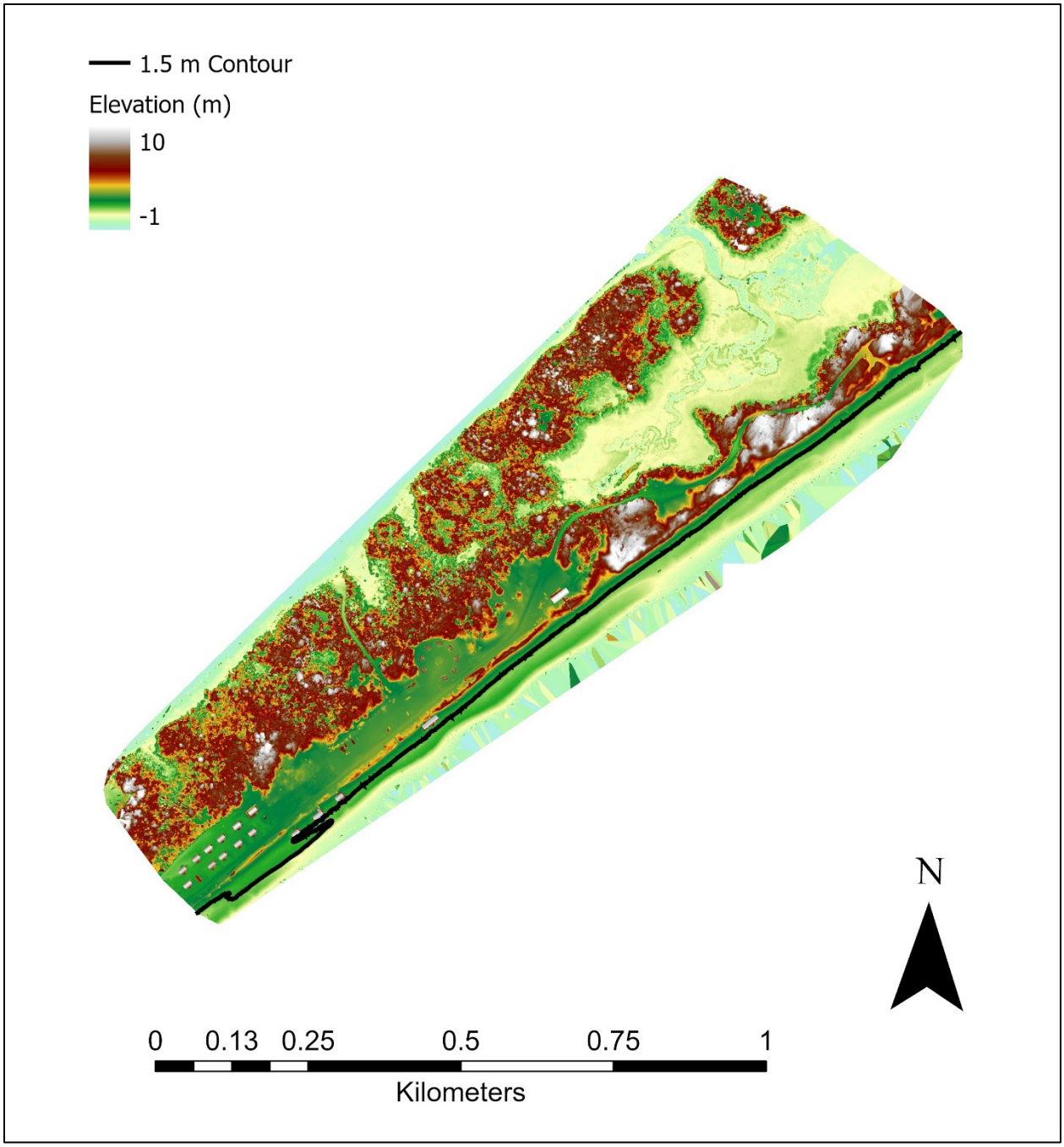


Figure 5.32. DEM of the Northeast Recreation Area on Onslow Beach Created from UAS Imagery Obtained on May 14, 2019.

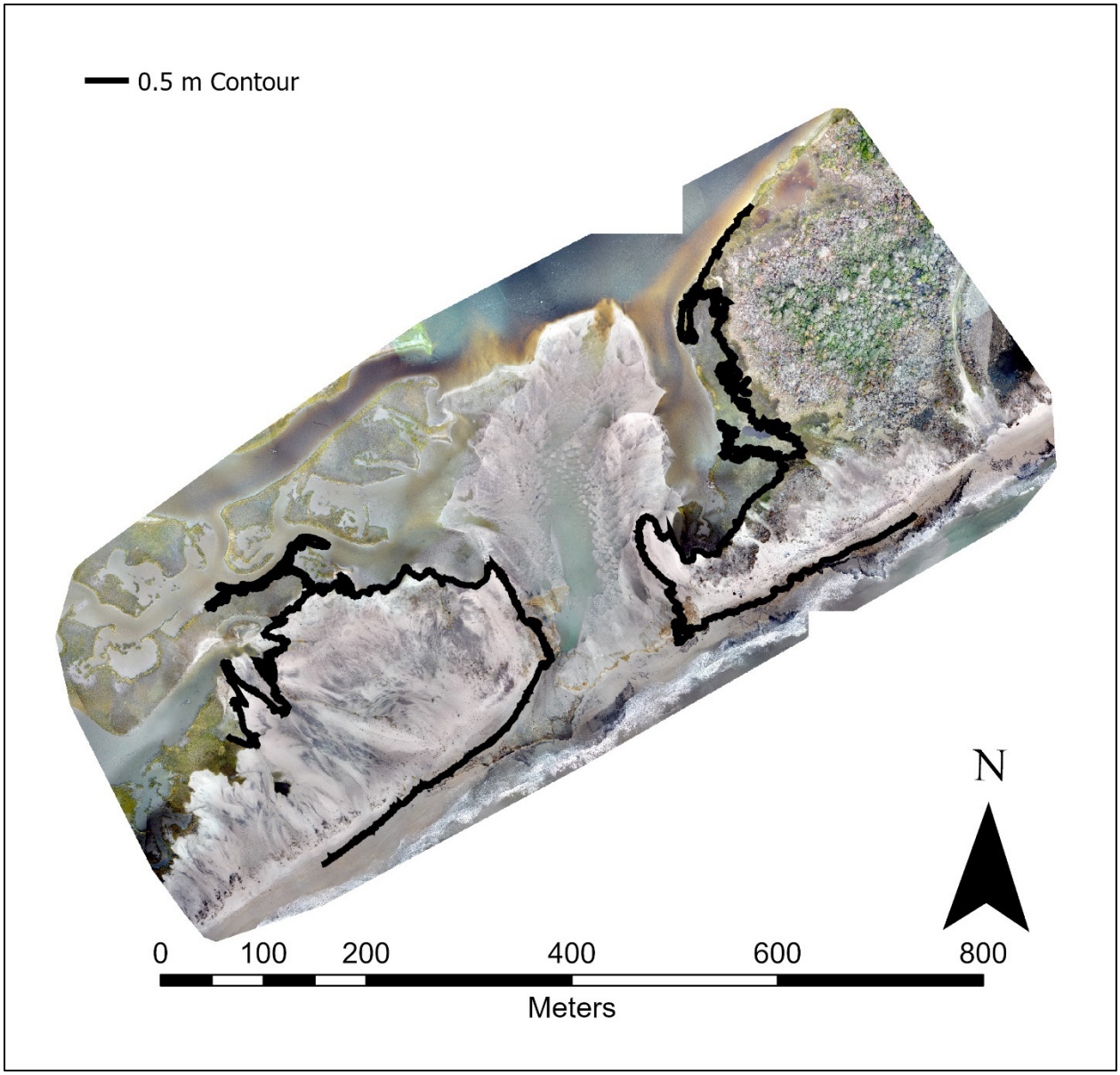


Figure 5.33. Orthomosaic of the Washover Fan (Overwash Area) on Onslow Beach Created from UAS Imagery Obtained on December 17, 2018.

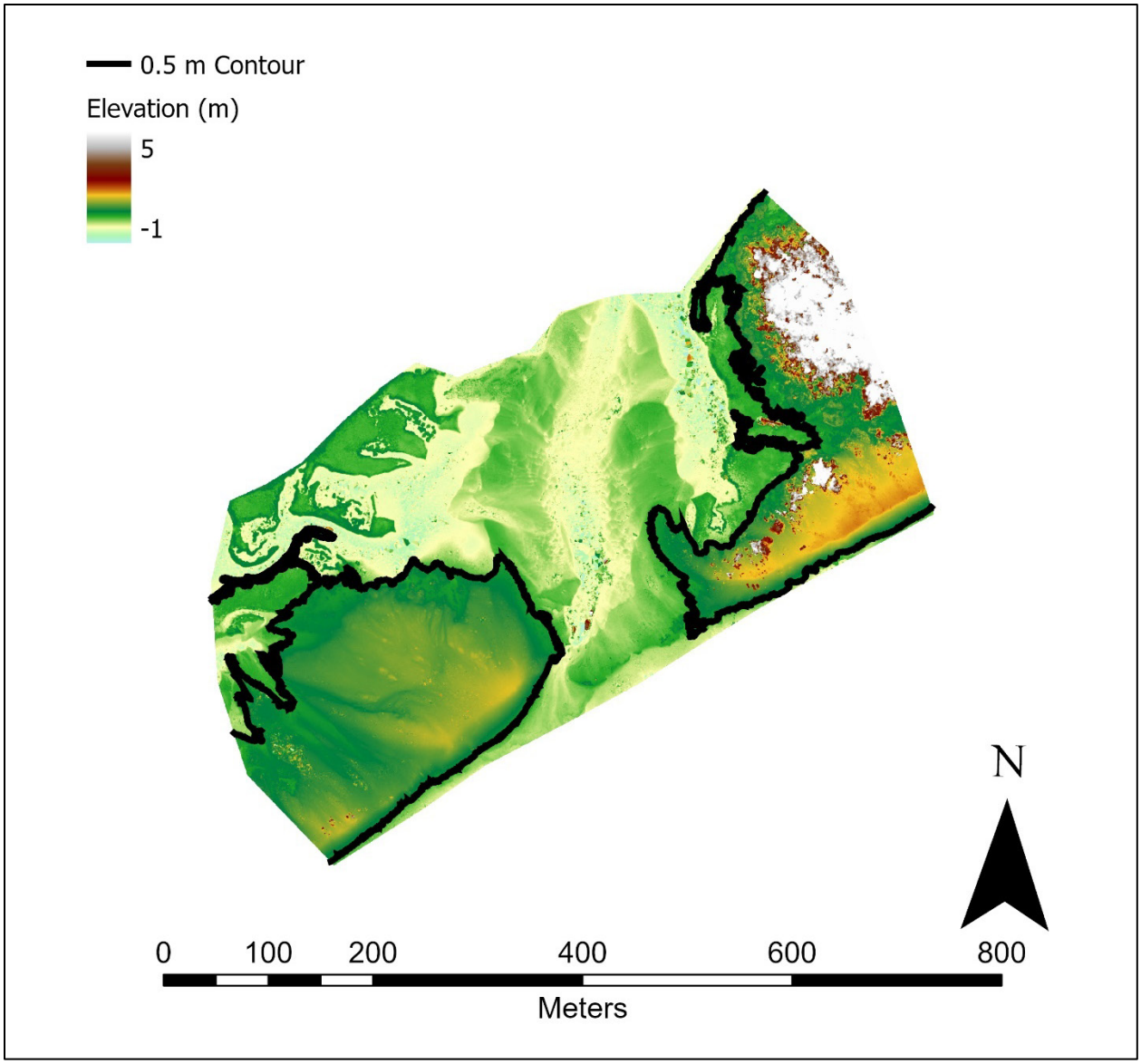


Figure 5.34. DEM of the Washover Fan (Overwash Area) on Onslow Beach Created from UAS Imagery Obtained on December 17, 2018.

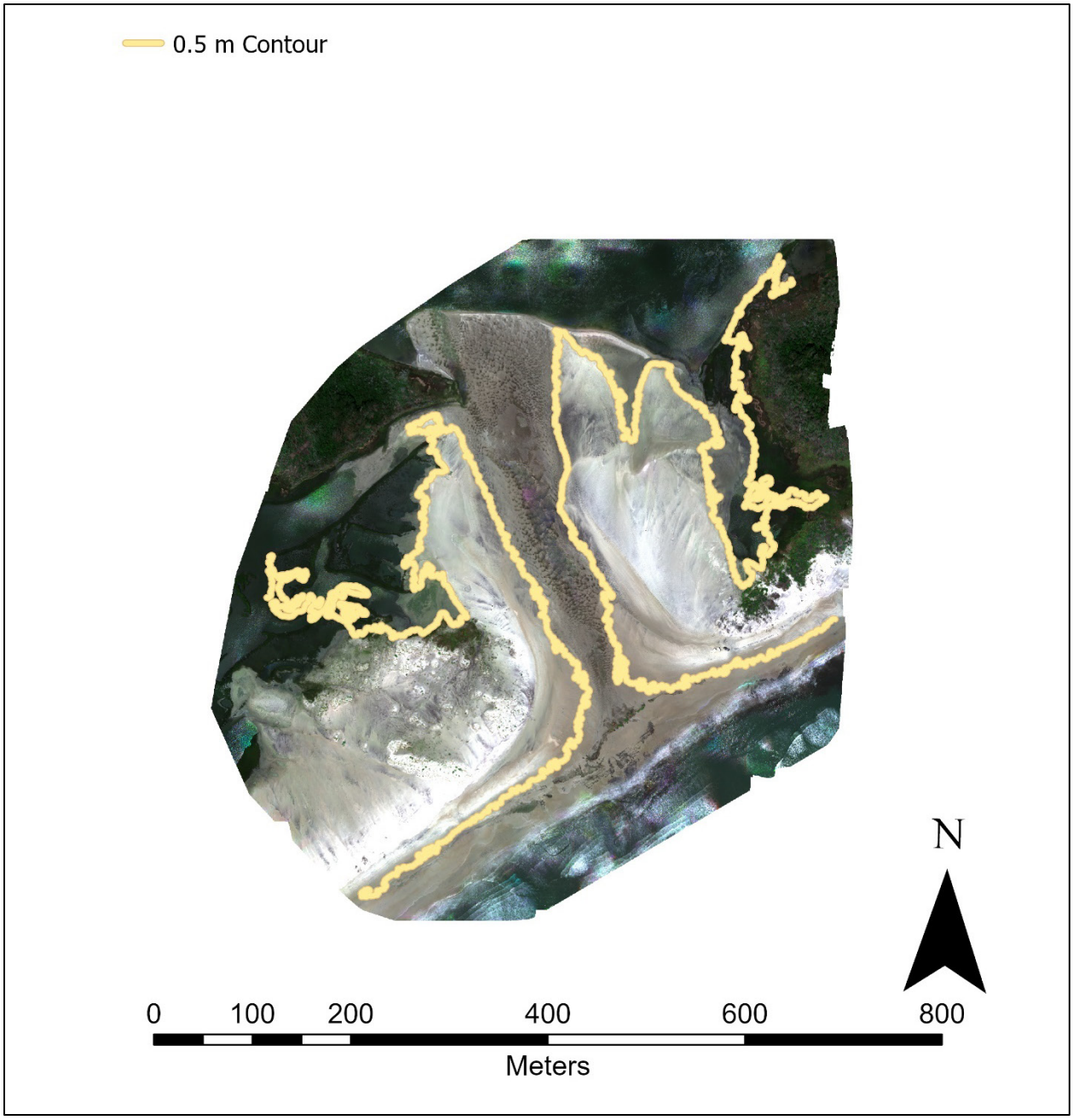


Figure 5.35. Orthomosaic of the Washover Fan (Overwash Area) on Onslow Beach Created from UAS Imagery Obtained on August 18, 2020.

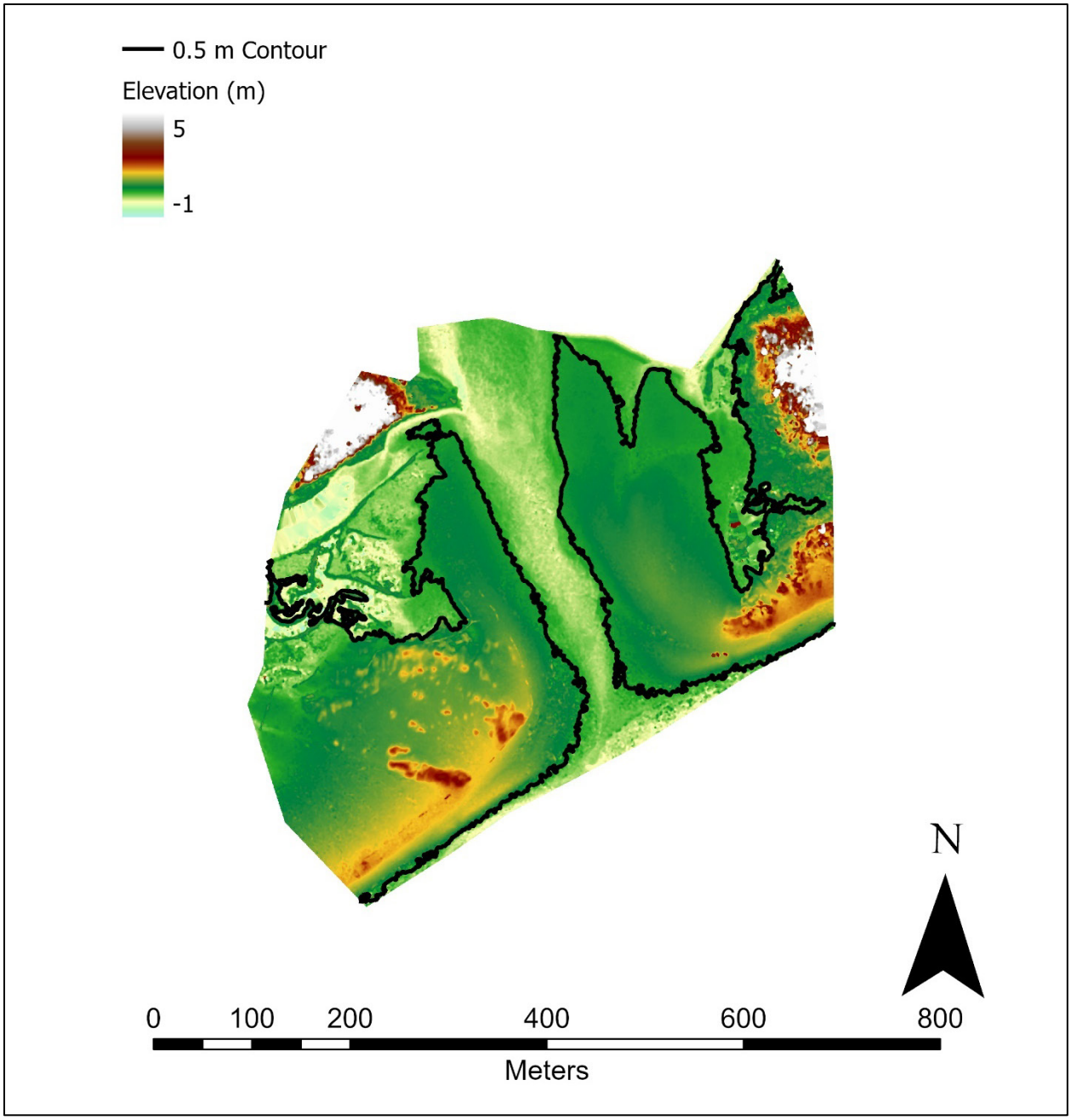


Figure 5.36. DEM of the Washover Fan (Overwash Area) on Onslow Beach Created from UAS Imagery Obtained on August 18, 2020.

5.1.6.3 OBJECTIVE 3 Species of special concern

The sea turtle crawl marks were created at 9 locations across Bird Island on October 28, 2019 (Figure 5.37A). The wind speed was 6 m s^{-1}, gusting to 10 m s^{-1}, for about 2 hours between the time we created the marks to when they were initially imaged with the eBee X. This wind speed is well above the 5 m s^{-1} threshold velocity for the transport of sand and explains why the marks are not more pronounced in the initial image (Figure 5.38A). The 9 crawl marks were recognized by an independent observer in the initial RGB mosaic. We imaged Bird Island again on October 29, 2019, after the wind speed was above the threshold sand-transport velocity for an additional four hours (Figure 5.37B). The independent observer identified the 9 crawl marks again on this final mosaic, but their expression was even more subdued than the previous day (Figure 5.38B).

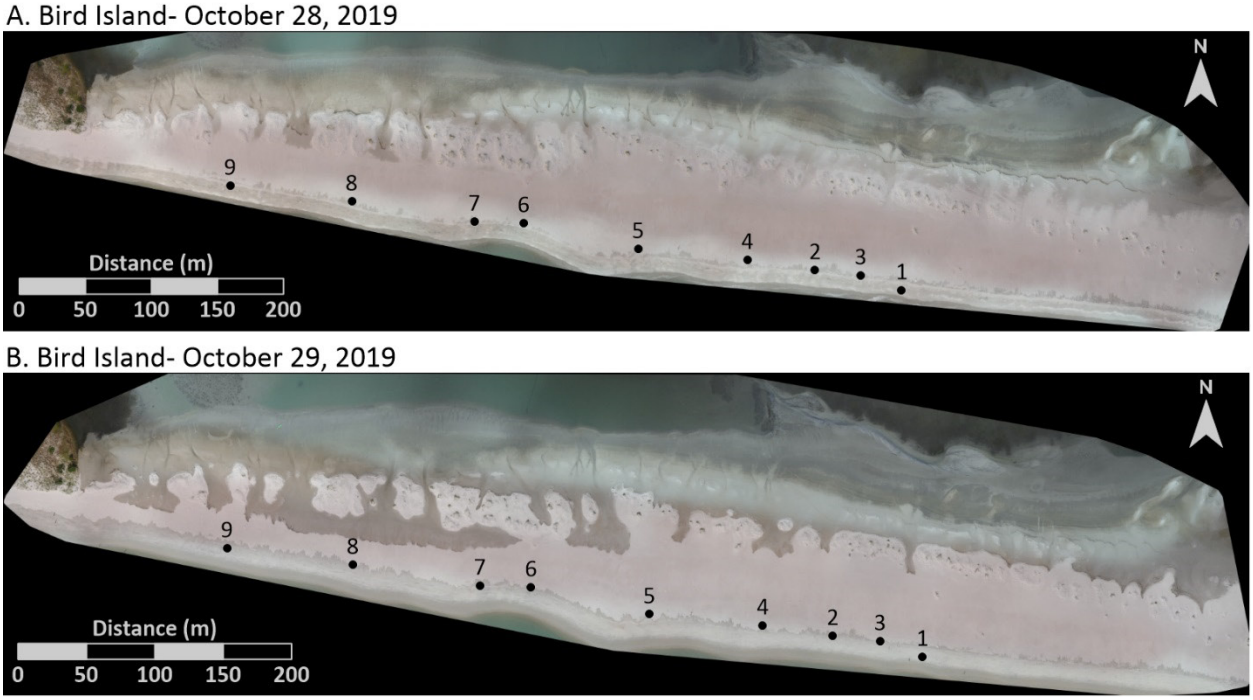


Figure 5.37. Mosaic of Bird Island from Images Collected with the eBee X on the Day the Turtle Crawl Marks Were Made (A) and the Subsequent Day (B).

The location of each crawl mark is indicated by a black circle and labeled by number.

Figure 5.38. Example of What Crawl Mark 4 Looked Like 2 Hours After it Was Created (A) and ~ 24 Hours After It Was Created (B), as Identified by An Independent Observer.

5.2 TEST DESIGN (FIRE)

5.2.1 CONCEPTUAL TEST DESIGN

Tests were designed to understand the ability of UAS to improve both real-time situational awareness during prescribed fires (objectives 2, 3, 4, and 5) and monitoring/measuring fire effects (objectives 1 and 3). A combination of flight tests and end-user interviews/feedback at the CNF, TNC, MCBCL, and TTRS were used to meet performance objectives. Limited availability to work on prescribed fires at MCBCL did provide opportunities to engage with other agencies and organizations with similar goals and objectives for managing ecosystems with fire. Approaches for using UAS on prescribed fire are broadly applicable across the southeastern coastal plain.

5.1.1 Habitat Assessments: Burned areas were mapped with RGB video and imagery to understand the potential to improve MCBCL methods of assessing fire quality, and to communicate a host of information to fire managers about the quality of a burn in meeting objectives. While only post-fire flights are needed to map area burned and severity (crown scorch), by gathering pre-fire information as well, shifts in habitat character (e.g., shrubs versus herbaceous cover reflecting repeated season of burn over time) can be tracked.

5.1.2 Hotspot Identification: Post-burn flights were flown with dual RGB and thermal video to identify areas that were still actively flaming or smoldering. Locations of hotspots determined through traditional ground-based sampling were compared to hotspots determined via UAS.

5.1.3 Situation Awareness Assessment: A usability and spatial awareness assessment of a small personal drone was conducted with trained DoD environmental managers. Operators launched a small drone and used the system to gain perspective on their current location and nearby conditions. This included providing compass bearings to navigational landmarks used in the burn plan including key rally points for fire operators. A follow up interview and survey of the participants and observers was implemented.

5.2.2 BASELINE CHARACTERIZATION AND PREPARATION

Prior to flying on fires, communications with fire managers provided insights into the landscape and the general approaches used during prescribed fire operations. The team becoming familiar with standard protocols guided the development of the survey and information gathering sessions. While standard preparations were made to prepare for test flights, areas were examined on satellite imagery, and air space was checked, the majority of the preparations could not occur until the day of the fire. Final ignition locations, acreage to be burned, and location for the team were not determined until just before the fire. The team participated in pre-fire briefs which allowed for integrated planning with the crew and additional insights into the operations of prescribed fires (Figures 5.39 and 5.40). Objectives 1, 2, and 5 were directly targeted during and immediately after prescribed burns. Objective 4 proved difficult to directly test during an operational fire and that became apparent on the fires. Simulations were prepared to assess utility and ease of use in combination with surveys.

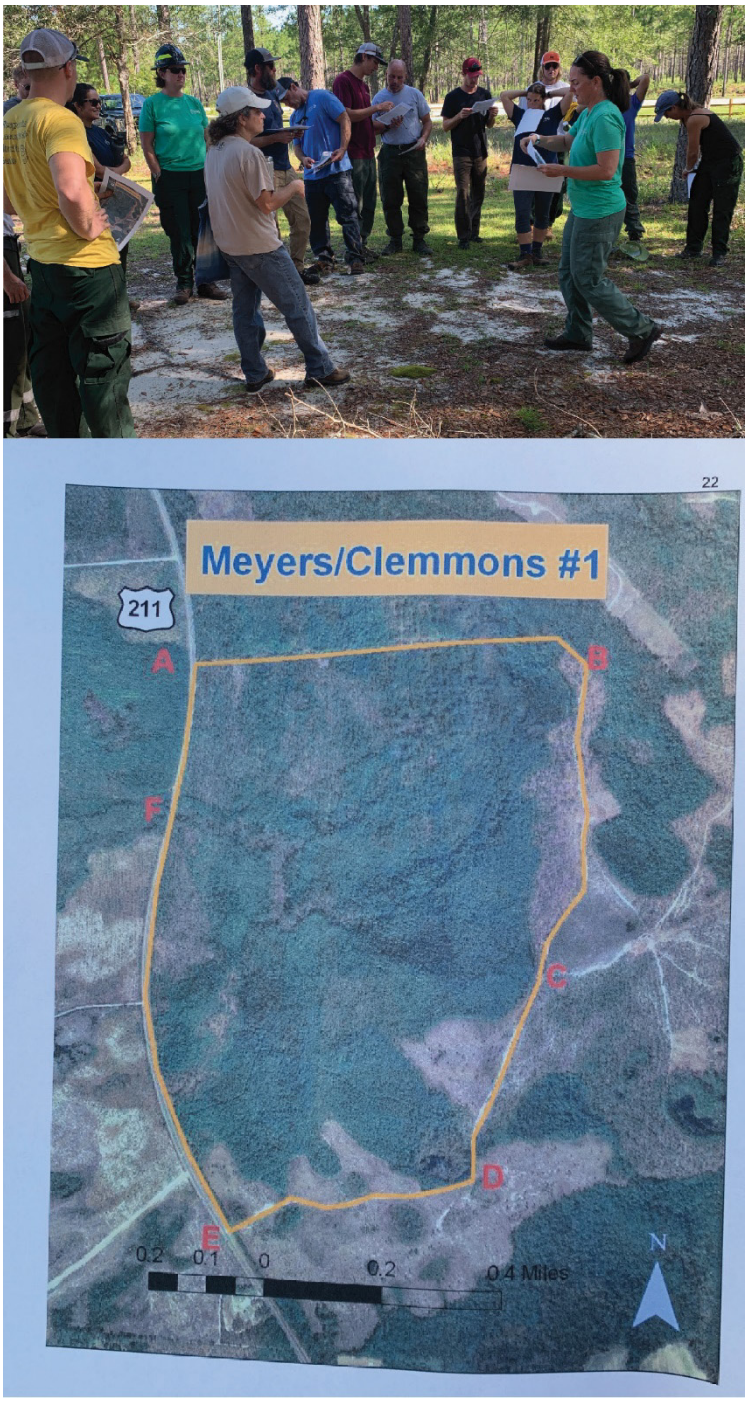


Figure 5.39. Green Swamp Preserve pre-fire Briefing by TNC Personnel (Top Panel) and Map with Staging Areas and Reference Points (Lower Panel).

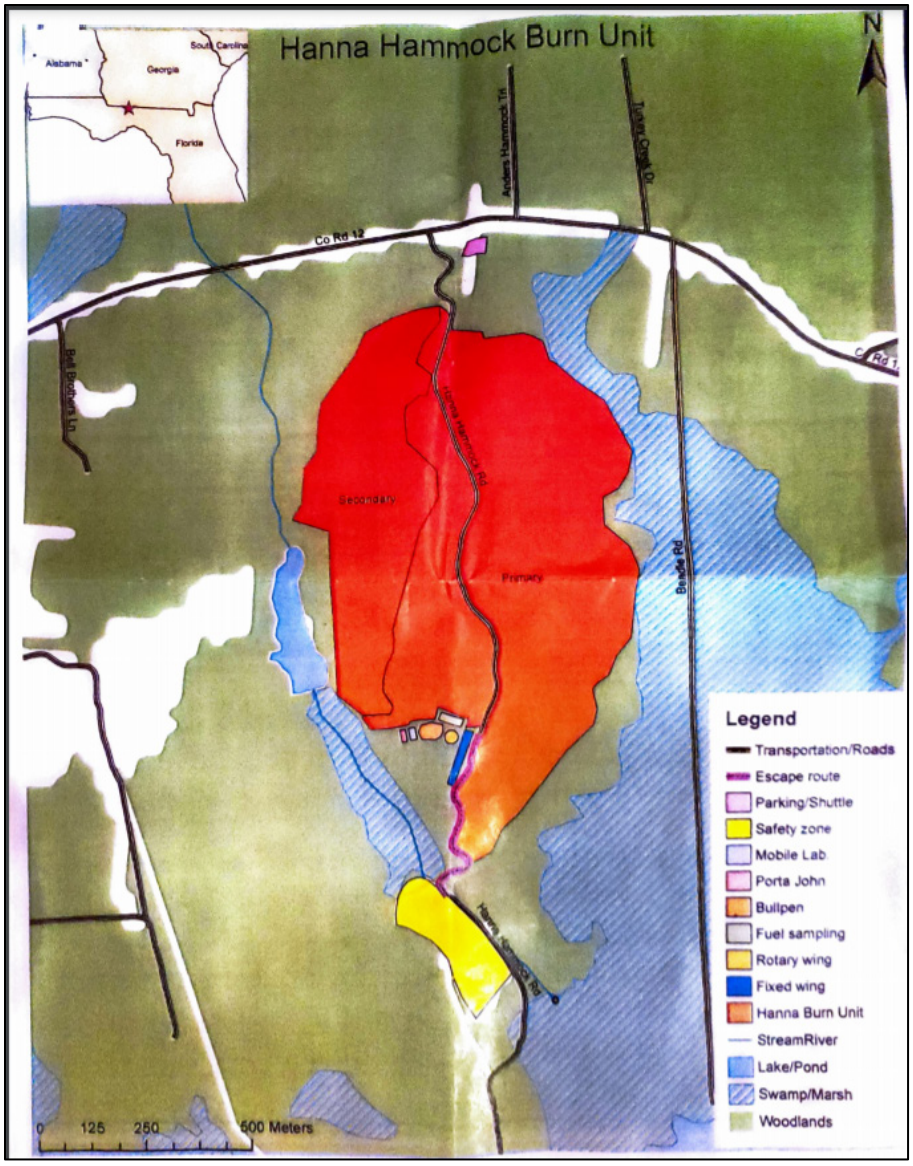


Figure 5.40. TTRS Pre-fire Briefing Map.

5.2.3 DESIGN/LAYOUT OF TECHNOLOGY & METHODOLOGY COMPONENTS

Prescribed fires were conducted by the cooperating organization to meet their management needs and testing was most effective on operational burns, therefore no special considerations were asked for during demonstrations. All fires were carried out operationally. Demonstrations were conducted with fixed-wing and multirotor UAS, examples of which are depicted in Figure 4. UAS, specifically the eBee X fixed-wing (see Figure 5.3) and Parrot Anafi multirotor aircraft (Figure 5.41), were fitted with EO (RGB) and IR sensors for each mission demonstration. The multirotor was used for both situational awareness and mapping, while the fixed wing was exclusively for post-fire mapping.

Figure 5.41. Anafi USA (Parrot).

5.2.4 FIELD TESTING

Field testing took advantage of every prescribed fire opportunity to demonstrate the utility of UAS in prescribed fires. Ultimately four locations and organizations were utilized to meet the objectives. Table 5.7 outlines the activities at each site.

Table 5.7. Locations and Activities Where Objectives Were Achieved and the Equipment Used.

Location	Activity	Objective	Equipment	Date
CNF	Survey/info gathering	4,5	Anafi	5/2019
TTRS	Fire	1,2	eBee, Anafi	2/2021
TNC	Fire	1	Anafi	8/2019
MCBCL	Survey/simulation-demonstration	4,5	eBee, Anafi	2/2020 4/2021

5.2.4.1 Operating Parameter: Orthomosaic RGB Imagery

UAS collected RGB imagery is at the core of habitat assessment, which is reflected in objective 1 as post-fire mapping severity and extent of burn. Pre-fire mapping, as mentioned above, provides the ability to track long-term habitat change. Mapping of pre- and post-fire only required producing an orthomosaic of the site and a spatial resolution <1.0 m. The eBee X was configured to collect photos of the site in a single grid pattern with each photo overlapping an adjacent photo by >50% (Figure 5.42), collecting approximately 500 images. No GCPs were necessary. Images were processed through Structure from Motion software to generate the final orthomosaic and analyzed through supervised classification in ArcGIS.

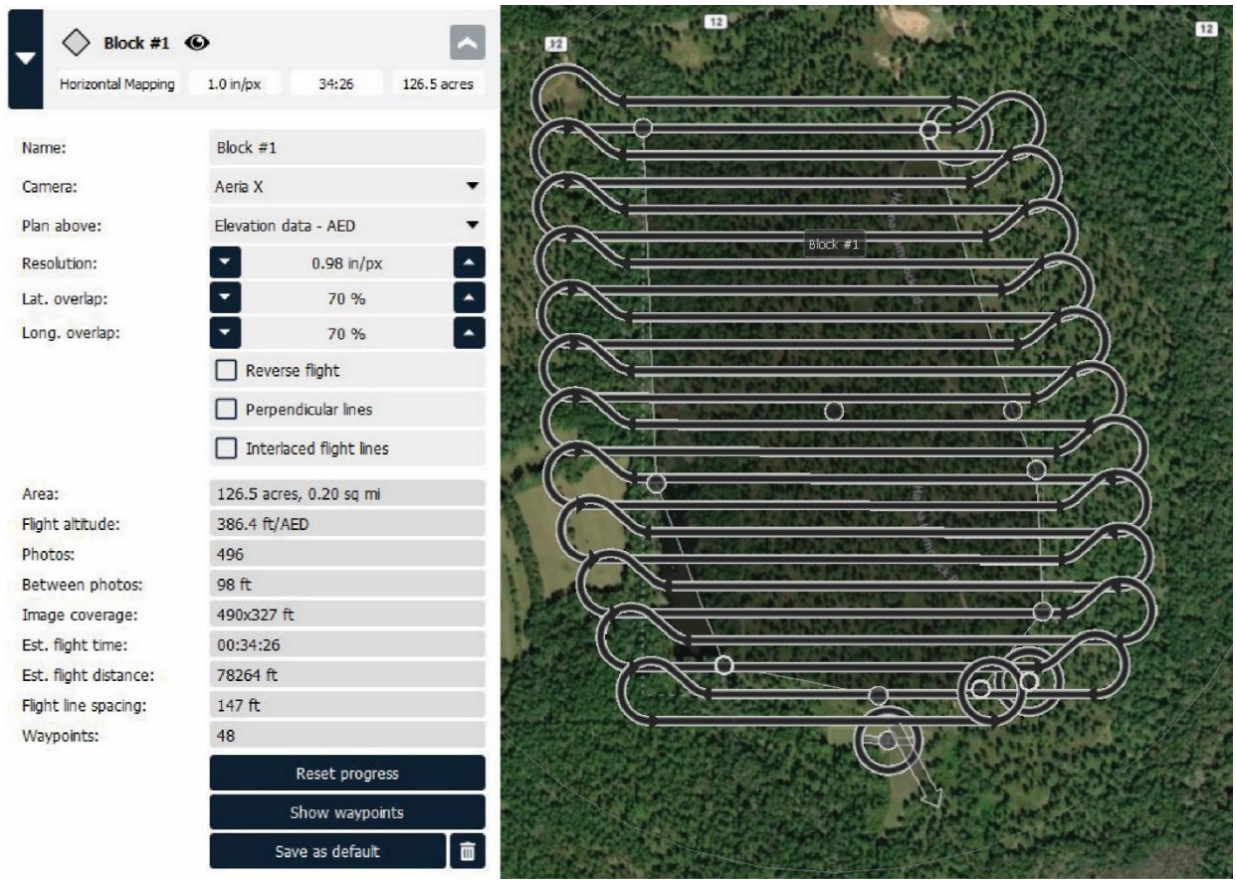


Figure 5.42. Mission Plan at TTRS for the Sensefly eBee Created in the eMotion Software.

5.2.4.2 Operating Parameter: Live Video (RGB)

Live video in RGB provides a real-time, overhead perspective for situational awareness. The Anafi's RGB sensor provided live video feed to the operator. There is no processing necessary, however the video is archived on a SD card for later review. Fire crews can observe a variety of landscape and safety features. In coordination with the burn boss, the drone team (operator and visual observer) piloted the drone to observe the progression of the fire line and the locations of fire-crew personnel. The burn boss could view the live-video feed and instructed the drone team towards areas of concern.

Figure 5.43. UAS Operator and Burn Boss (Left Panel) Examining the Visual RGB Feed Provided by the UAS (Right Panel).

5.2.4.3 Operating Parameter: Live Video (Thermal)

Live video in thermal provides a real-time, overhead perspective for hot spots (Objective 2). Fire crews can safely evaluate a stand following active fire, searching for smoldering and burning hot spots. These observations were conducted after prescribed fire was complete and done during a time called "mop-up." After a fire, the concern is that smoldering and burning fuels (large stumps, for example) will re-ignite and spark, creating potential, unattended, wildfire hazards. Locating hot spots without having to enter a stand was tested for efficiency (Figure 5.44). The safety advantage is clear.

The equipment tested for 5.2.4.2 Operating Parameter: Live Video (RGB) is the same equipment for thermal live video, thus providing the fire manager a dynamic UAS with multiple functions. The Anafi provides data fusion with a thermal overlay over the normal video footage to provide both thermal signatures with the context of a scene.

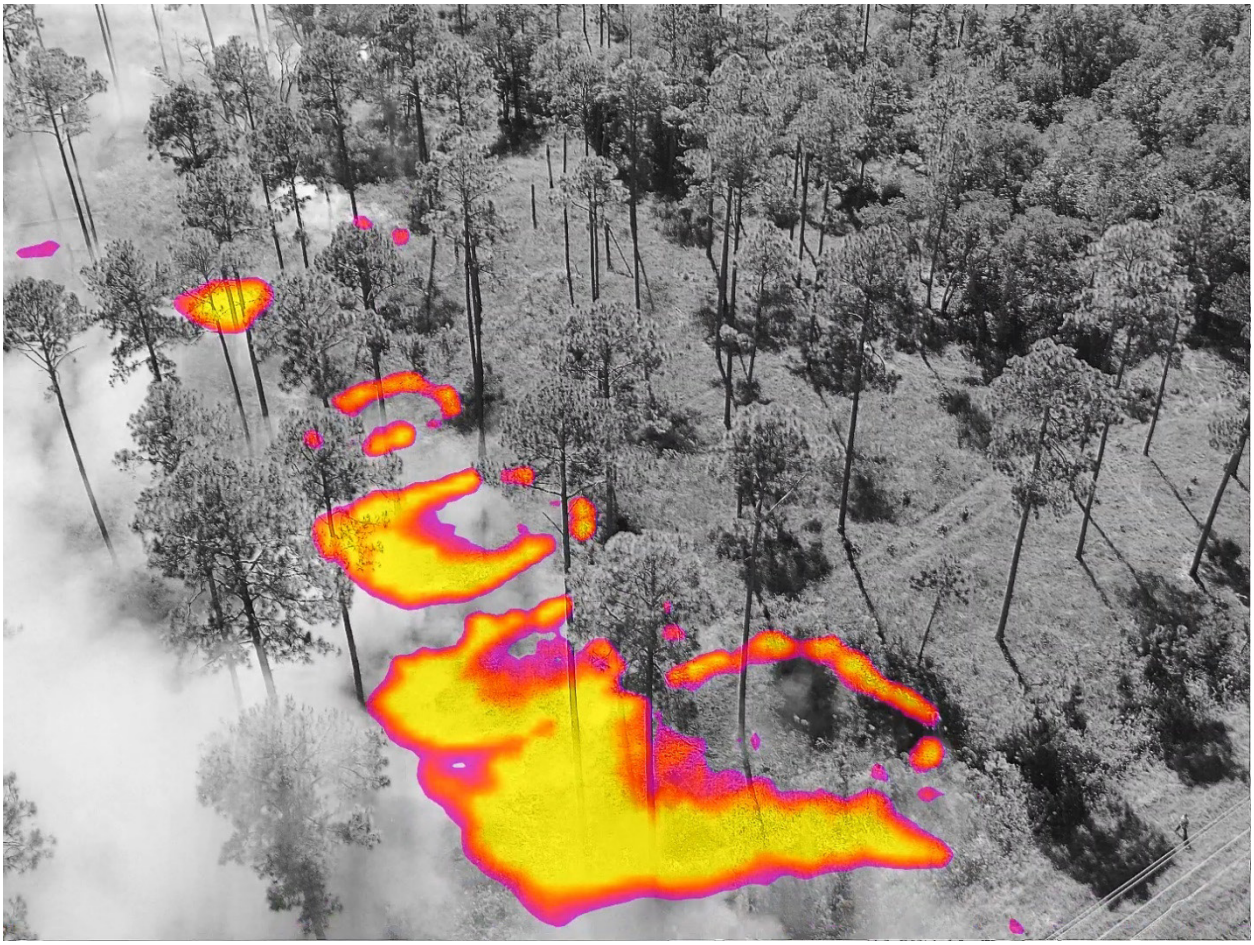


Figure 5.44. Thermal Overlay Live Visual and Recording by the Fused EO/IR Video Feeds in the Anafi Flight Application.

The RGB is transformed to grayscale to allow the thermal overlay to stand out.

5.2.5 SAMPLING PROTOCOL

Before and after burn imagery was collected using multirotor and fixed-wing aircraft on TNC and TTRS lands (Table 5.7). Mission planning was done prior to arrivals and modified day-of-burn, after the preburn brief at each of the sites.

- TNC, a 150 ha (370 acre) stand was burned in the Green Swamp and a small parcel (6.5 acres) was mapped using the Anafi before and after a prescribed burn. Live hotspot identification using RGB/thermal video and ground-truth transects along the fire line (during burn), and feedback from participants (after training and post-burn).
- TTRS, a 60 ha (150 acre) stand was burned and mapped using the eBee X aircraft before and after a prescribed burn. Live hotspot identification using RGB/thermal video and ground-truth transects along the fire line (during burn), and feedback from participants (after training and post-burn).

Working with MCBCL, CNF, TNC, and TTRS, we operated in a diversity of burn conditions and management styles. Participants in our training and demonstrations were interviewed, and a follow-up online survey (using standard Likert scale measures) captured end-user qualitative assessment of the feasibility and utility in using drones for fire management. Qualitative Objectives were met through a variety of information gathering sessions. We collected qualitative data in the form of both informal interviews/feedback and formal surveys from fire burn crew personnel (e.g., burn boss, firing boss, technicians). A sample survey can be found in Section 5.2.6.5.

Emphasis of information sessions for qualitative metrics was based on:

- Ease of Use*: ability of a firefighter to use UAS technology, who can effectively use a drone to get a bearing to a rally point and navigate to that point*
- Improved Situational Awareness: *responses that indicate positive feedback of UAS use compared to ground-based methods*

5.2.6 SAMPLING RESULTS

5.2.6.1 OBJECTIVE 1 Improve efficiency of fire assessments

Two parcels of forest were imaged pre- and post-burn and the details of those missions are included in Table 5.8. Before and after imagery clearly show the extent of the burn area (Figures 5.45 and 5.46), while further analyses can be run to generate more qualitative measures of burn efficacy (see Appendix C).

Table 5.8. Mission Details for Demonstrated Pre- and Post-burn Imagery Collection at Two Sites and the Time Required to Create the Products for Visual Inspection and Geospatial Analysis.

Site	UAS Area (acres)	Aircraft & Sensor	Flight Time (min)	# Images	Processing time (min)	Resolution (cm)
Green Swamp Preserve	6.5	Anafi RGB/Thermal	6	35	20*	2.25
Tall Timbers Research Station	85	Anafi RGB/Thermal	10	Live video	NA	4K
Tall Timbers Research Station	85	eBee RGB	38	~500	120**	2.93

*CPU: Intel(R) Core(TM) i7-6800K CPU @3.40GHz; RAM: 64GB; GPU: NVIDIA GeForce GTX 980

**CPU: AMD Ryzen Threadripper 1950X 16-Core Processor; RAM: 64GB; GPU: NVIDIA GeForce GTX 1080 Ti

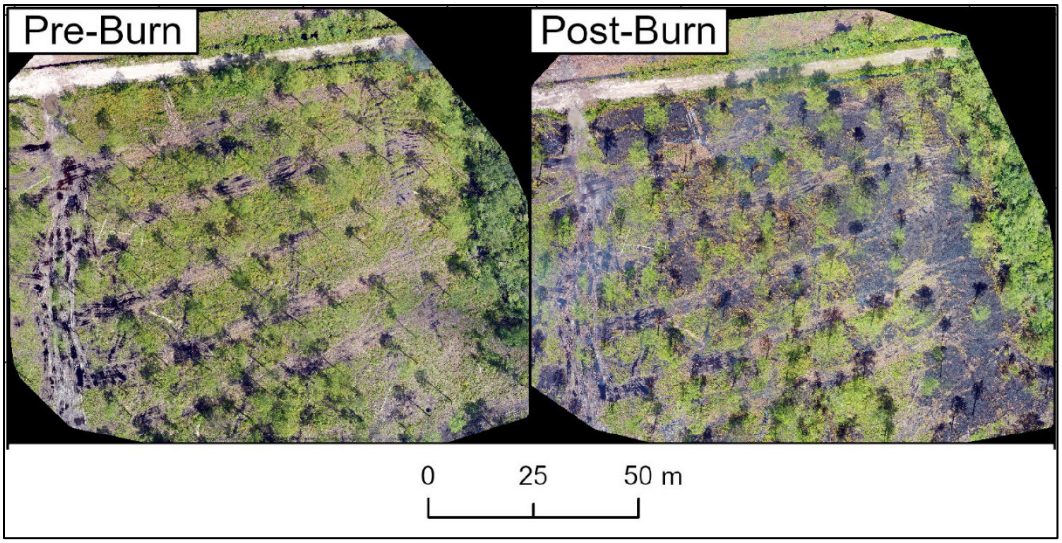


Figure 5.45. Green Swamp Preserve RGB Orthomosaics of Sample Area Before and After Prescribed Fire.

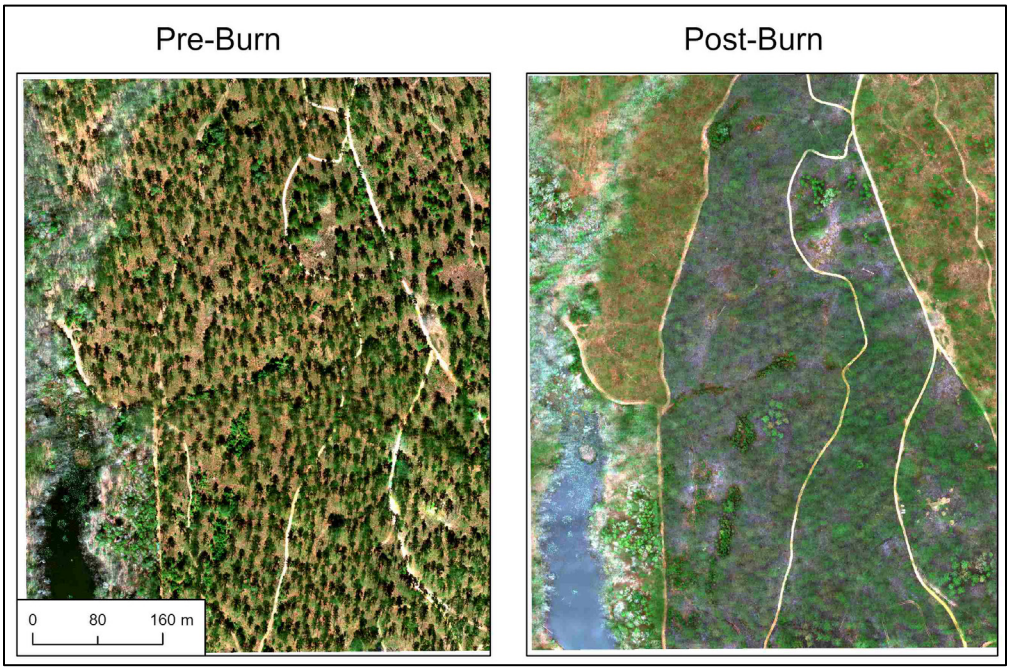


Figure 5.46. TTRS RGB Orthomosaics Before and After Prescribed Fire.

5.2.6.2 OBJECTIVE 2 Accurately identify fire hotspots using UAS in longleaf pine forest

Use of thermal imagery during the burn was able to effectively track fire movement and areas that were still actively burning. This matched ground observations of areas that were within visual range of the perimeter survey (Figure 5.47), but also identified areas that were obstructed from view and beyond visual range (Figure 5.48).

Figure 5.47. Thermal Image of Active Burn Areas Along with a Fire Crew Observing Burn Sites.

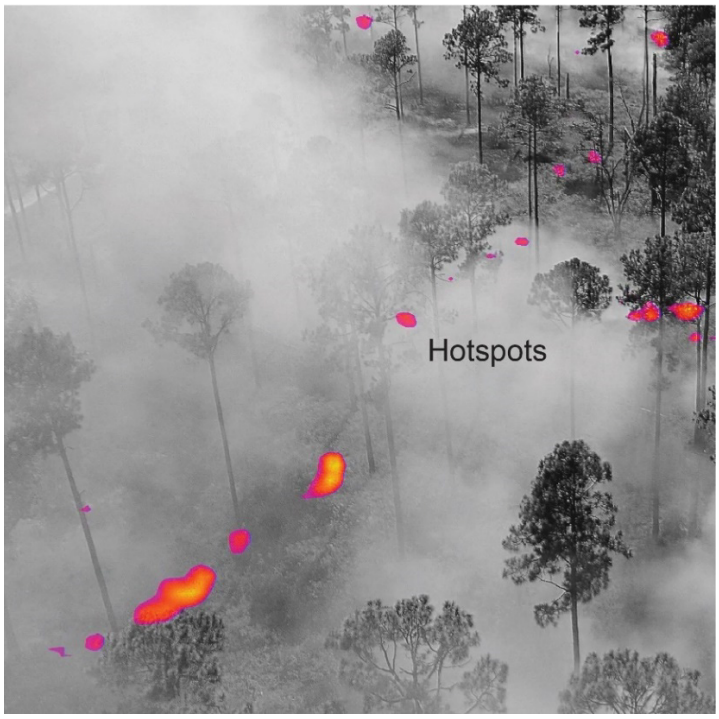


Figure 5.48. Thermal Image of Area After Fire Progression to Identify Areas that Are Still Actively Burning.

5.2.6.3 OBJECTIVE 3 Cost reduction

Pricing estimates between helicopter operations and UAS missions were compared considering the operations incorporated into the demonstration. Estimates of helicopter costs for CNF fire management include a $1,700 daily access fee and $1,300 per hour operations cost. Costs of UAS operation were calculated and detailed in Section 7.0. The per hour cost for UAS operations when initial capital investment is distributed across the UAS lifespan is much lower than the hourly costs for manned operations.

5.2.6.4 OBJECTIVE 4 Ease of use

Course-trained fire personnel were able to launch, operate, and recover UAS technology to obtain their bearings and survey their surroundings (Figure 5.49). Additionally, DoD participants were interviewed and surveyed to gather their impressions for ease of use. (See comments provided in Section 5.2.6.5).

Figure 5.49. A Trained MCBCL Fire Crew Member Operates the UAS and Gathers Information About His Surroundings.

5.2.6.5 OBJECTIVE 5 Situational awareness

We sought to demonstrate both ease of use and improved situational awareness of UAS during prescribed fires. To fulfill these objectives, we collected qualitative data in the form of both informal interviews/feedback and formal surveys from fire burn crew personnel (e.g., burn boss, firing boss, technicians) (Figure 5.50).

"This application (drones) would be very useful for flying pocosins, pre-burn, where we want to verify that pocosins are wet before burning." (*if water in pocosins, they would use the pocosin edge as a known edge the fire would burn to*)

"Drones would be great for the burn boss, who's in charge of so many different aspects of fire safety and management. They're usually driving around the whole time; the ability to stay put would be very beneficial."

"From the perspective of the burn boss, being able to stand still, with a view of the "action" from the drone, and not have to be running around would be hugely beneficial and efficient... Having the drone operator standing physically close to the burn boss (repeater screens would really be ideal, so they can each be seeing the same thing), so the burn boss can see what's happening and make the calls about how to proceed... Essentially, the same scenario as heli ops (the heli pilot is simply flying and being told where to go by the burn boss)."

"It can be very difficult from a helicopter to spot a fire crew and gear on the ground. Drones could improve this situational awareness immensely! We'd never even need to call a heli (unless for aerial ignition) if we had drone capabilities."

"Hotspot identification after would be a very useful application, perhaps the most useful." *(not in the case of a massive ignition or a wildfire, but for monitoring what's hot along the fire lines in a ground (prescribed) fire)*

In response to seeing the screen and visual perspective from the Anafi: "Oh, hell yeah! Sweet!!"

In the instance of a wildfire (not a prescribed burn): "If we have one of those flare up, we have a huge lag time (4+hrs minimum) before we can get the resources (heli) from the state; in the interim, the multicopter could be a very useful tool."

Quotes from staff of MCBCL Environmental Conservation Branch

After demonstrating the UAS applications (drone and sensor options) in the field, we asked the following questions to the prescribed fire personnel present (n = 4):

SURVEY QUESTIONS Please rate the following using the scale below: 1= Very Unuseful/Very Unlikely, 2 = Unuseful/Unlikely, 3 = Neutral, 4 = Useful/Likely, 5 = Very Useful/Very Likely

1. How useful is the aerial perspective provided by drones? **100% responded Very Useful**
2. Does the Electro-Optical camera have the resolution to provide useful information? **100% responded Very Useful**
3. Does the InfraRed camera have the resolution to provide useful information? **100% responded Very Useful**
4. Does the drone achieve a high enough altitude (<400') to provide a useful perspective? **100% responded Very Useful**
5. Does the drone cover enough area / distance to provide useful additional information? **50% responded Useful; 50% responded Very Useful**
6. Likelihood you would integrate drones if given the opportunity? **100% responded Very Useful**
7. Likelihood you would invest funds for UAS training? **100% responded Very Useful**
8. Is 20 minutes of flight time enough to increase situational awareness? **50% responded Useful; 50% responded Very Useful**

Combined with the quoted feedback above, we feel confident saying that we have met our qualitative performance objectives.

Figure 5.50. Fire Managers from MCBCL Observe UAS Visual Feeds (EO and IR) during a Partner Meeting.

6.0 PERFORMANCE ASSESSMENT

6.1 PERFORMANCE ASSESSMENT (COAST)

6.1.1 OBJECTIVE 1 Survey Efficiency

Demonstrate improved efficiency, accuracy, resolution and cost of coastal mapping using a UAS versus ground-based and manned-aircraft methods.

Barrier island management is commonly centered around monitoring sand volumes because if sand volume persistently decreases through time, restoration such as the installation of sand fences, planting dune grasses, and beach nourishment needs to be considered as options to maintain elevation and protect infrastructure. To compare the various methods of beach surveying we calculated beach volume at the site using data from the two transects, images from the eBee X, terrestrial LiDAR, and Airplane Lidar (Table 6.1). Volumes were measured from a horizontal plane at 0 m NAVD 88, and measurements based on the transects, the eBee X and the terrestrial LiDAR should be similar because those data were collected at the same time. The Airplane LiDAR data were collected eight months earlier which explains why that volume is ~2,500 m^3 lower than what was measured using the other methods. Beach volume based on the transects (10,805 m^3) was calculated as (A_{T1} x D/2) + (A_{T2} x D/2), with A = the area between the surface and 0 m NAVD88 at each transect and D = the distance between transects. Error associated with the transect volume measurement (± 463 m^3) is based on the GPS error at each measurement location and was the lowest of the methods tested; however, this error is an underestimate because it incorrectly assumes that the cross-beach morphology, measured at each transect, is constant for half the distance between transects. Volume error associated with the eBee X (528 m^3) and the terrestrial LiDAR (404 m^3) is defined as the standard deviation of the residuals between the respective digital elevation models and the 24 check points multiplied by the survey area. Volume measurements based on the eBee X and Terrestrial LiDAR are both similar (within error), but higher than the volume measured from the two transects. Volume error for the airplane LiDAR (1,002 m^3) is the reported 0.1 m vertical accuracy of the laser returns multiplied by the survey area and was the highest of all methods. The resolution of the eBee X orthomosaic (2.54 cm) is an order of magnitude higher than the airplane (30.0 cm). The survey based on the eBee X images achieved comparable or better accuracy and resolution over traditional manned aircraft and ground-based methods. In addition, it only took 10 minutes to map the small area using the eBee X (including take-off and landing) in comparison to 120 minutes for the ground-based methods, far exceeding the goal of 25% increased mapping efficiency. The cost of equipment and processing is also less for UAS than ground-based and airplane methods. That information is presented in section 7.0. Processing considerations are further discussed in Section 6.1.4.

Table 6.1. Beach Volumes Measured Using the Various Survey Methods.

Method	Beach Volume (m^3)	± Error (m^3)
Transects	10,805	463
eBee X	11,953	528
Terrestrial LiDAR	11,815	404
Airplane LiDAR	8,570	1,002

6.1.2 OBJECTIVE 2 Event monitoring

Demonstrate application of UAS for quantifying island impacts from seasonal or event-driven (storms, training) forcing, such as increased waves, wind, and water level.

Assessing storm impacts along barrier islands is always a challenge because storm paths are difficult to predict, which often results in a lack of pre-storm data. The US Geological Survey, NOAA, and the Army Corps of Engineers commonly map barrier islands after a storm, but lack a pre-storm survey. Obtaining pre- and post-storm surveys is also difficult because many other storm-preparation activities need to be completed prior to a storm, such as removing ground materials that could become projectiles in high wind, boarding up buildings, and evacuation. The research team had to prepare our homes and our work place for Hurricane Dorian; however, we still had time to collect pre-storm surveys. We demonstrated that pre and post storm surveys of a barrier island are easy to obtain using a UAS and it followed that regular monitoring of beach morphology was also achieved easily, as demonstrated at multiple sites along Onslow Beach and communicated to base personnel through a white paper (Appendix B) and a half-day demonstration event.

6.1.3 OBJECTIVE 3 Species of special concern

Demonstrate application of UAS for monitoring species of special interest in areas with UXO.

Monitoring and managing nesting sea turtles is challenging along the northeastern end of Onslow Beach and adjacent Browns Island due to UXO. Current methods include periodic airplane flights with a visual observer noting the presence of crawl marks. Results are unverifiable and survey frequency is every two weeks and likely miss many false crawls and nests. We achieved 100% detection of nine turtle crawls up to 24 hours after they were created using images obtained from the eBee X. Turtle monitoring with a UAS can be done frequently and results can be confirmed by the images, and archived for better threatened and endangered species monitoring.

6.1.4 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) softwares like Pix4D or the Pix4D-based Esri (ArcGIS) companion package Drone2Map. These softwares 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. An area of Onslow Beach surveyed was a 67ha section of the island, where we collected 686 images (24 MP), which would fall into the Large Projects designation above. The image set was processed on a machine with an Intel Core i7 CPU @ 2.90GHz, 16GB RAM, and an NVIDIA GeForce GTX 1060 and took approximately 7 hours to fully process and generate the 2D and 3D products. In comparison, the post burn image set for TTRS covered 85 ha, included 578 images and took only about 2 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-intense activity) occurs.

6.2 PERFORMANCE ASSESSMENT (FIRE)

6.2.1 OBJECTIVE 1 Improve efficiency of fire assessments

Initially, this objective was going to be measured through efficiency of mapping (m^2 mapped/hour) and data resolution (cm/pixel) using fixed wing and multirotor UAS. The success criteria would have been met if the total time required for UAS fire area mapping was less than half that of the traditional methods, including aircraft staging time and labor required for each method (See Section 7.0). Over the course of the project, we have learned that many groups (including our partners) use no quantitative metrics to assess burn efficacy, relying on the assumption of 100% burn across the acreage or qualitative perimeter scans of a parcel. Therefore, there was no benchmark to assess the efficiency of this method; rather, we have introduced a pathway for quantitatively assessing burn efficacy that was previously unachievable. This was further supported by qualitative information we received for Objectives 4 and 5 (see Section 5.2.6.5). Processing considerations are further discussed in Section 6.2.6.

6.2.2 OBJECTIVE 2 Accurately identify fire hotspots using UAS in longleaf pine forest

Accurate detection of active hot spots was clear in the RGB and thermal video. Through interactions and personal communications with fire crews from the 4 different organizations, it became evident that searches for hotspots are generally restricted to the perimeter of a fire area, as that area is assumed to be the most dangerous should there be a re-ignition. A fire of several hundred acres could take considerable time to search on foot for hotspots. A perimeter search can be done rapidly by vehicle but can miss smaller spots. The advantage to adding a UAS for fire crews is the ability to now survey the entire stand and assess the hotpot in relation to surrounding vegetation (for example, unburned vegetation that could ignite) (Figure 6.1).

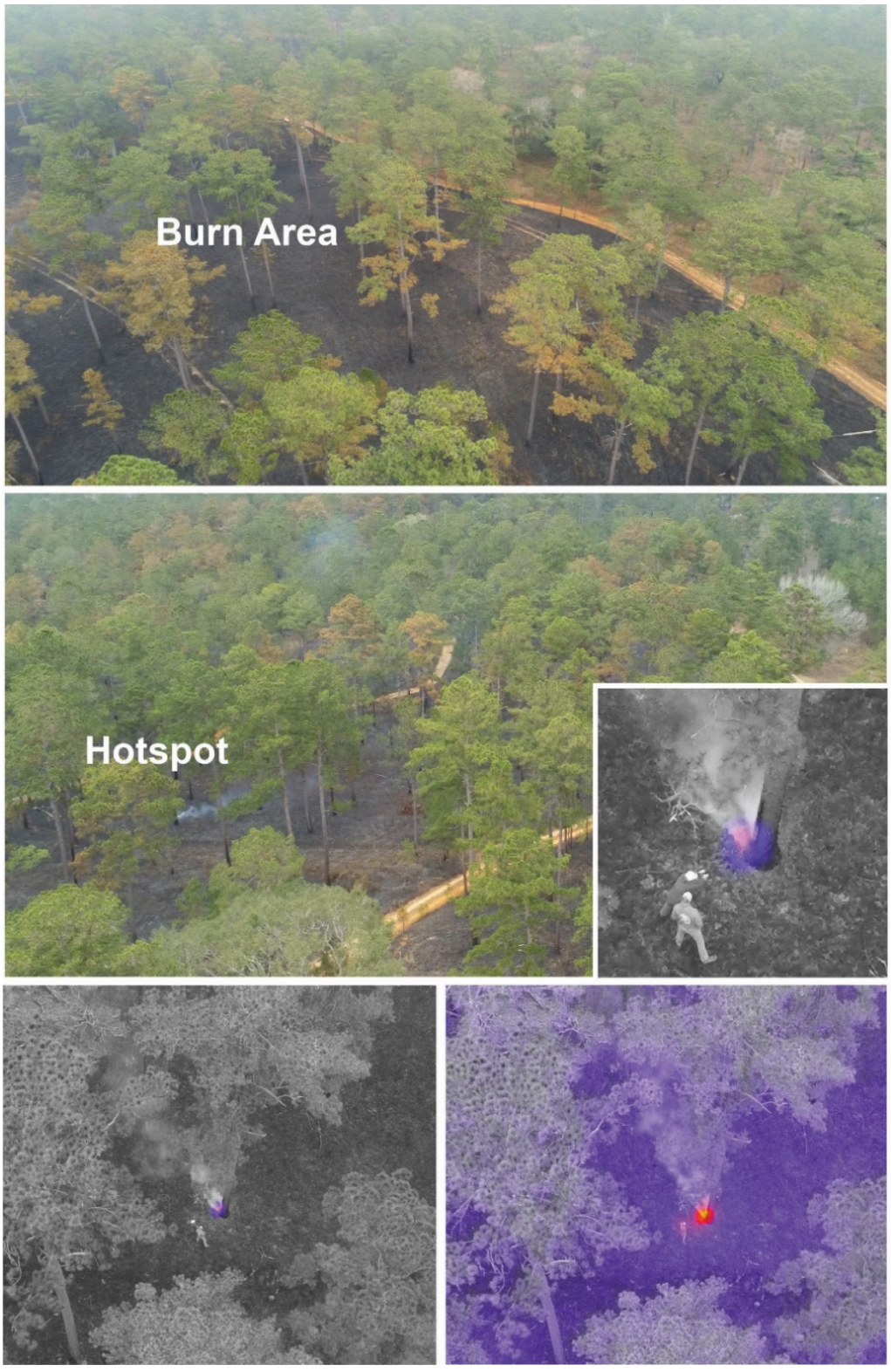


Figure 6.1. UAS Providing Situational Awareness, Showing the Burn Perimeter (Top Panel) and Active Hotspots (Middle Panel and Inset).

Thermal displays can be adjusted to amplify the thermal signature (bottom panels).

6.2.3 OBJECTIVE 3 Cost reduction

The costs associated with fire monitoring (US$/hour) were generated for both UAS and occupied aircraft. Costs of contracting a manned operation (including aircraft, personnel, and fuel over multiple burn seasons) were compared to the costs involved with purchasing and operating a UAS (including aircraft, sensors and accessories, training, and personnel time to operate the UAS that will be available through multiple burn seasons). The objective was met; UAS fire monitoring is substantially (>50%) less costly than contracting manned operations. (See Section 7.0). The utility of using UAS for certain operations around fire management and the cost savings associated is conditional upon certain burn variables, like size of the area being burned. UAS for fire monitoring is most beneficial in smaller burn areas (< ~200 ha), which are generally too small to require manned aircraft support. However, in larger burn areas, UAS can prove a highly useful tool to supplement manned operations, enhancing the capacity to monitor progression and fire line infringement.

6.2.4 OBJECTIVE 4 Ease of use

Trained personnel demonstrated the ability to safely and comfortably operate small UAS during a controlled burn. We documented fire personnel use of drones and we recorded feedback of trained fire managers about their comfort level using UAS and how it changed since participating in our program. Feedback was obtained through a combination of in person interviews as well as an online survey using standard Likert scale questions. The objective was met; all fire manager participants indicated an increased comfort with operating UAS and were able to successfully deploy UAS in the field. The more a new technology is used and integrated into a workflow, the more comfortable the users will become and more easily adapt to newer iterations of that technology.

6.2.5 OBJECTIVE 5 Situational awareness

Trained personnel demonstrated improved situational awareness during a controlled burn by using a small UAS for locating other personnel and active burn areas. Like Objective 4, we recorded feedback from participating fire managers about how situational awareness is affected by UAS use, which was obtained through interviews and an online survey. The objective was met; all respondents indicated that UAS increased situational awareness around burn operations.

6.2.6 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:

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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 Basic UAS Qualification (BUQ) training. Cost elements that are not applicable have been removed from the tables.

Table 7.1. Cost Model for Aircraft and Sensors.

Cost Element	Data Tracked During Demonstration	Estimated Costs
Procurement	Component costs for demonstration.	eBee X: $13,500 RTK/PPK Activation: $5,500 Anafi USA: $14,000 SODA 3D: $4,000 AERIA X: $4,000 Ancillary Equipment*:$1,200
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): $150/flight hour Visual Observer (VO): $100/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 ground LiDAR and accompanying required GPS survey unit. For fire management, the cost was compared to operating and access fees incurred by forestry helicopters.	Terrestrial LiDAR: $114,000 Trimble RTK GPS: $23,658 Access to NC VRS: $500 (academic price) Mobile hotspot: $50/mo **AS350B3 (heli)** flight time rate/hour $1,260 **Bell 407 (heli)** flight time rate/hour $1,193 Daily rates vary from $1200 to $2400 for Exclusive Use contracts and easily triple for any call-when-needed or on-demand contracts.

**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 selected both fixed-wing and rotary-wing aircraft to allow launch/land from most environments. Figures supplied in the table above are from manufacturer quotes dated from December, 2018 and at the conclusion of this report in June, 2021, costs remain unchanged. Many manufacturers offer bulk discounts for ordering several aircraft and sensors together. It is beneficial for an organization to purchase several aircraft on a single order for subordinate units. This will allow for the purchase of more systems and in turn add capabilities to a larger number of land managers.

Table 7.2. 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.	RiSCAN PRO software: $5000 (initial purchase) Annual maintenance agreement: $2,039 Trimble Business Center software: $2,295

Flight software is critical to operations as the aircraft cannot fly without it. The senseFly eBee X utilizes a computer-based program namd eMotion, and the Parrot Anafi uses the FreeFlight 6 tablet application. eMotion is included in the purchase of the eBee X package and FreeFlight 6 can be found on iTunes or Google Play for a free download. Mapping missions with the Anafi are performed via the free application Pix4DCapture.

All other known fixed-wing drones on the market include the operating software in the purchase of the aircraft as well. Most rotary-wing aircraft are flown via freely downloaded applications, which allow for basic flight functions.

Table 7.3. 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- Perpetual one-time license: $5,000
Operation costs	Image processing software is based upon a yearly subscription. Will have to be re-purchased annually.	~$800 /yr
Maintenance	Complete updates with latest version. No additional costs expected for updates outside of annual fee.	N/A
Lifetime	Indefinite assuming patches downloaded with latest version and firmware corresponding to aircraft and software.	N/A
Benchmark	Drone data processing cost compared to ground LiDAR software required for usage (coastal application). Cost of mission kit compared to ground visual assessment (fire application)	Merrick Advanced Remote Sensing (MARS) software: $10,000 (initial purchase) Annual maintenance: $4,995

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. Px4DMapper or similar application is essential.

Table 7.4. 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 Marine Corps order. Our expansion project (RC19-5218, REDDIE) will expand training efficiencies and costs across MCIEAST.

7.2 COST DRIVERS

A number of factors should be considered when choosing drones for coastal natural resource assessment and fire management. Initially, the nature of the management problem or question needing to be answered may drive this choice. For example, 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. Furthermore, in the present project the drone kit provided to installations was targeted at the broadest array of applications, which may not be necessary for certain locations (e.g., DoD sites that don't require longer endurance fixed wing flights to survey coastal areas). Tailoring the kit to suit an installation's specific needs may reduce the overall per flight costs if some pieces are not needed, but, likewise, further customization of the kit (more sensors) may increase the per flight costs. 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. These 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 USA ($7,000). However, as these systems become more prominent in the UAS market, their pricing should decrease.

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 and terrestrial laser scanning. Terrestrial LiDAR only provides topographic data, whereas the drone can provide topography, standard color, multispectral, thermal, and hyperspectral data - often in the course of a single survey.

There are situations unique to DoD (and perhaps to each installation) that may present additional savings. For example, a portion of Onslow Beach at MCBCL is an impact area with UXO. Loggerhead sea turtles nest in this area and surveying requires either the use of manned aircraft or escorts by the Explosive Ordnance Division (EOD). These alternatives can cost in the thousands over the course of the turtle nesting season. There are also two additional large impact areas that are over 10,000 acres; skills learned and applied at Onslow Beach using drones can now be used to survey these areas for T&E species that occupy this habitat. Entry by foot requires EOD escorts and UXO sweeps, adding additional costs and time away from unit activities for EOD members.

7.3 COST ANALYSIS AND COMPARISON

Aerial remote sensing platforms generally have three primary costs: acquisition of platform and sensors, their maintenance, and operational costs (planning, deployment, and piloting), and pilot training/staffing. Additional costs include insurance, analysis software, transportation, and supplementary fieldwork needed for ground truthing. In many cases, drones bypass significant costs prior to deployment by virtue of their small material value and extreme portability. Occupied aircraft or helicopters entail considerable purchase and maintenance costs owing to their size and safety requirements, but drones have low purchase and maintenance costs owing to their reduced size and risks.

The affordability of drone platforms is perhaps one of the most obvious positive qualities of the technology for use in natural resource management, and a growing number of studies, including the work conducted under this project, have indicated significant cost savings for some applications. It is challenging to directly compare the operational costs of UAS methods against operational costs of occupied aircrafts, which vary greatly by mission requirements. Maintenance costs for drone platforms are remarkably low, while operational costs such as piloting may not deviate as significantly.

While challenging, it is useful to contemplate comparisons between traditional methods applied to natural resource management at DoD installations (in our case ground-based surveys and surveys conducted with occupied aircraft) with drone-based approaches. For the purposes of this comparison, we employ basic costs provided above in Tables 7.1-7.3 to generate survey costs at an hourly rate and a spatial range of a square kilometer. These final per hour and per area costs were calculated using the acquisition, operation, maintenance, and associated software fees given an estimated number of surveys each year across the equipment lifespans. The quadcopter will likely be flown 112 times/yr (twice weekly). The eBee will be flown weekly during summer months (turtle surveys) and monthly during the rest of the year for coastal and other natural resource monitoring (25 flights/yr).

In terms of drone-based surveys using the fixed wing aircraft, we expect an hourly cost of $643. This value is less for the quadcopter survey at $326, largely due to lower acquisition costs and the number of times we anticipate deploying the quadcopter. In comparison, chartering occupied aircraft for surveys is estimated to cost between $1,000 and $1,200 per hour. These comparisons are especially useful for considering programs that charter aircraft frequently to conduct turtle surveys in areas of UXO or that depend on federal organizations like the USGS and NOAA for collecting post storm LiDAR data using a manned aircraft.

In terms of per hour costs, ground-based laser scanning surveys are cheaper per hour than a drone-based approach. This does not hold true for comparisons across spatial metrics. While terrestrial LIDAR surveys may cost less per hour, they are less efficient at covering larger areas. In this case, the estimated costs per square kilometer of survey area become relevant, and are much higher ($8,300) than drone-based costs ($1,000 to $1,300 for fixed-wing and quadcopter respectively). Operationally, it becomes important when it takes 5 days to map one-eighth of Onslow Beach using the terrestrial LiDAR in comparison to a single fixed wing drone survey. See Table 7.5 for a comparison of the aforementioned costs.

There is increasing evidence that on-demand and real-time assessment of environmental conditions can only be performed in a cost-effective way with a UAS, and examples from other projects bear this out. In population surveys of Sandhill cranes (Mailey 2013), drone-based surveys incurred a low cost ($2,600) that was 60% that of the same survey using a government-owned aircraft ($4,300) and just 7% the projected cost of the same survey using a private contractor ($35,000). Similarly, operating costs for drone-based surveys of seals in 2016 (~$200 per day and $500 per flight) were lower than those of surveys from occupied aircraft (~ $350 per day and $2,200 per flight hour) - a cost difference greater than a purchase of two new research-grade drone systems (Pricing, January 2019 pricing) including combined thermal and RGB camera systems. Cost benefit analyses for other applications show similar results. For example, drone applications in wildfire management could provide an estimated 31% cost savings for fire suppression activities compared to conventional helicopter-based approaches (Christensen 2015). In examples from Mesa County, CO, USA UASs accomplished volumetric estimates of materials in a landfill for $300 operational costs (not including the cost of acquiring the aircraft) whereas the same task using an occupied aircraft would entail $10,000 operational costs. Similarly, UASs accomplished volumetric assessments of aggregates at a gravel pit for $120, again in contrast to the $10,000 operational costs using an occupied aircraft (Anonymous 2013). There are situations unique to DoD that present additional savings. For example, a portion of Onslow Beach at MCBCL is an impact area with UXO. Loggerhead sea turtles nest in this area and surveying requires either the use of manned aircraft or escorts by the Explosive Ordnance Division (EOD). These alternatives can cost in the thousands over the course of the turtle nesting season. There are also two additional large impact areas that are over 10,000 acres; skills learned and applied at Onslow Beach using drones can now be used to survey these areas for T&E species that occupy this habitat. Entry by foot requires EOD escorts and UXO sweeps, adding additional costs and time away from unit activities for EOD members.

Table 7.5. Cost Comparisons Between Traditional and Drone-based Approaches.

Scenario	Method	Costs*		Considerations
		Per hour	Per km^2	
Shoreline/island storm impact assessment	Occupied Aircraft	$1000-$1200	Variable	Additional on-demand contract costs Precision limitations
	Unoccupied Aircraft	$325- $650	$1000-$1300	Not subject to availability Greater precision flexibility
	Ground-based (LiDAR)	$415	$8300	High equipment investment costs Greater potential for accessibility issues
Turtle Surveys	Occupied Aircraft	$1000-$1200	Variable	Low temporal resolution due to infrequency of flights
	Unoccupied Aircraft	$325- $650	$1000-$1300	High precision, temporal resolution, efficiency
	Ground-based (on foot surveys) **	NA	NA	Inefficient Prohibited in areas with UXO Lack of aerial perspective

** Costs calculated using conservative estimates for equipment lifetimes, personnel labor rates for surveying and relevant post-survey data management, and ancillary equipment and software all itemized in 7.1 Cost Models.*

***Ground-based assessments not applicable because demonstration was focused on application in areas of UXO.*

8.0 IMPLEMENTATION ISSUES

8.1 CHALLENGES TO ENGAGEMENT -

In general, it is critical for leadership to be supportive of and empower the UAS users. Support is required for air space approval, frequency coordination, and the reserving of training areas for flights. With military leadership (that guides installation use) rotating out of duty stations every 2-3 years, it is also important for civilian leadership to carry the program long-term. We found this support to be great at times and not at others, as different personnel came aboard.

Engagement with the MCBCL Fire Program Managers was challenging; in spite of steady communication attempts, we were unsuccessful in getting the necessary coordination to participate with them directly in prescribed burn activities. Therefore, the project team made alternative plans to fulfill our performance objectives. We created opportunities to work with other regional land managers (e.g., TNC in NC, TTRS in Tallahassee, FL) and successfully demonstrated both the quantitative and qualitative fire management objectives. The MCBCL Fire Program Managers did participate in in-person meetings and feedback sessions to help us understand prescribed fire use in the context of MCBCL. Additionally, the fire demonstration event provided a summary of UAS in fire management that included flying, review of data, and a problem-resolution session. Following these engagements, the team is confident that the drones will be used for situational awareness as well as some fire effects mapping at MCBCL. Two MCBCL fire technicians participated in training and were engaged and very enthusiastic about drone applications. There were no implementation issues or challenges to engagement related to the coastal monitoring component of the project.

8.2 APPLICABLE REGULATIONS

- Cybersecurity/Blue UAS: The landscape of regulations guiding the use of UAS on DoD installations is dynamic and constantly evolving. Over the course of this project alone there were several changes to procedures that required new documentation and cyberwaiver processes. By the end of the project, the enforcement of the 2020 National Defense Authorization Act (NDAA) again shifted the policies and the provided UAS in the mission kit were no longer able to be flown on DoD lands. The severely limited list of approved drones for use on installations is being evaluated. Drones allowed under the 2020 and 2021 NDAA are named “Blue” drones and while other drones can be used with appropriate cyberwaivers, there is strict adherence to no Chinese components or manufacturing. Other covered countries include Iran, Iraq, and N. Korea.
- MCIEAST Order (REDDIE): Under the REDDIE project (RC19-D3 5218), which was developed to build on this project and expand to other US Marine Corps installations, an order codifying the pathway for UAS programs managed and run by natural resources staff was produced. The order outlines training and other requirements to become a permitted drone pilot under an installation’s program, and provides continuity under rotating military leadership.
- Installation-specific requirements: Due to the complex airspace associated with training on MCBCL, range and the associated airspace must be checked out from range control in advance. The standard checkout sequence begins two weeks prior to the desired flight event. This timeline is not feasible for on-demand flights in support of wildfires and post natural disaster events.

- FAA SSI/ Class G waiver: To combat the malicious use of drones over national security sensitive locations, the Federal Aviation Administration (FAA) established Special Security Instructions (SSI) airspace over most DoD facilities across the United States. In order for civilians to fly inside of these established SSI areas, users must obtain written permission from the installation Commanding Officer.
- Threatened & Endangered (T&E) species are always of concern and caution needs to be taken whenever flying in an area that is occupied with identified listed species. MCBCL has biologists dedicated to the management of T&E species, thus the installation has the staff to coordinate with the US Fish and Wildlife Service as needed.

8.3 PROTOCOL DOCUMENTS

The following protocol documents were developed for this project and are included in this report as appendices.

- Standard Operating Procedures - Small Unmanned Aerial Systems (Appendix D)
  - At the inception of this project, MCBCL lacked the framework to establish a UAS program for civilians. The Standard Operating Procedures document was developed to assist with this deficiency by assigning program responsibilities, providing templates for standard aviation documentation, etc.

- Remote Sensing Field Guide (Appendix E)
  - The Remote Sensing Field Guide provides best practices for students on data collection via UAS. Due to the complexities of collecting aerial imagery, this document was designed to be a quick reference guide in the field for pilots to ensure they're using the best parameters for the desired mission set.

8.4 END-USER CONCERNS, RESERVATIONS, AND DECISION-MAKING FACTORS.

The most frequent concerns expressed by MCIEAST users and leadership (and frequently expressed by any group when new technology is introduced) include:

- Financial: Can they afford the technology and earmark the necessary money in budgets?
- Time: Supervisors question if there will be too much demand on people's schedules?
- Bureaucracy: Implementation relies on a strong leadership framework to work through the program pathway and move paperwork through the system.

The formalizing of the program through the combined work with RC19-5218 (REDDIE) has resulted in a MCIEAST order that provides the formal pathway for the program to continue and grow as each installation wants. Throughout training and demonstrations with MCBCL, other installation groups (e.g., Installation Development and Design, Range Control) have expressed a desire to also use drones in their work.

The success of implementing drone UAS technology within MCBCL and other DOD installations ultimately relies on the buy-in and commitment from installation leadership and land managers. In our training courses, we anticipated - and were met with - some significant reservations about ease-of-use and utility of the technology. Through our Remote Pilot Course series, via hands-on demonstrations and flight practice, and effective classwork, we documented a complete reversal of those reservations. Course completion reviews documented positive feedback about:

- Confidence of land managers to successfully employ drones in their work
- The vast benefits of the technology when compared to the current, more costly, and less efficient means of conducting operations.

Furthermore, we demonstrated significant cost reductions (Section 7), ease of use and improved situational awareness using drones in prescribed fire applications (Sections 5.2.6.3, 5.2.6.4, 5.2.6.5).

8.5 RELEVANT PROCUREMENT ISSUES

The drone market is a constantly evolving commercial market due to the interface of the technology with complex issues like cybersecurity concerns, international relations, and trade wars. At the time of purchase, the US-1 (made by Impossible Aerospace) was a revolutionary aircraft advertising a flight time of just over an hour. Coupled with a strong camera in the Forward Looking Infrared (FLIR) Duo Pro R, this aircraft was anticipated to perform a wide span of mission sets including fire management, coastal mapping, and live video collection. Impossible Aerospace's business model was targeting law enforcement agencies as their primary customer. Due to current world events, the company struggled and ceased operations in 2020. In the best interest of the project, we opted to replace the US-1 in the mission kit transferred to MCBCL with the Anafi USA. This replacement drone is manufactured by a mature UAS company, Parrot SA.

We were able to make this shift without changing our overall budget by using travel line item budget excesses resulting from COVID-19 travel restrictions and a shift to virtual training. This switch between aircraft ultimately resulted in a mission kit better suited to the bases and helped us achieve a more positive outcome.

The above replacement however, was also short-lived as the flight controller is prohibited due to Chinese components, and the team is finalizing an additional replacement of the Anafi USA. The shift by all of DoD to Blue UAS in early 2021 (with the above-mentioned enforcement of the 2020 NDAA) created an additional layer of complication and procurement challenges. There are now limited supplies of Blue drones and, when available, at significantly increased costs. A quadcopter similar to the one originally provided at a cost of $2,000 now costs approximately $14,000. This cost shift may prove to be too much for early, unfunded programs to sustain. However, as new Blue UAS are added to the approved list and more manufacturers become a part of the process, this landscape will once again change.

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APPENDIX A POINTS OF CONTACT

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APPENDIX B USING DRONES TO QUANTIFY COASTAL CHANGE

Using Drones to Quantify Coastal Change

Background

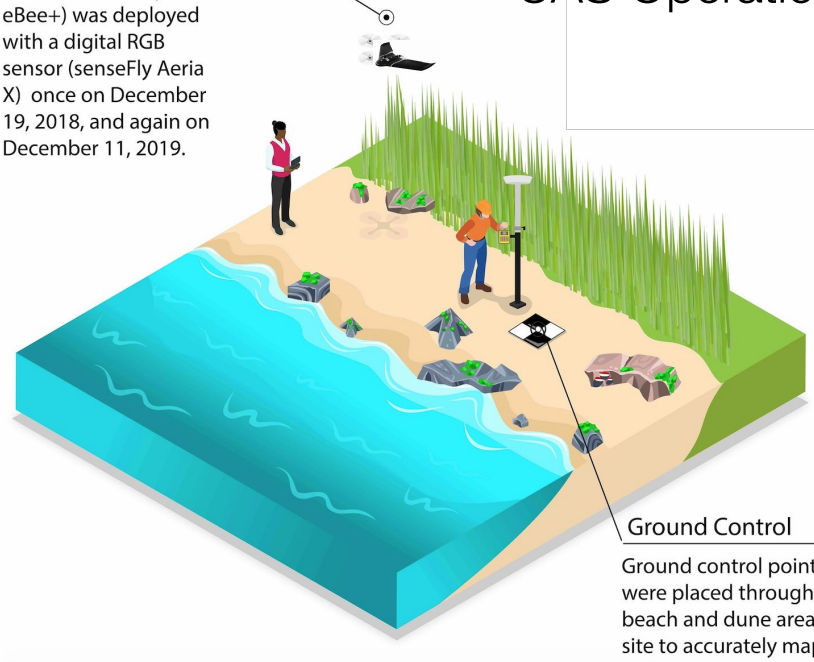
Coastal land currently faces large environmental threats, including sea level rise and increased frequency and intensity of coastal storms. Assessment of change in response to these threats is critical to coastal land management. However, it is difficult to assess impacts from coastal storms in a safe, timely, and efficient manner. The Duke University Marine Robotics and Remote Sensing Laboratory has partnered with the UNC Institute of Marine Sciences, Attollo LLC, and the Department of Defense to demonstrate the capability of drones, or unoccupied aircraft systems (UAS), to solve these assessment obstacles in areas used for Marine Expeditionary Forces.

Our team has collected drone imagery to track 2D shoreline movement and 3D volumetric changes at Onslow Beach, North Carolina to reflect both long-term processes and short-term storm impacts.

UAS Operations

UAS Flights

A fixed-wing commercial UAS (senseFly eBee+) was deployed with a digital RGB sensor (senseFly Aeria X) once on December 19, 2018, and again on December 11, 2019.



Ground Control

Ground control points (GCPs) were placed throughout the beach and dune area of our site to accurately map change in these areas

Products

- **RGB Orthomosaic**
  UAS-SfM stitched map view of entire site
- **2-D Shoreline Change**
  Tracking dune feature movement over time
- **Subtraction Raster**
  Elevation and volumetric changes over time

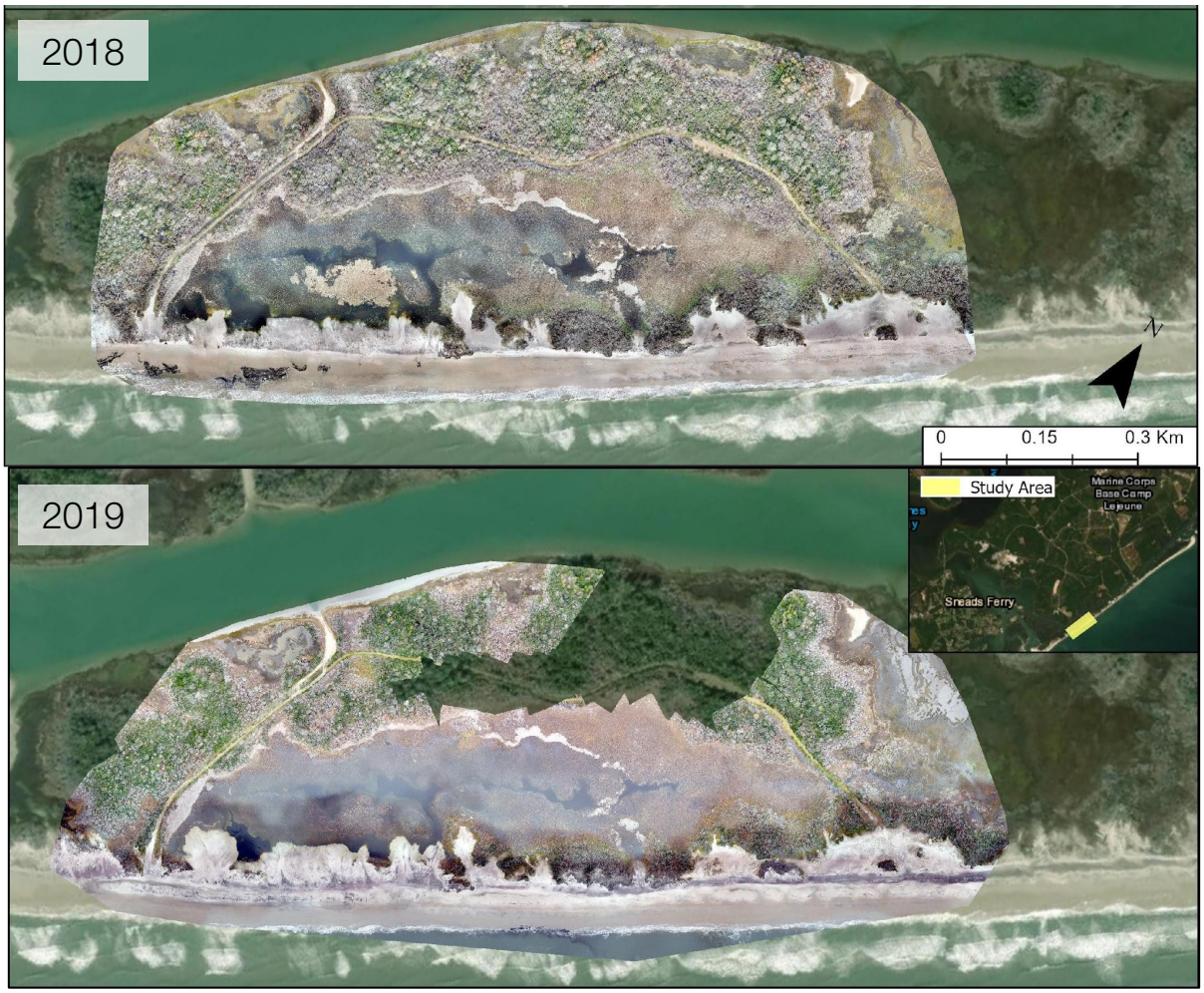
CONFIRM

Using Drones to Quantify Coastal Change

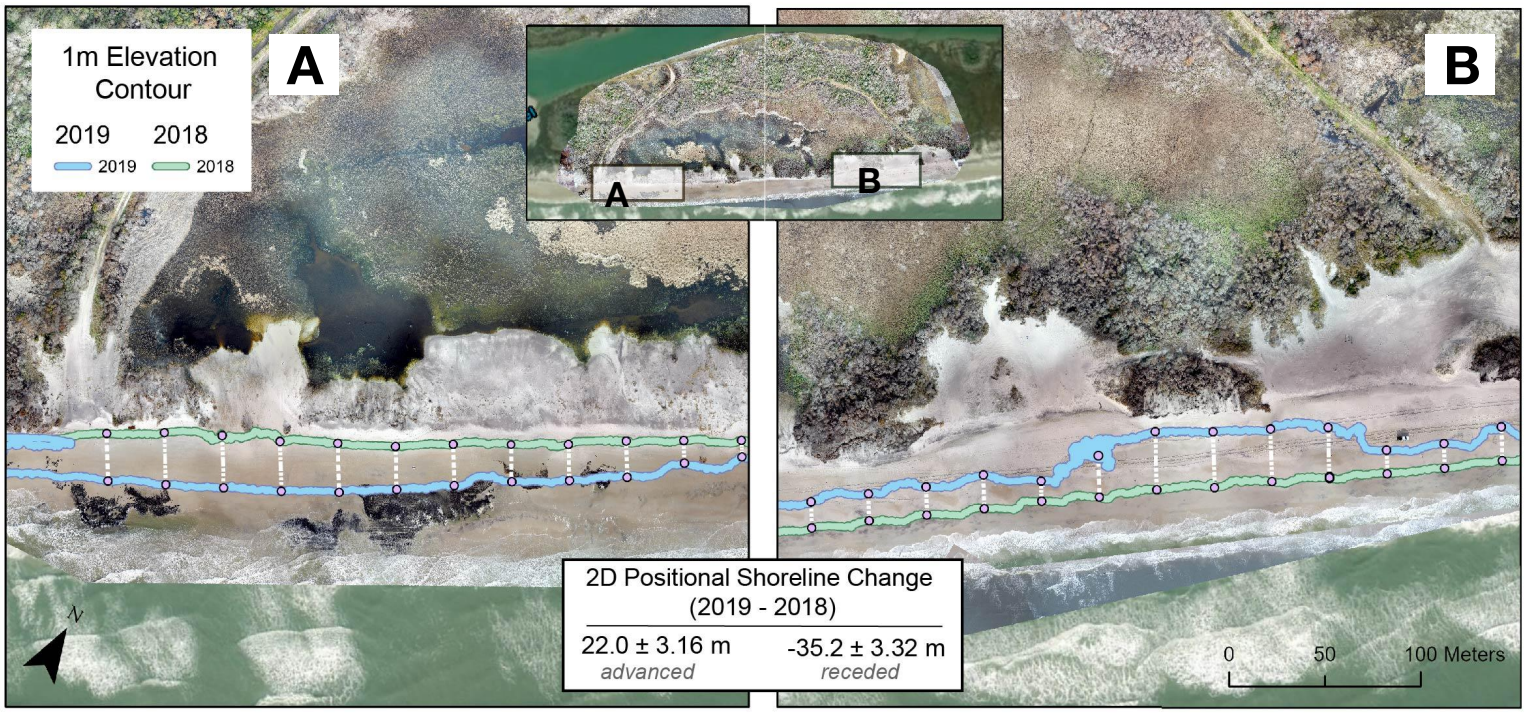
RGB Orthomosaic Generation

The UAS collected overlapping imagery in parallel transects with 70% overlap across the study area, capturing approximately 500 images (5472 x 3648 pixels), over a total flight time of ~30 minutes and covering a total area of approximately 0.065km^2 or 160 acres with an average Ground Sampling Distance (GSD) of 2.6cm/pixel.

Individual optical, or Red-Green-Blue (RGB) images were collected by the UAS and processed in photogrammetry software Pix4DMapper Pro (v. 4.2.26). High overlap between images allowed Pix4D to stitch images into an orthomosaic, a full-site image.



Using Drones to Quantify Coastal Change



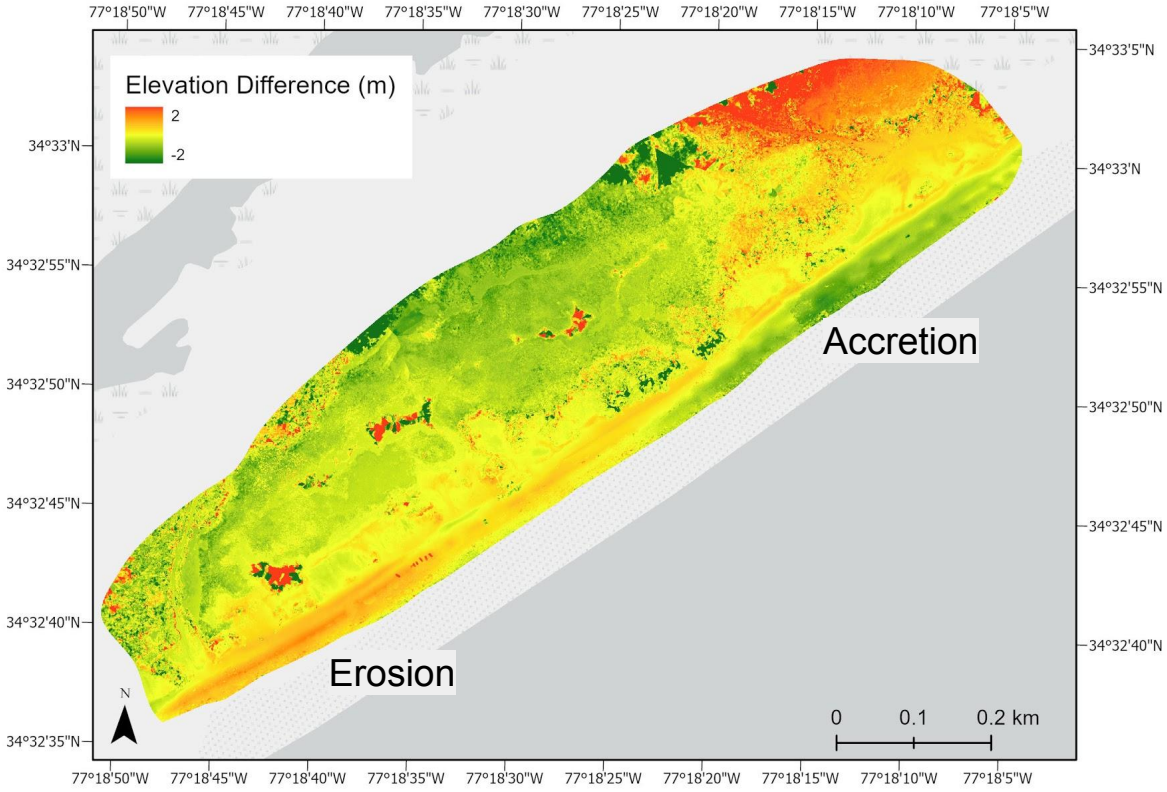
2D Shoreline Movement

Pix4D generated a dense point cloud (~120-140 points/m^3) of XYZ values across the study area from Structure from Motion (SfM) photogrammetry of overlapping UAS imagery. A Digital Surface Model (DSM) was generated from an Inverse Distance Weighted (IDW) interpolation of the point cloud. The resultant DSM had a grid resolution of 2.6cm/pixel (1 x GSD).

Generated DSMs were effectively Digital Elevation Models (DEMs), as they were georeferenced using the image geotags from the aircraft's onboard survey-grade Global Positioning System (GPS) and further adjusted by referencing the ground control points (GCPs). Demonstrated elevation differences between 2019 and 2018 DEMs are the result of coastal change during the year elapsed.

Elevation contours were drawn in ArcGIS Pro (v. 2.5.2) to measure movement of the 1 meter elevation contour from 2018 to 2019. At the southwestern end of the site (Left panel), the 1-m contour appears to have advanced by 22 meters, while at the northeastern end of the site (Right panel) the 1-m contour receded by 35 meters.

Using Drones to Quantify Coastal Change



Subtraction Raster

Elevation difference across the site from 2018 to 2019 was computed by subtracting the 2018 DEM from the 2019 DEM in ArcGIS Pro. Elevation differences within the Root Mean Square (RMS) error of each SfM project were masked to zero to represent true changes in elevation.

The subtraction raster demonstrates that the beach appears to be accreting on the southwestern end of the site and eroding on the northeastern end of the site. This supports the patterns of shoreline recession and advancement in the 2D shoreline change analysis and explains the disappearance of the exposed peat deposits (black surfaces) seen on the beach in the 2018 imagery.

This study provides an example of the potential to use consumer-grade UAS to understand short-term coastal change. The methods presented in this report can be scaled up to quantify changes (positional spatial movement, volume differences) in specific areas of interest to inform long term monitoring efforts.

This project was carried out in partnership with Duke University Marine Lab, University of North Carolina at Chapel Hill, UNC Institute of Marine Sciences, and Attollo LLC with funding through the Environmental Security and Technology Certification Program

APPENDIX C USING DRONES TO QUANTIFY FIRE BURN AREA

APPENDIX C.

Using Drones to Quantify Fire Burn Area

Background

Prescribed fires are a tool used to manage forest ecosystems. Careful attention is paid to the timing and placement of burns to minimize human exposure to smoke, reduce both fuel loads and the risk of fire escape, and achieve ecological goals. To rapidly assess the effectiveness of these burns, Unoccupied Aircraft System, or UAS, are deployed to collect imagery before and after a fire. From these images, managers can quantify the consumption of fuels and map burn extent. In addition, UAS can be used to achieve situational awareness during a prescribed fire.

Unoccupied Aircraft System (UAS) Operations

A commercial UAS (DJI Mavic 2 Pro) was deployed for two flights, pre-burn and post-burn flights, collecting overlapping imagery over the study area. The UAS was equipped with 20M RGB sensor and captured 35 images (5472 X 3648 pixels), contributing to a total flight time of ~3 minutes and covering a total area of 0.026km^2 (6.52 acres).

Products

- **Orthomosaic**

Using Pix4DMapper Pro (v. 4.2.26), Structure-from-Motion (SfM) photogrammetry of overlapping UAS images stitches together imagery into a map of the entire study area.

- **Classified survey area**

The study area was classified into three categories: Barren, High Vegetation, and Low Vegetation in ArcGIS Pro to assess changes in cleared area before and after a burn.

- **Digital Surface Model (DSM)**

DSMs, rasters representing the surface elevation (effectively the vegetation height) across the entire study area, were generated in Pix4D at resolution 2.2cm/pixel.

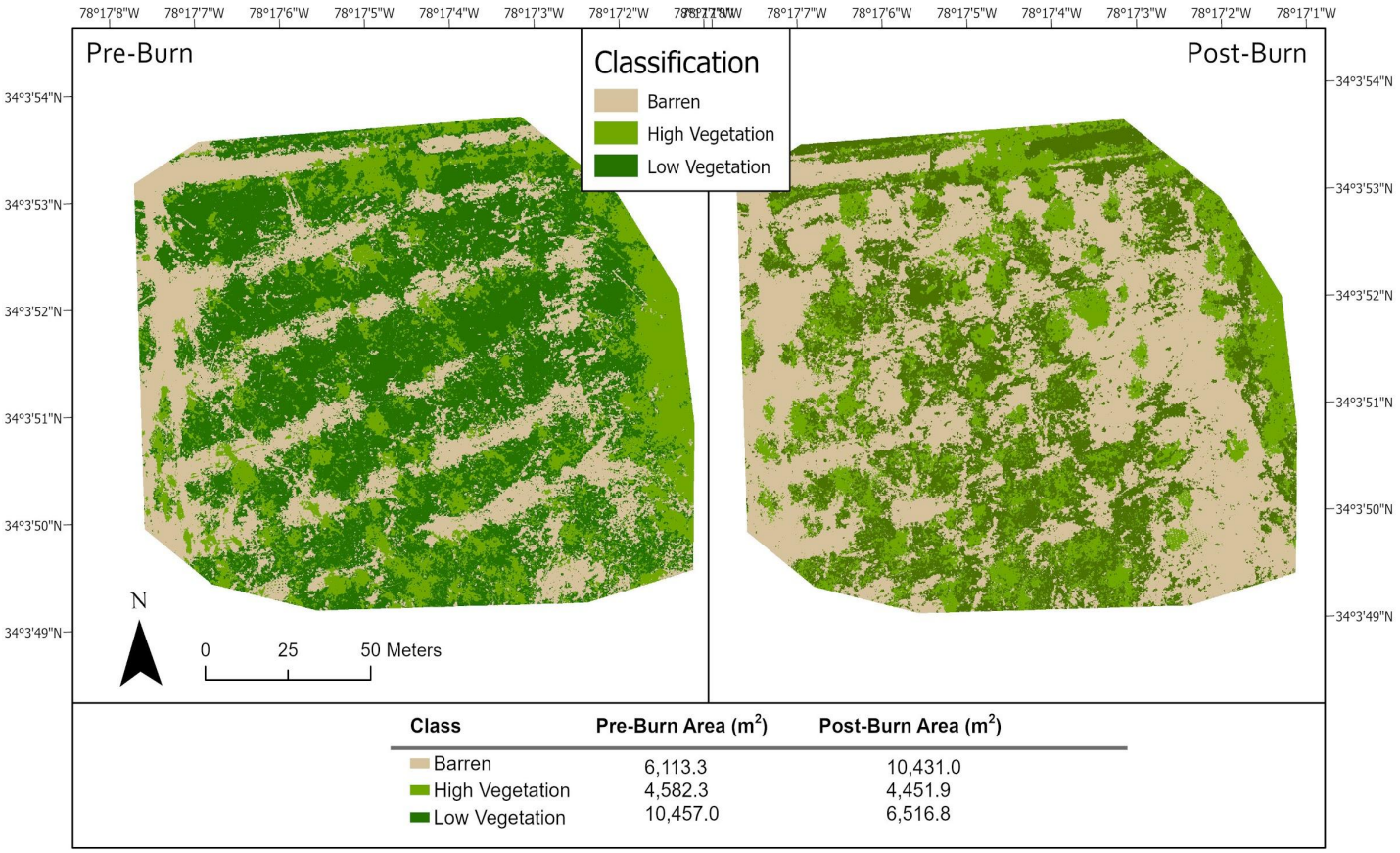
- **Subtraction Raster**

The difference between the resultant DSMs from the two flights was calculated as:
Pre-Burn DSM - Post-burn DSM, generating a raster showing difference in elevation across the study area.

[1]*https://www.serdp-estcp.org/Featured-Initiatives/Range-Sustainment/Wildland-Fire-and-Prescribed-Burning*

COASTAL AND FIRE MANAGEMENT CONFIRM

Using Drones to Quantify Fire Burn Area



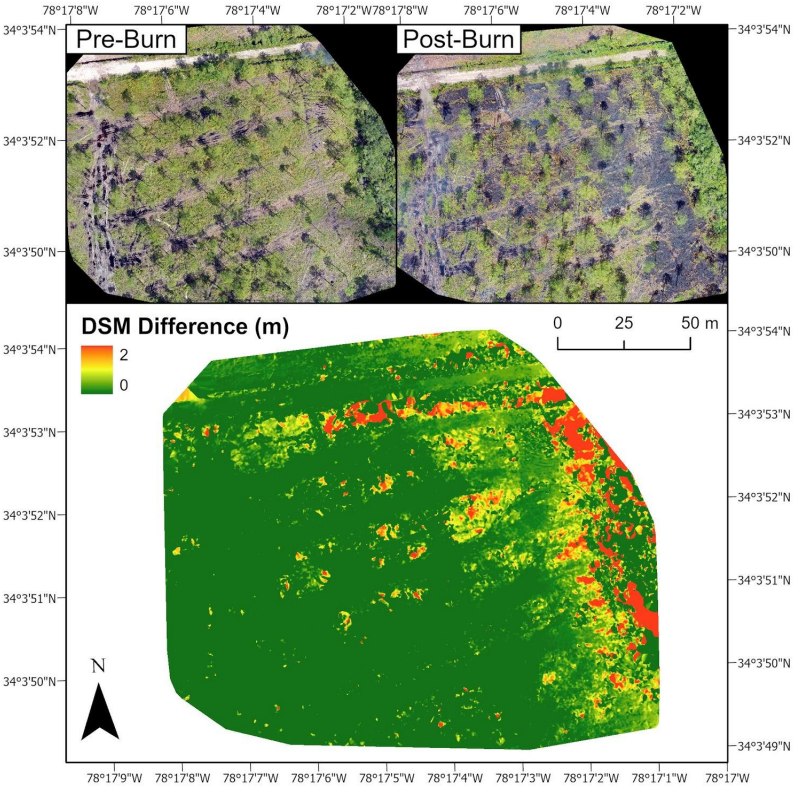
Class	Pre-Burn Area (m^2)	Post-Burn Area (m^2)
Barren	6,113.3	10,431.0
High Vegetation	4,582.3	4,451.9
Low Vegetation	10,457.0	6,516.8

Classified Survey Area

Orthomosaics generated in Pix4D were classified using a supervised classification in ArcGIS Pro (v. 2.5.0). Supervised classifications require the user to train the tool by identifying sample areas of each class in the study site. From the RGB properties of the sample areas, or training samples, the classifier tool learns to automatically classify the rest of the study area. In this analysis, ~20 training samples were identified across the orthomosaic for each class: Barren, High Vegetation, and Low Vegetation. Object based classification grouped neighboring pixels together based on similarity, and classified pixels according to the classification scheme provided.

The burn affected mostly low vegetation, clearing 3940.2m^2 of low vegetation, reducing the low vegetation cover of the study area by 28.6%. High vegetation, which is generally only impacted by excessively hot burns, remained constant pre- and post-burn as expected.

Using Drones to Quantify Fire Burn Area



Digital Surface Model Generation

Structure-from-motion photogrammetry, performed in Pix4DMapper, generated a dense layer of points, called a point cloud, representing XYZ (longitude, latitude, elevation) locations across the study area. Originally containing approximately 200 points/m^3, the point cloud elevations were smoothed into a continuous surface using an Inverse Distance Weighted (IDW) technique. The resultant surface, called a Digital Surface Model (DSM), had a grid resolution of 2.2cm/pixel. A subtraction of the post-burn (cleared) DSM from the pre-burn (full vegetation) DSM represents the vegetation lost during the burn.

Subtraction Raster

The DSM difference (pre-burn - post-burn) was computed by subtracting the two DSMs in ArcGIS Pro. Negative raster values, which were likely the result of imperfect alignment of the DSMs, were excluded. The greatest elevation differences were seen on the eastern side of the site. This is reinforced by a simple orthomosaic comparison and the classifications in the previous section, in which it can be seen that the eastern side of the study area appears to be most impacted by the burn.

Conclusion

Basic RGB UAS imagery can be used to quickly assess burn effectiveness using several image analysis products. This example was conducted over just a small parcel of a burn area and could be easily scaled up using a fixed wing UAS.

This project was carried out in partnership with Duke University Marine Lab, University of North Carolina at Chapel HIll, UNC Institute of Marine Sciences, and Attollo LLC with funding through the Environmental Security and Technology Certification Program

APPENDIX D STANDARD OPERATING PROCEDURES – SMALL UNMANNED AERIAL SYSTEMS

APPENDIX D.

COASTAL AND FIRE MANAGEMENT

CONFIRM

ENVIRONMENTAL MANAGEMENT DIVISION (EMD)

Marine Corps Base Camp Lejeune

STANDARD OPERATING PROCEDURES (SOP)

Small Unmanned Aerial Systems

"...to protect current and future training capabilities by respecting and maintaining the natural environment..."

Attollo, LLC.

Mission Statement

1. Situation. Aviation is an inherently complex and unforgiving enterprise. The subset of Unmanned Aircraft Systems (UAS) is no different. The separation of the pilot from immediate danger does not remove them from the responsibility to be a professional pilot. The policies and procedures set forth in this manual form the guidelines for all flight operations.

2. Mission. The mission of our SUAS program is to support the informational requirements established by EMD and its sustainability objectives in order to effectively and efficiently continue to protect current and future training capabilities by respecting and maintaining the natural environment.

3. Execution. SUAS flight operations will be planned and executed in accordance with references 3 and 4 (pages 6 - 7). The intent of this Standard Operating Procedures (SOP) is to consolidate and reference any higher authority guidance and to specify those procedures and requirements applicable to the conduct of SUAS flight operations. In no instance shall this order be interpreted to establish criteria less restrictive than those specified in the references.
   This SOP is not intended to cover every possible situation and does not relieve personnel from the responsibility to exercise good judgment and common-sense regarding circumstances not specifically addressed herein. Should a conflict arise between this manual and directives published by higher authority, the latter shall prevail.

4. Administration and Logistics. This manual is maintained within the cognizance of the Camp Lejeune Environmental Management Division. Recommendations concerning the contents of this SOP may be forwarded via email to the Operations Officer. Proposed changes should cite section, paragraph affected, references used, and rationale for the proposed change.

5. Command and Signal. This SOP is applicable to all EMD SUAS operators and personnel identified as SUAS support and is effective the date signed.

I. M. NATURE
EMD DIRECTOR

DRAFT

Glossary

Note: yellow highlighted fields indicate a field that may be changed as the user sees fit.

- ARC – Aircraft Reporting Custodian
- AVO – Air Vehicle Operator
- BUQ – Basic UAS Qualifications
- CRM – Crew Resource Management
- DAA – Designated Acting Authority
- EMD – Environmental Management Division
- GCS – Ground Control Station
- HAZREP – Hazard Report
- IMC – Instrument Meteorological Conditions
- MSL – Mean Sea Level
- NOTAMs – Notice to Airmen
- OEM – Original Equipment Manager
- OPSO – Operations Manager
- ORM – Operational Risk Management
- POR – Program of Record
- R&I – Read & Initial
- RPIC – Remote Pilot in Control
- RTB – Return to Base
- SOP – Standard Operating Procedures
- STAN Board – Standardization Board
- TTPs – Tactics, Techniques, and Procedures
- UAS/SUAS – Unmanned Aircraft System/Small Unmanned Aircraft Systems
- VFR – Visual Flight Rules
- VMC – Visual Meteorological Conditions
- VO – Visual Observer

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Record of Changes

Log completed changes as indicated.

Change Number	Change Date	Change Description	Change Authorization
1	7 Aug 19	Initial Draft.	ATTOLLO LLC
2	2 Jun 20	Edits and Formatting	ATTOLLO LLC

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1. ADMINISTRATION

1.1 Introduction

- This SOP establishes standard procedures for EMD SUAS personnel in the execution of flight operations and shall be used as a baseline for developing sound judgment and operational techniques.
- Deviations from these procedures are authorized only in situations when, in the judgment of the qualified Air Vehicle Operator (AVO), safety of flight, or personnel justify such deviations. Any deviations will be briefed to the EMD Operations Officer at the first available opportunity.

1.2 General Admission

- It is the individual and direct responsibility of all EMD SUAS personnel to thoroughly review, understand, and possess a working knowledge of the applicable sections of this SOP and all directives referenced herein.
- It is not feasible to specify procedures for all circumstances and situations that may occur; however, it is expected that sound judgment and common sense will be exercised in those cases where the provisions of this SOP do not apply.

1.3 References

- If a contradiction arises between procedures contained in this SOP and other regulations, the more senior regulation shall be observed.

Ref#	Reference Title
1	COMNAVAIRFORINST 3710.90
2	CNAF M-3710.7
3	NAWCAD AIRWorks GROUP 1&2 SOP

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4	MCI-East Camp Lejeune Base Order 3710.30
5	MCI-East Camp Lejeune Range Control SOP 3570.1A
6	MCBUL 3710

- Electronic copies of all references and enclosures will be maintained by the EMD Operations Officer. Each section shall be updated annually at the direction of the Operations Officer.

1.4 Definitions

- ”Shall” indicates a procedure or action is mandatory.
- ”May” indicates a procedure or action is optional.
- ”Will” indicates the futurity of an event and in no way construes a requirement for action or compliance.
- ”Should” means a procedure or action is recommended.

1.5 Changes and Waivers

- Changes to this SOP shall require written approval from the Operations Officer or designated representative. Changes are formal and long-term modifications that are most often published via EMD Standardization Board (STAN Board) minutes. Interim changes to this SOP will be implemented and maintained electronically on a shared drive folder until formally incorporated in this document.
- Waivers to the SOP shall require verbal or written approval from the EMD Operations Officer. Waivers are temporary modifications that are most often published via electronic means, and will be canceled upon approval of formal changes, completion of requirements, or completion of the operation for which a waiver was approved.

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1.6 Read and Initial

The Operations Officer shall establish and maintain an electronic Read & Initial (R&I) share drive folder in order to bring aircrew attention to regulations, techniques, flight hazards, changes or addendums to this SOP, and any other information pertinent to flight operations. All R&I's shall be reviewed by all SUAS personnel prior to flight operations.

1.7 Flight Schedules

- An EMD SUAS flight schedule should be routed by the Operations Officer to all EMD SUAS personnel by 1600 the day prior to flight operations.
- The Operations Officer (OPSO) may produce a weekly schedule for every day involving flight operations. The weekly should be routed by 1600 on Thursday of the week prior.
- Example Flight Schedule:

DATE	AIRCRAFT	RANGE	TIME	PERSONNEL	MISSION
7-Aug-19	SUAS / EBEE	EA AREA	1000-1200L	AVO: Smith, John VO: Coberg, Susan	Mapping
7-Aug-19	SUAS / EBEE	EC AREA	1200-1400L	AVO: Smith, John VO: Coberg, Susan	Training

1.8 Flight Logbooks

- SUAS flight logbooks for all aircrew shall be maintained by individual AVOs. At the end of every month, individuals will send their SUAS monthly flight hours to the Operations Officer for tracking purposes.
- The logbooks shall be updated daily immediately following flight operations. The logbooks shall be audited at the end of each quarter. All aircrew shall sign their logbooks for the previous quarter upon completion of the quarterly audit. It is the responsibility of the individual aircrew to ensure their logbook is up to date and accurate.
- An electronic version is available so that aircrew may capture data in the field per the template provided in Appendix A but maintain monthly and lifetime totals personally.

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2. AVIATION SAFETY

2.1 Aviation Safety

The primary operational objective for EMD SUAS operations is to provide a safer, more cost-effective means to capture aerial and remotely sensed data, while protecting and maintaining the environment. A safety-centered program must be in place to ensure individuals are assessing risk, taking advantage of the resources available to them to aid their decision making, and are prepared for any contingencies they may face in the execution of their flight duties. It is not cost effective to run an unsafe program.

2.2 Operational Risk Management (ORM)

- All flights require an ORM analysis. This analysis shall be documented by the AVO on a Risk Assessment Worksheet (RAW) prior to the flight. For further information, refer to the SUAS Appendix B.
- RAW sheets shall be prepared 48 hours prior to flight operations beginning. The RAW sheets will be submitted with the flight schedule to the Natural Resources Manager for review and comments.

2.3 Crew Resource Management (CRM)

- All aircrew members shall receive an annual Crew Resource Management brief. Refer to Appendix C for a CRM discussion aid to supplement training.

2.4 Crew Day and Crew Rest Requirements

- Albeit there is less physical and mental demand in flying remotely operated aircraft than a manned aircraft, all crew members must be aware of how acute fatigue affects their psychomotor and cognitive performance, such as decision making and judgement. It is recommended that remote aircrews adhere to a Crew Day limitation of 14 hours for duties involving flight operations. Any crew members scheduled for a Crew Day longer than 12 hours will be listed on the RAW sheet as “medium risk.” A Crew Day is the time

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personnel are on duty during a 24 hour period.

- Crew Rest is the non-duty time before a flight duty period begins. Crew Rest should not normally be less than 10 hours. Crew Rest is recommended for 8 hours, at minimum, of uninterrupted rest and time for transportation and chow.
- Circadian rhythm cycles should be considered when scheduling crew members for duties involving flight operations.
- The individual crew members are ultimately responsible for determining if they are adequately rested for a flight and must speak up if they are not safe to fly.

2.5 Standardization Board (STAN BOARD)

- The mission of the Standardization Board (STAN Board) is to establish and review the SOP, ensure standardization between SUAS AVOs, and ensure adherence to published instructions. The STAN Board shall make recommendations regarding previous and new designations of qualified AVOs. The board shall convene Quarterly and the minutes retained for two years within the STAN Board share drive file.
- Membership should include the Operations Officer, SUAS Lead Instructor, and one qualified AVO. The OPSO will chair the STAN Board.

2.6 Pre-Mishap Plan

- An EMD Pre-Mishap Plan is established and will be maintained and reviewed annually by the Operations Officer. A hard copy of the pre-mishap plan will be maintained with the aircrew when flight operations are being conducted (Appendix D). All personnel involved in flight operations shall thoroughly familiarize themselves with the contents prior to commencement of flight operations.
- The EMD representative at any deployed location should initiate a mishap plan drill to exercise and test the system (as appropriate).
- In the event that emergency flight operations result in a reportable mishap, the AVO shall notify the Program Manager and execute the reporting process in accordance with the established mishap response plan.

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- A root cause analysis will be performed in the event of any abnormal or emergency flight operations. An analysis aid is provided in Appendix E. The non-POR (program of record) (POR) UAS ARC and flight operation personnel shall review results of this analysis and determine if the UAS is airworthy for flight.
- If, in the ARC's judgment, a hazard to aviation safety is identified that could benefit others within the small UAS community, a Hazard Report (HAZREP) will be filed with the Naval Safety Center at the ARC's discretion.

2.7 Safety/Site Survey of Location

- Prior to beginning flight operations at a location that the EMD has not operated out of before, they shall conduct a safety survey to determine the operating areas for both safety and ability to support planned operations.
- Site Surveys will be conducted in accordance with the SUAS Site Survey Checklist in Appendix F.
- The Remote Pilot in Command (RPIC) is responsible for the completion of the site survey checklist prior to the operation.
- A Site Survey shall be completed for any location that has not been operated out of for greater than one year.

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3. Responsibilities and Training

3.1 Qualifications

Basic UAS Qualifications (BUQ): Possess the Basic UAS Qualifications (BUQ) knowledge, skills, and capabilities required of Group 1 and 2 per the "Joint Unmanned Aircraft Systems Minimum Training Standards" (CJCSI 3255.01).

- Basic UAS Qualifications BUQ level I: BUQ-I is the minimum recommended training level for UAS Crewmembers who perform duties other than pilot. Possess required aviation knowledge and UAS knowledge-based skills to fly under Visual Flight Rules (VFR) in Class E, G, and restricted/combat airspace <1200' above ground level (AGL).
- Basic UAS Qualifications BUQ level II: Possess required aviation knowledge and UAS knowledge-based skills to fly under VFR in Class D, E, G, and restricted/combat airspace <18,000' mean sea level (MSL).

3.2 Designations

- The ARC is the approving authority for all designations. The STAN Board will make recommendations for aircrew designations. The ARC is assigned by the Designated Acting Authority (DAA) per OPNAV 3710.
- The following are SUAS designations:
    - Air Vehicle Operator (AVO): The AVO exercises direct control of the UAS. The AVO has the ultimate responsibility for the safe operation of the UAS. The AVO shall be BUQ level II qualified to operate SUAS aboard military installations.
    - Visual Observer (VO): The VO assists the AVO in maintaining situational awareness and complying with their "see-and-avoid" duties. VOs shall always maintain verbal contact with the AVO and must be able to advise the AVO of any hazards that may arise during the operation. The VO should be BUQ level I qualified to act as a SUAS observer aboard military installations.

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3.3 Air Vehicle Operator (AVO)

- The AVO is the individual who has been properly trained and qualified to operate the SUAS. The AVO is physically located at the Ground Control Station (GCS) and has positive control of the air vehicle.
- The AVO tasks shall include:
    - Operate the aircraft during all mission phases.
    - Obtain mission objectives and aircraft configuration prior to launch.
    - Coordinate with appropriate Air Traffic Control agencies for flight and airspace clearance (as required).
    - Execute emergency procedures, as necessary.
    - Operate sensor payloads.
    - Identify potential mission issues, such as terrain or other obstructions associated with mission objectives.
- To be designated to perform the duties of an AVO, at a minimum the individual shall:
    - Possess the Basic UAS Qualifications (BUQ) level 2, knowledge, skills, and capabilities required of Group 1 and 2 aircraft (Appendix J).
    - Received introductory and familiarization training on the type/model/series SUAS they will employ, including basic and emergency flight operations.
    - Have been nominated by the SUAS Stan Board and designated by the ARC.

3.4 Visual Observer (VO)

- The VO is the individual who has been properly trained and qualified to assist the AVO in maintaining situational awareness and complying with their “see-and-avoid” duties.
- The VO tasks shall include:
    - Assist the AVO with pre-flight and equipment set up, as required.
    - Assist the AVO with maintain communications with external agencies, as required.
    - Assist the AVO with maintaining visual line of sight with the aircraft and clear of traffic and other obstacles or hazards.
- To be designated to perform the duties of an VO, at a minimum the individual shall:

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- Possess the Basic UAS Qualifications (BUQ) level 1, knowledge, skills, and capabilities required of Group 1 and 2 aircraft.
- Have been nominated by the SUAS Stan Board and designated by the ARC.

3.5 Training

- Training is an important aspect of operations and will impact the way EMD will execute flight operations. EMD will take every available opportunity to train while refining and updating Tactics, Techniques, and Procedures (TTPs).
- It is recommended that individual training sorties are scheduled for each AVO, or a time is set aside prior to or after missions to conduct refresher training flights.
- It is recommended that each AVO, once a month exercise the following core skills, during live flight operations, which are introduced in the requisite BUQ I & II training courses:
  - Mission Preparation: Weather & NOTAMS, checklists, contingency procedures, charts, and aircraft performance data.
  - Communication Planning: Voice and data link management
  - Aircraft Operations: Mission briefing, general flight rules and regulations, range regulations, basic maneuvers, emergency procedures, and mission debriefing.

3.6 Currency and Proficiency

- Proficiency is the initial acquisition of a new skill, an AVO proving they have the capability to perform that function. However, flying skills degrade over time. Currency is how frequently, or more specifically, the last time a skill was performed at a proficient level. It is the responsibility of the individual AVO to manage date last flown so that they maintain currency in these skill sets.

3.7 Currency Requirements

- See MCIEAST-MCB CAMLEJO 3710-.30A for currency requirements.

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Days since last flight	Refresh Requirement
<30	None.
30-59	(1) self-paced training flight.
60-89	(1) refresher flight with a current AVO.
90+	(2) refresher flights with a current AVO.

3.8 Operations Officer (OPSO) Responsibilities for Training

- The OPSO will produce and update mid-range training plans in accordance with this SOP. The quarterly training plans will identify all training exercises and specific goals and designations for key personnel (focuses of effort) involved in those evolutions. The quarterly training plan should list all EMD AVOs and identify goals as specific training for each individual.
- Due dates are as follows:
    - The quarterly training plan shall be a four-month plan based off the fiscal calendar, covering each fiscal quarter plus one month, and is due to all SUAS personnel on the 15th of August, November, February, and May.

3.9 Training Forms

Training Forms will be used for all training events for all SUAS personnel (Appendix G).

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4. FLIGHT AND GROUND OPERATIONS

4.1 Standard Launch Sequence Timeline

Below is an example of a standard launch sequence timeline. Proper pre-flight planning shall be utilized to determine an accurate sequence of events and timelines.

1. ETD -0+30. Conduct flight brief.
2. ETD -0+15. AVO/VO conducts preflight inspections.
3. ETD -0+05. AVO/VO verifies air and range space.
4. ETD -0+03. Radio calls for intention to launch.
6. ETD 0+00. Launch.

4.2 Flight Briefing

- The AVO is responsible for the flight brief and de-brief. Portions of the brief may be delegated by the AVO for development and delivery. At a minimum, the brief will cover all the required items from the SUAS briefing/debriefing guide Appendix H.

4.3 Preflight and Aircraft Acceptance

- The AVO is the final authority that an UAS is ready for flight. The AVO shall personally inspect the aircraft and ascertain the severity and impact of unresolved discrepancies and pending maintenance.
- The AVO is authorized to conduct service maintenance items recommended by the Original Equipment Manufacturer (OEM) or supplying vendor. Any advanced maintenance items must be conducted by an approved supplier or vendor.

4.4 Radio Communication

- Radio communications are the primary means of communication between aircrew members and range control. It is recommended that handheld radios should be available

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for use at all times. Cellphones should only be used as a backup. Both the handheld radios and phones should be tested prior to commencing flight operations.

4.5 Engine Start and Launch

- The AVO shall be in a position to see the aircraft prior to starting the engine and shall remain in a position to see the aircraft launch.
- The AVO should try to launch within +/- 3 minutes of scheduled launch time.

4.6 Return to Base (RTB) and Landing

- RTB should be in accordance with the mission brief, but the AVO may RTB early based on the following guidance:
    - RTB for any safety of flight reasons to include, emergencies and deteriorating weather in the working area or the launch and recovery site.

4.7 Flight Debrief

- A detailed mission debrief will be conducted at the end of every mission. The AVO is overall responsible for the mission debrief.

4.8 Night Operations

- Aircraft preflight shall be conducted using adequate white lighting to ensure proper preflight inspection. When possible, preflight should be conducted during daylight hours.
- All external aircraft lights (overt and covert) shall be ON, when airborne, unless approved otherwise.

4.9 Weather

- All SUAS flight operations shall be restricted to Visual Meteorological Conditions (VMC), which are defined as 3 statute miles visibility, 500 feet below, 2000 feet horizontal distance from clouds. Flight into Instrument Meteorological Conditions (IMC) shall be avoided to the maximum extent possible. Flight into visible moisture is prohibited.

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- In the event of forecast inclement weather, the AVO should continue normal preparation for flight operations until a logical point has been reached to pause that preparation and monitor the accuracy of the forecast and its potential effect on scheduled flight operations. System checks and inspections should be completed to minimize the delay in launching the aircraft as much as possible. Decisions to adjust the launch time or cancel the flight should be coordinated with the coordinating agencies at the earliest opportunity. The AVO has the final authority to adjust or cancel the flight mission.

4.10 Emergency Procedures

- Immediately execute the memory or checklist items provided by the OEM or vendor to safely recover the aircraft.
- During an emergency priority should be given to aviation items (i.e. safely keeping the aircraft aloft), navigation items (i.e. safely maneuvering the aircraft to recovery), and communication items (i.e. telling VO's, coordinating agencies). These items may happen in sequence or in parallel to successfully solve the emergency issue.
- Time permitting, the AVO will inform coordinating agencies of the emergency conditions and intentions. The VO should provide technical assistance if available and begin executing the Pre-Mishap plan checklist.

4.11 Search and Recovery Procedures

- In the event of a downed aircraft, the AVO shall immediately initiate the recovery effort to attempt to establish the exact location of the downed aircraft via onboard sensors. Last known locations from the GCS should be recorded.

4.12 Logistics & Equipment

- All mission equipment items are listed in Appendix I for accountability and sustainment.

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5. APPENDICES

Appendix A: Flight Logbook

It is recommended to utilize DroneLogBook.com or a similar flight logging application for ease of use. Provided below is a paper copy for an example template if applications are not available.

SUAS FLIGHT LOG										
Date	Year	Time	Aircraft	Location	Airspace Class	Details	Flight time (hr)	T/O	Land	Batt	Batt %
2/5	2019	1000	AC1	EA	R	Mapping	0.5	1	1	BAT1	0.73

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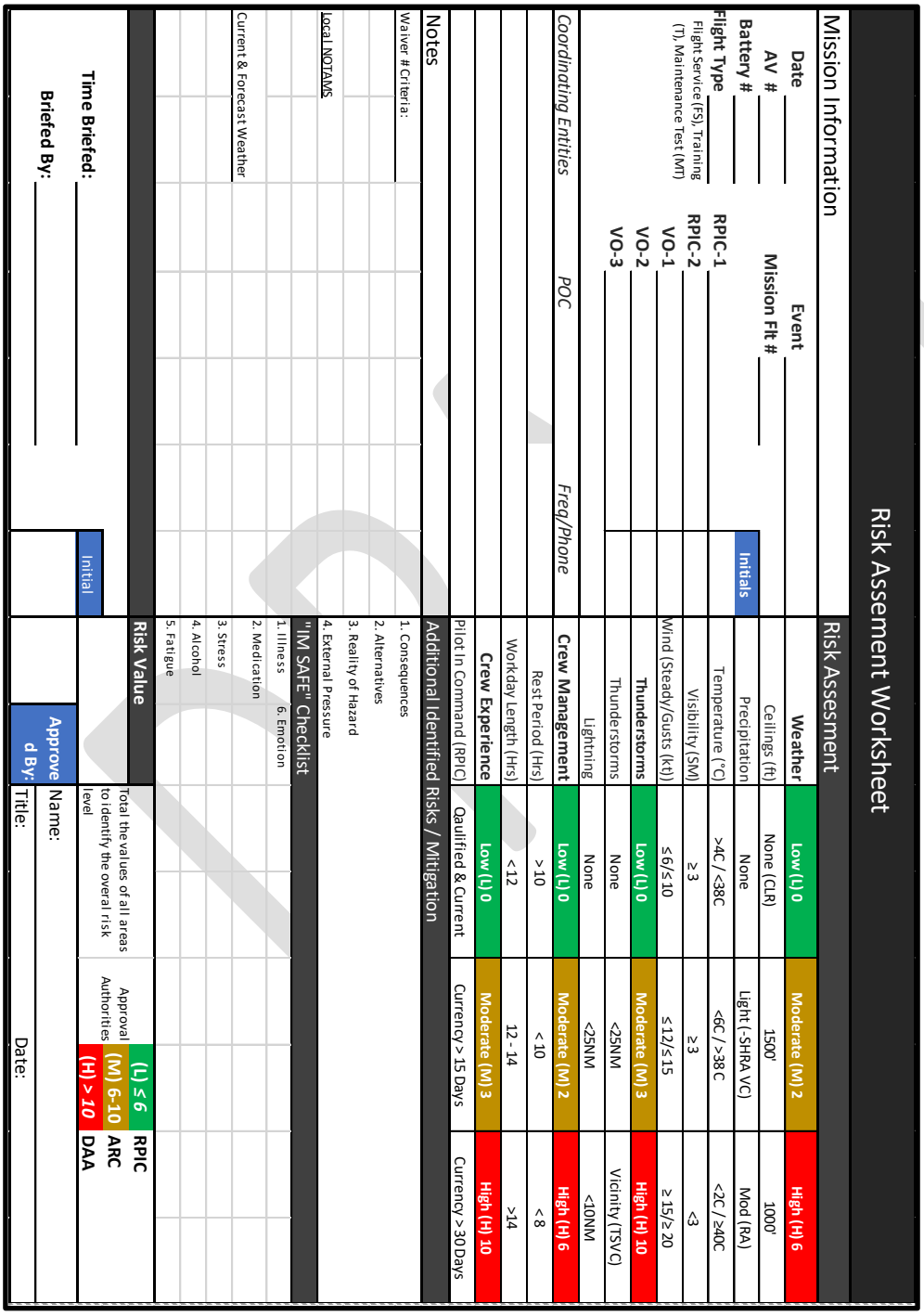
APPENDIX B: Operation Risk Management, Risk Assessment Worksheet

This is a Risk Assessment Worksheet template and should be filled out before every flight to ensure the flight is flown within established safety parameters. In the case of a mishap, this will be a crucial document.



Risk Assesment Worksheet

Mission Information

Date _____ Event _____

AV # _____ Mission Flt # _____

Battery # _____

Flight Type (Flight Service (FS), Training (T), Maintenance Test (MT))

RPIC-1 RPIC-2 VO-1 VO-2 VO-3

Coordinating Entities | POC | Freq/Phone

Local NOTAMS

Current & Forecast Weather

Waiver # Criteria:

Time Briefed:

Briefed By:

Initial

Risk Assesment

	Initials	Low (L) 0	Moderate (M) 2	High (H) 6
Weather				
Ceilings (ft)		None (CLR)	1500'	1000'
Precipitation		None	Light (-SHRA VC)	Mod (RA)
Temperature (°C)		>4C / <38C	<6C / >38 C	<2C / ≥40C
Visibility (SM)		≥ 3	≥ 3	<3
Wind (Steady/Gusts (kt))		≤6/≤10	≤12/≤15	≥ 15/≥ 20
Thunderstorms		**Low (L) 0**	**Moderate (M) 3**	**High (H) 10**
Thunderstorms		None	<25NM	Vicinity (TSVC)
Lightning		None	<25NM	<10NM
Crew Management		**Low (L) 0**	**Moderate (M) 2**	**High (H) 6**
Rest Period (Hrs)		> 10	< 10	< 8
Workday Length (Hrs)		< 12	12 - 14	>14
Crew Experience		**Low (L) 0**	**Moderate (M) 3**	**High (H) 10**
Pilot In Command (RPIC)		Qaulified & Current	Currency > 15 Days	Currency > 30 Days

Notes

Additional Identified Risks / Mitigation

"I'M SAFE" Checklist

1. Illness
2. Medication
3. Stress
4. Alcohol
5. Fatigue
6. Emotion

1. Consequences
2. Alternatives
3. Reality of Hazard
4. External Pressure

Risk Value

Total the values of all areas to identify the overal risk level

Approval Authorities

(L) ≤ 6 RPIC

(M) 6-10 ARC

(H) > 10 DAA

Approved By:

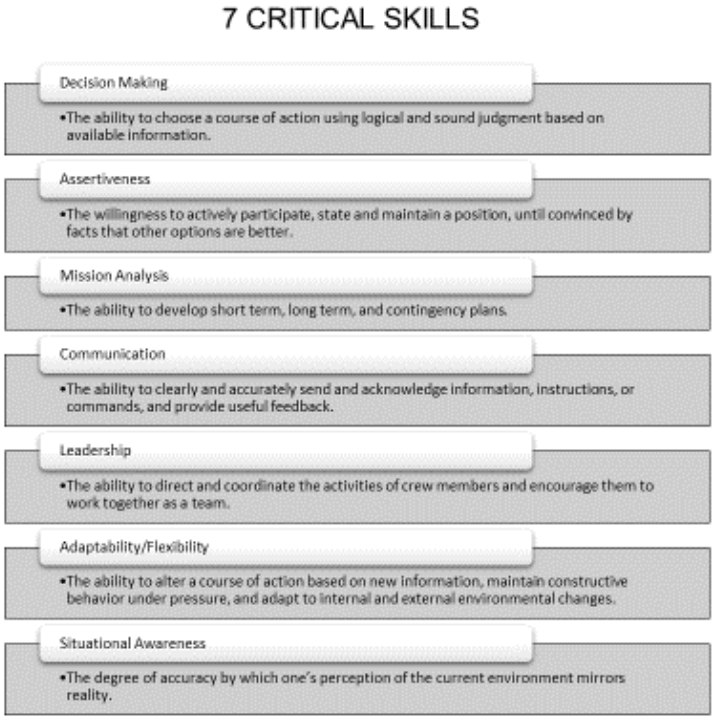
Name:

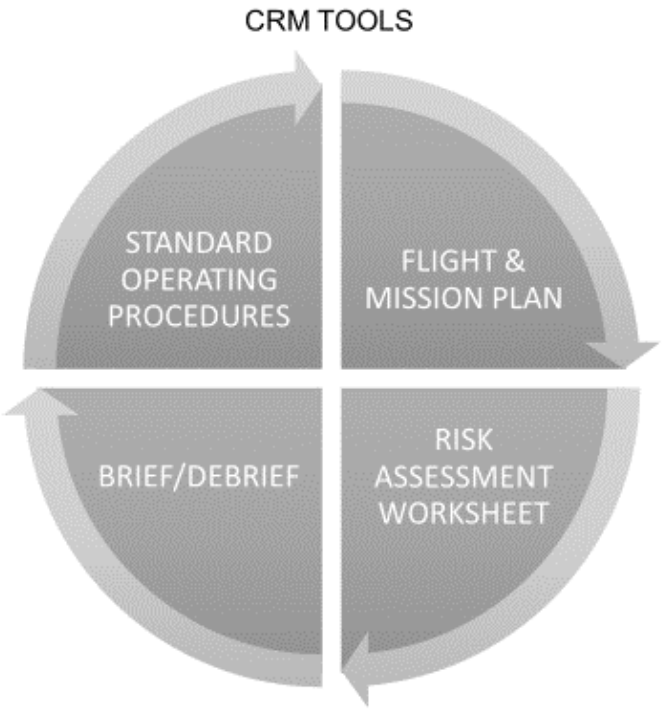
Title:

Date:

APPENDIX C: Crew Resource Management Aid

The goal of CRM is to improve mission effectiveness by minimizing crew preventable errors, maximizing crew coordination, and optimizing risk management. The diagram below describes each of the 7 critical skills to CRM and the tools for implementation. Being aware of these skills and tools will increase performance and safety during aviation operations.





Appendix D: Pre-Mishap Plan

Should a mishap occur, utilize the plan laid forth below to ensure all information is collected and correct procedures are followed. While filling out important information, it is also vital to follow the steps below to protect individuals involved and the flight data.

IMMEDIATE ACTION CHECKLIST

STEP	ITEM	TIME
1	RECEIVE NOTIFICATION AND FILL OUT MISHAP INFO SHEET	
2	BEGIN TELEPHONE LOG	
3	NOTIFY PERSONNEL IF MEDICAL RESPONSE IS REQUIRED	
4	NOTIFY KEY EMD AND CUSTOMER PERSONNEL	
5	SECURE ONSITE AND PERSONNEL RECORDS	
6	RECORD LOCAL WEATHER DATA	
7	DRAFT MISHAP REPORT	

STEP 1: MISHAP INFO SHEET

IF YOU ARE BEING NOTIFIED BY TELEPHONE, IMMEDIATELY ASK THE CALLER FOR: THEIR NAME AND PHONE NUMBER BEFORE CONTINUING BELOW.

DATE: _____ TIME: _____

NAME OF PERSON REPORTING MISHAP: _____

TELEPHONE NUMBER OF PERSON REPORTING: _____

DID THEY SEE THE MISHAP? _____

WERE MANNED AIRCRAFT WERE INVOLVED? _____

LOCATION OF MISHAP:_____

WAS/IS THERE A FIRE?_____

IS ANYONE INJURED?_____

TYPE OR DESCRIPTION OF AIRCRAFT: _____

AIRCRAFT TAIL NUMBER OR MARKINGS: _____

CONDITION OF AIRCRAFT: _____

DAMAGE TO PRIVATE PROPERTY?_____

WHO IS CURRENTLY AT THE MISHAP SCENE? _____

WHAT IS THE WEATHER LIKE AT THE MISHAP SITE? _____

STEP 2: MISHAP PHONE LOG

- DO NOT TAKE MEDIA QUESTIONS, RESPOND WITH STATEMENT BELOW:

"I CANNOT COMMENT ON THE EVENTS OF THE INCIDENT IN QUESTION, WE ARE COLLECTING AS MUCH INFORMATION AS POSSIBLE FOR AN INTERNAL REVIEW AND INVESTIGATION AND WILL MAKE ALL INFORMATION AND RESOURCES AVAILABLE TO THE APPROPRIATE STATE AND GOVERNMENT AGENCIES WHO MAY BE INVOVLED."

TIME(L)	EVENT: PHONE CALL, MESSAGE, PROBLEM, ETC	POINT OF CONTACT

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STEP 3: NOTIFICATION OF EMERGENCY SERVICES PERSONNEL

- If there are **serious or greater injuries** that occurred due to the mishap, stop the reporting process, and ensure that emergency medical services have been notified. Use sound judgement regarding lesser injuries, many moderate injuries may induce shock which can be life threatening if unaddressed. In all cases, ensure the injured have medical attention before carrying on the remaining reporting procedures.

Abbreviated Injury Score (AIS) Table

AIS-Code	Injury	Example	Chance of Death %
1	Minor	superficial laceration	0
2	Moderate	fractured sternum	1 – 2
3	Serious	open fracture of humerus	8 – 10
4	Severe	perforated trachea	5 – 50
5	Critical	ruptured liver with tissue loss	5 – 50
6	Maximum	total severance of aorta	100

STEP 4: NOTIFICATION OF EMD PERSONNEL

NOTIFY THE FOLLOWING EMD PERSONNEL WITH VOICE-REPORT BY PHONE AND FOLLOW UP WITH MISHAP REPORT VIA EMAIL.

1. John Smith (C): 502-649-6629

   EMAIL: john.smith@EMDuas.com
2. Susan Johnson (C): 850-345-8676

   EMAIL: susan.johnson@EMDuas.com

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STEP 5: SECURE ONSITE RECORDS AND ALL PERSONNEL RECORDS

1. Collect all logbooks, binders and, maintenance records for on-site activities.
2. Take pictures of COC or command center (if able), maintenance site, mishap aircraft, and mishap site.
3. Record any obstacles or hazards that may have taken place.
4. Save telemetry data and footage from the aircraft.
5. Place the aircraft in a safe location and ensure sensors and batteries are disconnected, in a safe condition and not leaking fluids.

NOTE:

A small Li-ion fire can be handled like any other combustible fire. For best result use a foam extinguisher, CO2, ABC dry chemical, powdered graphite, copper powder or soda (sodium carbonate). Water-based products are most readily available and are appropriate since Li-ion contains very little lithium metal that reacts with water. Water also cools the adjacent area and prevents the fire from spreading. Research laboratories and factories also use water to extinguish Li-ion battery fires. Halon is also used as fire suppressant, but this agent may not be sufficient to extinguish a large Li-ion fire.

STEP 6: RECORD LOCAL WEATHER DATA

FORECASTED WEATHER OF MISHAP LOCATION:

(1) AIR TEMP: _____

(2) REL HUM: _____

(3) DEW PT: _____

(4) WATER TEMP: _____

(5) WIND DIR: _____

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(6) WIND VEL: _____

(7) WIND GUSTS: _____

(8) CEILING: _____

(9) SKY COND: _____

(10) HORIZON: _____

(11) VISIBILTY: _____

(12) OBSTRUC: _____

(13) ALTIMETER: _____

(14) ICING: _____

(15) PRECIP: _____

(16) EXTREME WX: _____

ACTUAL WEATHER OF MISHAP LOCATION:

(1) AIR TEMP: _____

(2) REL HUM: _____

(3) DEW PT: _____

(4) WATER TEMP: _____

(5) WIND DIR: _____

(6) WIND VEL: _____

(7) WIND GUSTS: _____

(8) CEILING: _____

(9) SKY COND: _____

(10) HORIZON: _____

(11) VISIBILTY: _____

(12) OBSTRUC: _____

(13) ALTIMETER: _____

(14) ICING: _____

(15) PRECIP: _____

(16) EXTREME WX: _____

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FORECAST STATION NAME/LOCATION: _____

ACTUAL WX STATION NAME/LOCATION: _____

STEP 7: RECORD MISHAP REPORT

AFTER COLLECTING ALL INCIDENT INFORMATION, FILL OUT THE FOLLOWING REPORT AND DISSEMINATE TO APPROPRIATE EMD PERSONNEL ONLY:

1. REPORTING PERSON / COMPANY: _____
2. AIRCRAFT TYPE AND REGISTRATION NUMBER: _____
3. MISHAP LOCATION: _____
4. BRIEF NARRATIVE(5W's):

_____

_____

_____

_____

_____

_____

_____

_____

5. DAMAGE: _____
6. INJURIES/FATALITIES: _____
7. POINT OF CONTACT: _____

DO NOT RELEASE ANY INFORMATION FROM THIS REPORT OUTSIDE OF THE EMD; MANY OF THE DETAILS MAY BE EITHER PROPRIETARY OR PROTECTED BY THE PRIVACY ACT OF 1974.

THE ENCLOSED DOCUMENT(S) MAY CONTAIN PERSONAL OR PRVIELEGED INFORMATION AND SHOULD BE TREATED AS FOR OFFICIAL USE ONLY. UNAUTHORIZED DISCLOSURE OF THIS INFORMATION MAY RESULT IN CIVIL AND CRIMINAL PENALTIES. IF YOU ARE NOT THE INTENDED RECIPIENT OR BELIEVE THAT YOU HAVE RECEIVED THIS DOCUMENT(S) IN ERROR, DO NO COPY,

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DISSEMINATE OR OTHERWISE USE THE INFORMATION AND CONTACT THE OWER/CREATOR OF THE DOCUMENT REGARDING ITS USE AND RECOVERY.

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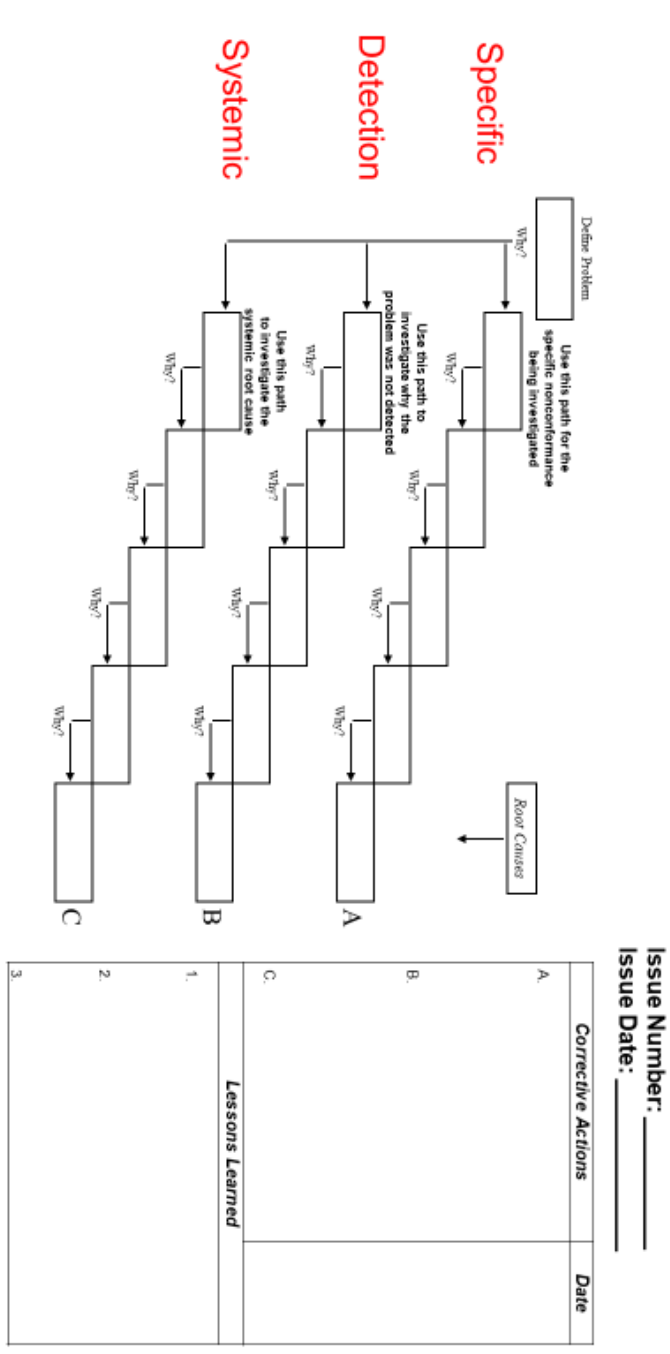
Appendix E: Root Cause Analysis Aid



A root cause is any factor that led to a nonconformance and should be eliminated through process improvement. A root cause analysis (RCA) encompasses a wide range of tools and techniques to uncover the cause of problems. A sample RCA is provided below.

1. Specific Cause – Why did the mishap occur?
2. Detection Cause – Why was the defect not detected?
3. Systemic Cause – Why was the "system" unable to prevent it?

Appendix F: Site Survey Checklist

Conducting a site survey when you are unfamiliar with the area will assist in completing the flight plan. Much of the site survey can be conducted before departing for the field and then can be verified upon arrival at the site. When each step is completed while surveying a site, initial and date.

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		

Print and Sign Names for site survey members.

EMD Coordinator:	
RPIC:	

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STEP 1: DETERMINE FLIGHT LOCATION

1. Record the coordinates for:
    a. The center point of operations (Lat/Long or MGRS):
        1. _____
    b. A box designed to contain flight operations:
        1. _____
        2. _____
        3. _____
        4. _____
    c. Site elevation
    d. Obstacles / Hazards
    e. Primary Geographical References
    f. Airspace boundaries and control measures
    g. Magnetic Variation

STEP 2: DETERMINE AIRSPACE & SPECTRUM REQUIREMENTS

1. What is the airspace profile above the site where you need to collect data?
2. Who is the primary coordination agency or method? (i.e. Cherry Point Airfield Operations or LAANC)
3. What radio frequencies are listed for that airspace? (i.e. Tower or CTAF)
4. Are there any special agencies required for further coordination?
5. Is it necessary to request frequencies for aircraft equipment or radios?

STEP 3: DETERMINE LAUNCH & RECOVERY SITES

1. How much clear from obstacle space is needed for the launch and recovery profile for each aircraft?

2. How many departure and approach directions are available in case of shifting winds? (e.g. NW-SE, SW-NE)

3. Are the aircraft fail-safe logic, and return home profiles safely deconflicted from hazards or

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obstacles?

STEP 4: DETERMINE COMMAND CENTER LOCATION AND REQUIREMENTS

1. Is a command center required to allow for longer duration operations, or persistence site presence for continued support availability?

2. What is the total power requirement of all the command center equipment? Is auxiliary power required for additional laptops, phones, coffee pots?

3. If so, is there power supplied at the site or will a generator be required?

4. Will fuel for generators be available on site? Is battery backup available if power is lost?

5. Is there space for adequate shelter to protect the equipment from intrusion of the elements (e.g. temperature, dust/particulate, smoke, water)?

STEP 5: CONDUCT WEATHER STUDY

1. What is the max / avg / min temperatures for the operating area during this time of year?

2. What is the max / avg / min dew point for the operating area during this time of year?

3. What is the max / avg / min relative humidity for the operating area during this time of year?

4. What is the max / average / min wind speed and gusts for the operating area during this time of year?

5. What is the max / average / min precipitation for the operating area during this time of year?

6. What is the precipitation average for the operating area during this time of year?

STEP 6: DETERMINE PERSONNEL REQUIREMENTS

1. Determine how many total people need to be supported on site (e.g. OIC, RSO, AVO, VO).

2. Are facilities available to meet basic human physiological needs at or near the site (i.e.

DRAFT

restrooms, water, food)?

3. Are facilities provided to capture waste on site (recycling, trash)?

STEP 7: DETERMINE MISSION KIT REQUIREMENTS

Ensure to capture all equipment which will be accounted for on site, initial upon inventory.

1. What types of data need to be collected?

    a.

    b.

    c.

2. Which sensors best meet the requirement of the data?

3. Which aircraft provides the necessary profiles, coverages and times to meet the data needs?

4. What ground gear is needed to support flight equipment?

MISSION KIT INVENTORY

MAJOR ITEMS	QTY	INVENTORY

DRAFT

STEP 8: DETERMINE SPECIAL COORDINATION INSTRUCTIONS

1. Does the area require coordination with a Range Control Facility?

    a. Gather a copy of range control regulations

    b. Gather range control coordination requirements (i.e. special range request)

2. Are there other agencies or parties that will be actively working in the range space, co-use or nearby?

    a. Collect radio frequencies, phone numbers as necessary

    b. Collect coordination POC phone and email.

STEP 9: COLLECT POINTS OF CONTACT

Establish all relevant agencies and their points of contact for quick reference.

AGENCY	NAME	CONTACT
		P: E:
		P: E:
		P: E:
		P:

DRAFT

		E:
		P: E:
		P: E:
		P: E:
		P: E:

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Appendix G: Aircrew Training Form

An Aircrew Training Form (ATF) can be implemented in a sUAS program to track the progress of pilot training. The instructor will grade the student utilizing an ATF similar to the one below, and then debrief the student on positive and negative aspects after the flight.

EMD

AIRCREW TRAINING FORM

DATE	
SUAS	
RANGE	
TIMES	

PERSONNEL	AVO:
	VO:
MISSION	

	ITEM	DND	FINISHED
A	**PLAN & PREP**		
1	Read and Review Weather & NOTAMS		
2	Review Airspace Charts and		
3	Review Aircraft Operating Limitations		
B	**BRIEF**		
1	Administrative Items		
2	Mission Items		
3	General Flight Rules		
4	Range Reuglations		
5	Basic Maneuvers		
6	Emergency Procedures		
C	**GENERAL EXECUTION**		
1	Preflight checklist		
2	Start Checklist		
3	Launch		
4	Routing		
5	Recovery		
5	Post-recovery checklist		
D	**SPECIFIC EXECUTION**		
1	Mapping Mission		
2	3D Model Mission		
3	Full Motion Video Mission		
4	Infrared Mission		
E	**DEBRIEF**		
1	Assess Mission Performance Standards		
2	Recall / Mission Reconstruction		
3	Lessons Learned		

REMARKS	
Goal	Review basic planning and local area procedures.
Requirement	Practice: Flight planning, briefing, and debriefing. Normal procedures from start to shut down. Local area procedures to include departure, en route, and terminal approach procedures. CRM throughout the flight.
Performance Standard	AVO demonstrates familiarity with aircraft system setup, conduct of preflight, engine start, aircraft launch, post launch, and recovery procedures. Execute all normal and emergency procedures in accordance with vendor guidance and applicable directives.
Prerequisite	Initial qualification
Reference	EMD SUAS SOP
Notes:	

FLIGHT BRIEF

Roll Call			**Environmentals**	
			Time:	Forecast:
Mission Overview			WInds:	Aloft:
Mission Objectives:			Visilbity:	
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**	
Launch& Recover Sites / MSA			KIO: Safety of Flight	
Working Areas / MSA			**Questions | Back Brief**	
Contingency Areas				
Hazards				
Restrictions / Waiver Criteria				

Appendix J: Types of UA

(1) Group 1 UA. Typically weighs less than 20 pounds. It normally operates VFR in Class E, G, and Restricted or Uncontrolled airspace below 1200' AGL at speeds less than 100 knots under a JMQ A mission. The JUMTS for Group 1 UAS is BUQ I and JMQ A.

(2) Group 2 UA. Typically weighs 21-55 pounds. It normally operates VFR in Class D, E, G, and Restricted airspace below 3500' AGL at speeds less than 250 knots under a JMQ A mission. The JUMTS for Group 2 UAS is BUQ II and JMQ A.

(3) Group 3 UA. Typically weighs more than 55 pounds, but less than 1320 pounds, and normally operates VFR in Class D, E, G, and Restricted airspace below 18,000' MSL at speeds less than 250 knots prosecuting J-ISR and JMQ A/B mission targets. The JUMTS for Group 3 UAS is BUQ II and JMQ B.

(4) Group 4 UA. Typically weighs more than 1320 pounds. It normally operates under VFR in all classes of airspace below 18,000' MSL (except U.S. and ICAO Class A) at any speed prosecuting J-ISR and JMQ A/B mission targets. The JUMTS for Group 4 UAS is BUQ III and JMQ B.

(5) Group 5 UA. Typically weighs more than 1320 pounds. It normally operates at altitudes higher than 18,000' MSL at any speed prosecuting J-ISR and JMQ A/B mission targets. The JUMTS for Group 5 UAS is BUQ IV and JMQ B.

APPENDIX E REMOTE SENSING FIELD GUIDE

APPENDIX E.

REMOTE SENSING FIELD GUIDE

CONFIRM|REDDIE PROJECT TEAM

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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:				Visilbity:	
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					

2. Risk Assessment Worksheet

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 t Of preflight planning.

Risk Assement Worksheet

Mission Information

Date		Event	
AV #		Mission Flt #	
Battery #			Initials
Flight Type		RPIC-1	
Flight Service (FS), Training (T), Maintenance Test (MT)		RPIC-2	
		VO-1	
		VO-2	
		VO-3	

Coordinating Entities	*POC*	*Freq/Phone*

Risk Assesment

Weather	**Low (L) 0**	**Moderate (M) 2**	**High (H) 6**
Ceilings (ft)			
Precipitation			
Temperature (˚C)			
Visibility (SM)			
Wind (Steady/Gusts (kt))			
Thunderstorms	**Low (L) 0**	**Moderate (M) 3**	**High (H) 10**
Thunderstorms			
Lightning			
Crew Management	**Low (L) 0**	**Moderate (M) 2**	**High (H) 6**
Rest Period (Hrs)			
Workday Length (Hrs)			
Crew Experience	**Low (L) 0**	**Moderate (M) 3**	**High (H) 10**
Pilot In Command (RPIC)			

Notes

Waiver # Criteria:

Local NOTAMS

Current & Forecast Weather

Additional Identified Risks / Mitigation

1. Consequences
2. Alternatives
3. Reality of Hazard
4. External Pressure

"IM SAFE" Checklist

1. Illness	6. Emotion
2. Medication	
3. Stress	
4. Alcohol	
5. Fatigue	

Time Briefed: _____ Initial

Briefed By: _____

Risk Value	Total the values of all areas to identify the overal risk level	Approval Authorities		
			(L) ≤ 6	RPIC
			(M) 6-10	ARC
			(H) > 10	DAA

Approved By: Name:

Title: Date:

RPIC Signture:_____

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.

The site survey checklist below is meant to be used with the COTS UAS Standard Operating Procedure document, Appendix F, which expands upon each step.

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

- Tide: beach mapping is best conducted at low tide to ensure the maximum amount of land is viewed.
- Flight path: due to long and linear beaches, it may not be feasible to fly with a cross wind trajectory. Testing different flight paths with estimated winds will optimize the efficiency and endurance of the UAS.
- 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.
- 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 different 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.

eBee X Sensors

The senseFly eBee X is equipped with a modular payload system allowing for the quick swap of a variety of payloads. There are four camera types fielded in the CONFIRM & REDDIE mission kits.

AERIA X

Sensor: APS-C

Lens: F/2.8-16 18.5mm

Resolution: 24 MP

ISO Range: 100-6400

GSD: ~2.5 cm/pixel @ 400 ft AGL

AERIA X is a high quality RGB mapping camera that provides DSLR like image quality. The camera offers excellent image detail and clarity in virtually all light conditions. This camera is ideal for creating orthomosaics and digital surface models (DSM).

S.O.D.A. 3D

Sensor: 1” RGB

Lens: F/2.8-11, 10.6mm

Resolution: 20 MP

ISO Range: 125-6400

GSD: ~2.8 cm/pixel @ 400ft AGL

The Sensor Optimized for Drone Applications (S.O.D.A.) provides 3 dimensional reconstructions in vertically focused environments such as urban and coastlines. The camera takes 3 images (2 oblique, 1 nadir) at every photo footprint. End products from this camera include 3D models along with 2D othermosaics and DSMs.

DUET T

Sensor: Thermal infrared (FLIR) / RGB

RGB Lens: F2/8-11 10.6mm

Thermal Lens: F/1.25 13mm

Resolution: Thermal: 640x512/ RGB: 5472x3648

GSD: Thermal: ~15 cm/pixel RGB: ~2.6 cm/pixel @ 400 ft AGL

The Duet T is equipped with a FLIR thermal camera and S.O.D.A. RGB. Images are captured simultaneously with the same geolocation for both images. Users are not capable of disabling one of the cameras. The two bands are collected in separate folders and can be deleted from the SD card as desired. Images collected from this sensor can be used to create orthomosaics and DSMs in RGB and thermal spectrums.

MicaSense RedEdge-MX

Sensor: Five band multispectral

Bands: Blue, Green, Red, Red edge, Near IR

Single-band resolution: 1.2MP

GSD: ~8.00 cm/pixel @ 400ft AGL

The RedEdge-MX is a precise multispectral sensor for advanced agricultural analysis. It captures both the spectral bands required for crop health indices and an additional blue band for deeper insights into specific issues. This sensor is ideal for creating normalized difference vegetation index (NDVI). Users should calibrate the sensor before each flight, using the provided calibration panel.

5. eBee X

Preflight Checklist

eBee X Pre-flight Checklist Checklist

Last update (2020-01-28)

1	Check area of operation for obstructions, people, and property
2	Check takeoff/landing exclusion if necessary
3	Check airframe for signs of damage
4	Check aircraft motors are mounted securely and check props for cracks and tightness
5	Check propeller o-rings are secure and are not cracked or damaged
6	Check wings are installed securely
7	Check wings and ailerons are in good condition and hinge mechanisms are not damaged
8	Check wiring is clear of mechanics and secured
9	Check payload is installed, connected, and secure
10	SD card/memory installed with sufficient space available
11	Lens cap removed
12	Lens clean
13	Check pitot tube is clear
14	Check ground proximity sensor is clean and unobstructed
15	Check GCS battery level
17	Turn off GCS wifi and bluetooth
18	Connect modem
19	Load flight plan and check mission, take off, and landing parameters
20	Check battery condition and install
21	Power up aircraft
22	Connect to aircraft
23	Upload flight plan to aircraft
24	Verify fail-safes settings are appropriate for mission
25	Test camera operations and perform any calibrations necessary
26	Check AV Health. RSSI/signal strength
27	Check AV Health. Battery
28	Check AV Health. GPS satellites

Best Mission Practices

- To maximize battery life, plan the mission for crosswind flight. Start at the point farthest away and work back towards the landing point to prevent a long transit with low battery.

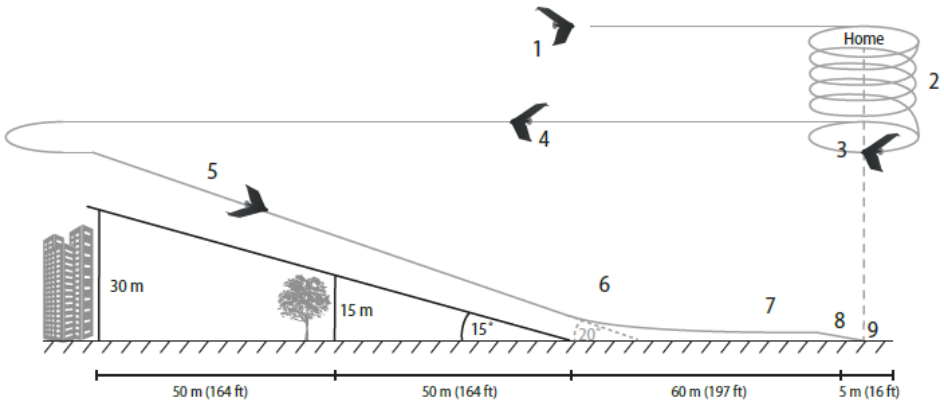
- Recommended minimum in-flight battery percentage: 30%
- Standard overlap: 70% lateral and longitudinal.
    - If flying a 3-D camera such as the S.O.D.A 3D, a “cross-hatch” flight pattern of perpendicular lines may be needed to fully develop all sides of the structure being mapped.
- Taking a sensor calibration image is an important step before every flight. It is crucial when flying the MicaSense RedEdge-MX for optimal imaging . : see User’s Manual under “Help” tab in eMotion for specific camera.
- For PPK processing, CORS with 1 second rate should be used for best results. See Section III of the eMotion user manual for detailed instructions.
    - Note: the RINEX file is uploaded via eMotion in the “Postflight” tab.

Maintenance & Care

- There are three options for charging a senseFly: Smart Battery.
  1. Flight Charge - 100%
  2. Storage Charge - 70%
  3. Shipping Charge - 30%
- If the aircraft is not going to be flown for greater than 2 weeks, batteries should be put into “storage charge” for long-term battery health.
- If the aircraft is not going to be flown for greater than 2 weeks, the O-rings and propeller should be removed to increase O-ring life by reducing stretching.

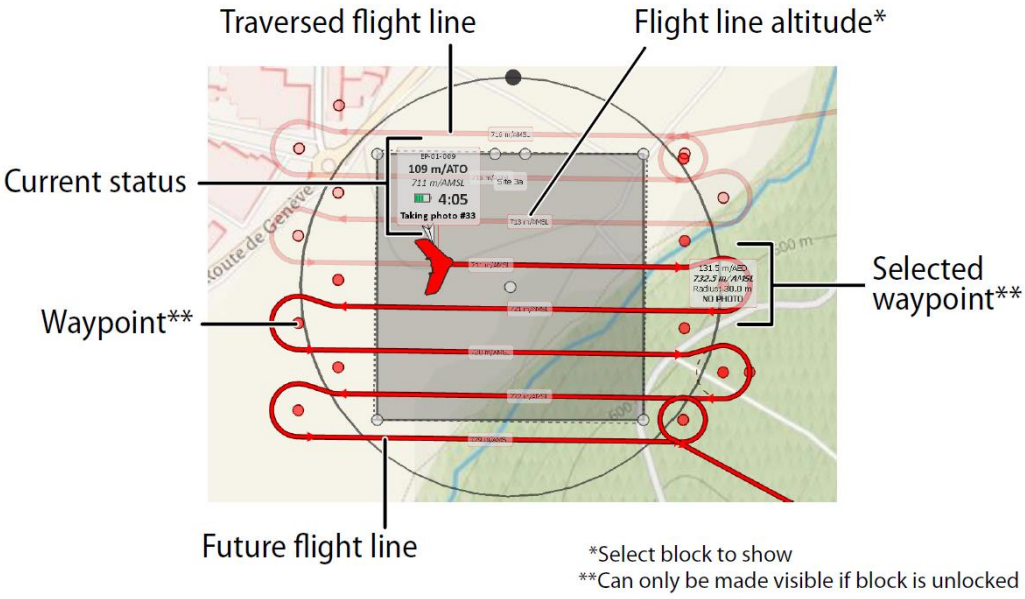
Landing Area Parameters

- All take-off and landings should be made into the most direct headwind possible. By default, landing altitude is set to the same altitude as take-off (0ft/ATO). You must edit this altitude if you are flying over uneven terrain, and the point at which the drone will land is at a different altitude to take-off.
- See below for Linear Landing procedures:



1. Home approach
2. Spiral up or down to between 50 and 75 m above landing spot
3. Circle to measure wind
4. Fly downwind
5. Landing approach
6. Level out at 20 m
7. Final braking at 3 m
8. Deep stall
9. Landing

eMotion Interface



7. Anafi Thermal

Preflight Checklist

ANAFI
— THERMAL —

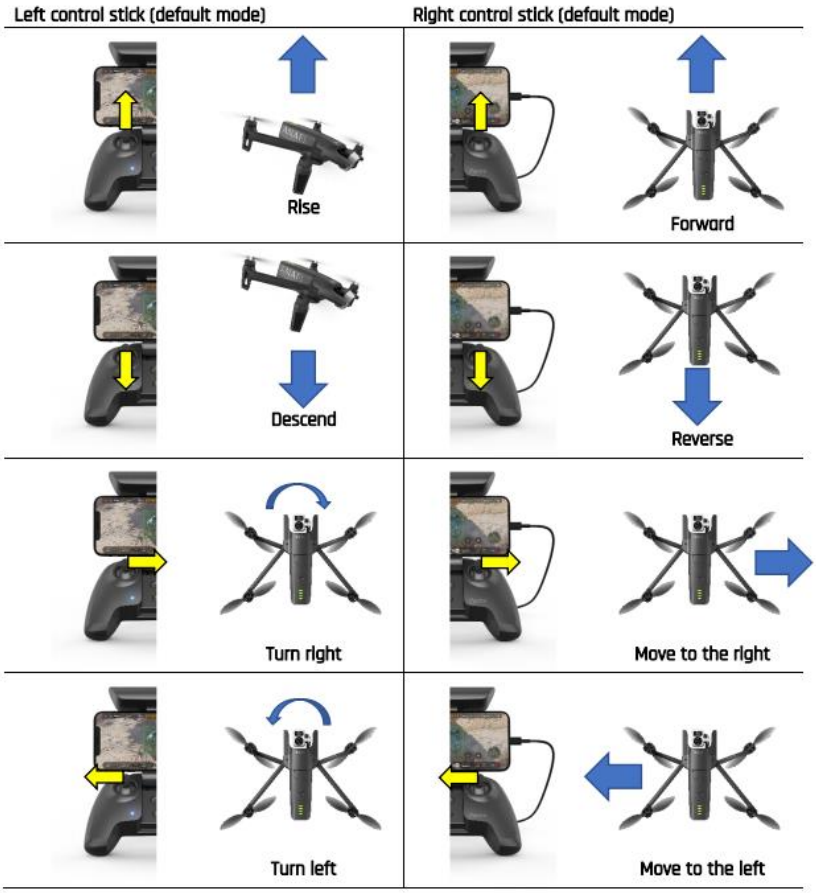
PRE-FLIGHT CHECKLIST

Equipment

- **Make sure you have downloaded the latest version of FreeFlight 6 and that both your Parrot Skycontroller 3 and your ANAFI Thermal have been updated with the latest versions of firmware.**
- **For the ultimate ANAFI Thermal experience, make sure you have the right USB-A cable to connect your Parrot Skycontroller 3 and your device.**
- **Make sure ANAFI Thermal is fitted with a microSD card with enough free memory space.**
- Make sure all four foldable arms of ANAFI **Thermal** are unfolded.
- Make sure its propellers are clean, intact and unobstructed.
- Make sure both ANAFI **Thermal**'s and **Parrot Skycontroller 3**'s batteries are fully charged.
- Make sure ANAFI **Thermal**'s battery is securely installed on the drone's body.
- Make sure the lens cap has been removed from ANAFI **Thermal**'s gimbal.
- Make sure ANAFI **Thermal**'s lenses are clean – if you need to clean them, hold the gimbal between two fingers so that you do not pressure its mechanism when you clean the lenses, and gently wipe the lenses with a microfiber cloth.

Flight Operations

FLYING



Battery Considerations

Correct battery installation

Incorrect battery installation

The Anafi will power on and appear normal even if the battery is not installed properly. Note the gap between the aircraft frame and battery in the right picture. Ensure battery sits flush during installation and preflight checks.

The tables below annotate the LEDs and corresponding flight time remaining:

When **ANAFI Thermal**'s smart LiPo battery is plugged to a power source and charging, **its 4 LEDs indicate in real time its level of charge**:

- LED 1 flashing: battery is between 0 and 25% charged;
- LED 1 steady & LED 2 flashing: battery is between 25 and 50% charged;
- LEDs 1 and 2 steady & LED 3 flashing: battery is between 50 and 75% charged;
- LEDs 1, 2 and 3 steady & LED 4 flashing: battery is between 75 and 100% charged;
- battery is plugged and all LEDs are off: battery is full.

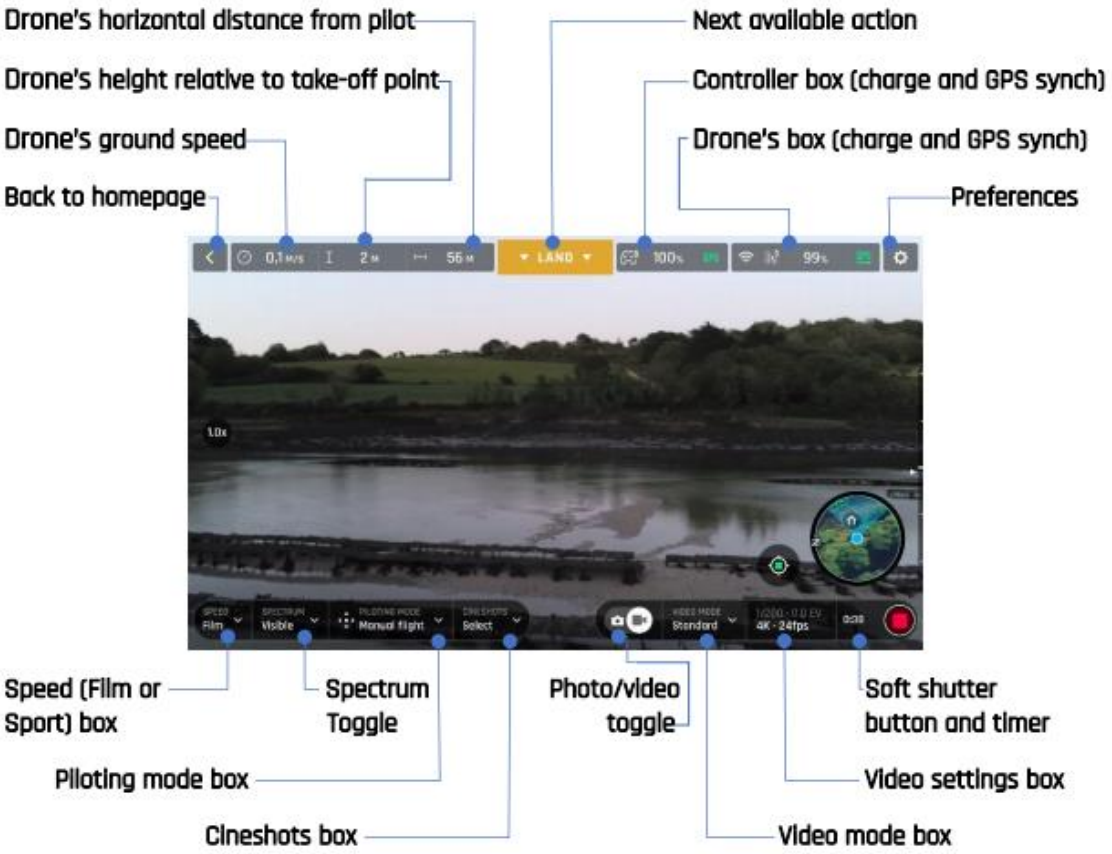
Similarly, when **your battery is not installed on ANAFI Thermal**, you can check its charge level at any time by pressing its power button:

- 1 steady LED lights up: battery is between 0 and 25% charged;
- 2 steady LEDs light up: battery is between 25 and 50% charged;
- 3 steady LEDs light up: battery is between 50 and 75% charged;
- 4 steady LEDs light up: battery is between 75 and 100% charged.

Finally, the same logic applies when **the smart LiPo battery is installed on the drone and when ANAFI Thermal is powered on**. The number of steady LEDs enables you to estimate your remaining flying time:

- 1 steady LED is lit up: less than 6 minutes flying time remaining;
- 2 steady LEDs are lit up: between 6 and 12 minutes flying time remaining;
- 3 steady LEDs are lit up: between 12 and 18 minutes flying time remaining;
- 4 steady LEDs are lit up: between 18 and 25 minutes flying time remaining.

FreeFlight 6



ANAFI **Thermal** and **FreeFlight 6** are packed with features which are accessible from the HUD. Before we present the *"PREFERENCES"* menu of **FreeFlight 6**, here is an overview of your drone's current piloting, Cineshots, Dronies, and visible video modes.

Piloting modes:
- Manual flight
- Cameraman
- Follow Me
- Smartdronies
- Touch & Fly: Waypoint & POI
- Flight Plan

Video modes:
- Standard
- Cinema
- Hyperlapse
- High-Framerate
- Slow Motion

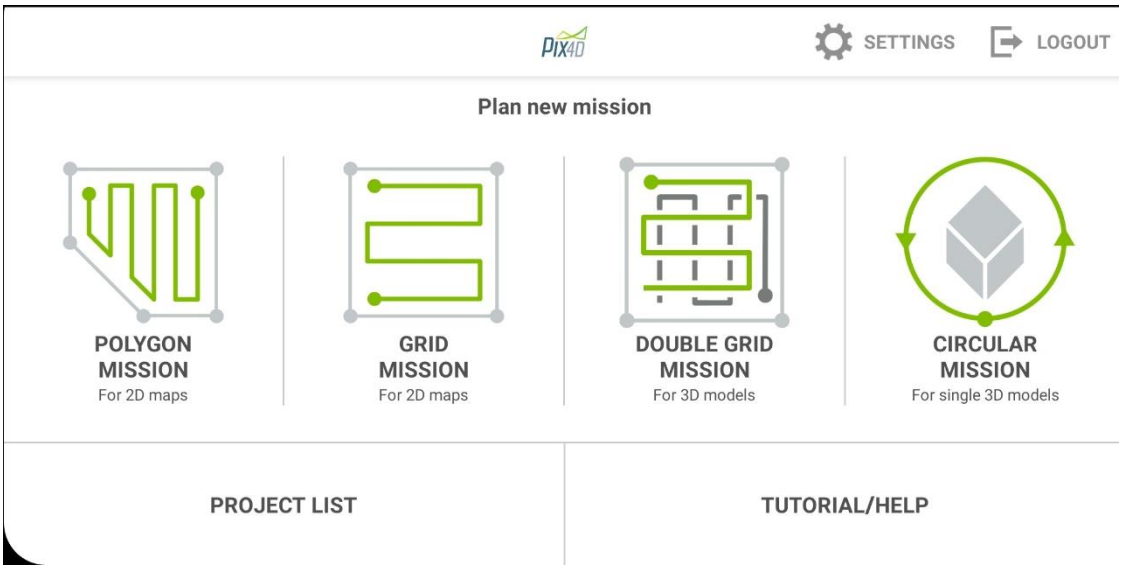
Cineshots:
- 360° (left & right)
- Reveal (30 & 60m)
- Spiral (30 & 60m)
- Epic (30 & 60m)

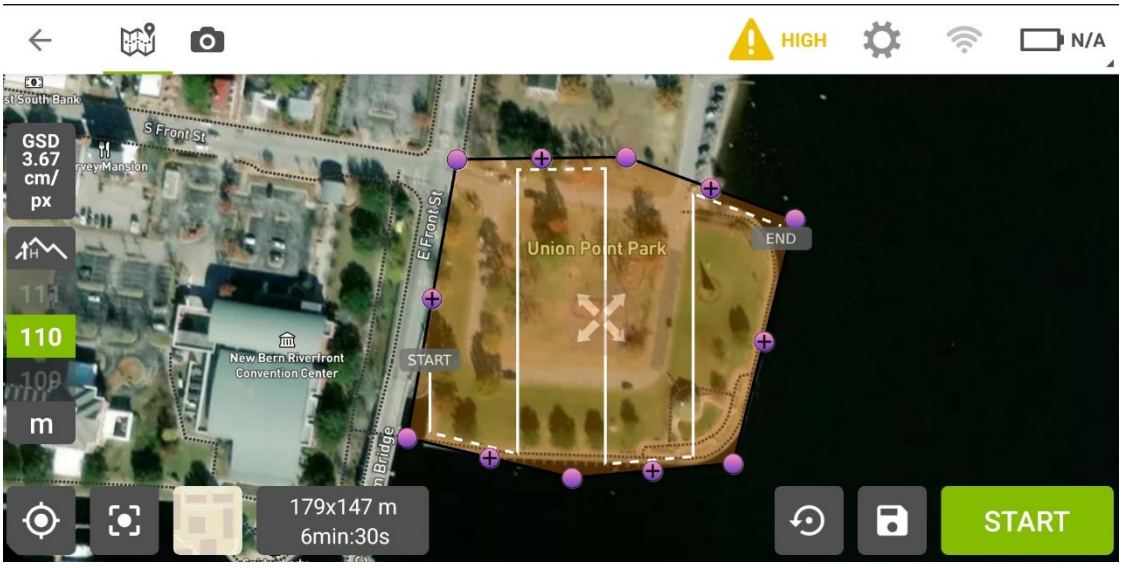
Smartdronies & POI Dronies
- Orbit
- Parabola
- Dolly Zoom
- Boomerang

Follow Me Dronies
- Orbit
- Parabola
- Tornado
- Boomerang

Pix4D Capture

The Pix4D Capture application is a great alternative when paired with the Anafi for mapping small areas, or sites that have an inadequate launch/recovery area for the eBee X. The application is capable of creating missions for 2D or 3D data collection.





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