ESTCP

FINAL REPORT

Hawai'i Munitions Test Range Complex

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14. ABSTRACT

The underwater environment presents unique challenges when developing technologies for the detection, classification, and remediation of munitions. Establishing underwater tests sites to conduct controlled assessments of MEC-related technologies in realistic environments is crucial in progressing toward operational status. The Applied Research Laboratory at the University of Hawaiʻi (ARL at UH) established the Hawaiʻi Munitions Test Range Complex (HI_MTRC) at two Oʻahu sites: Moku o Loʻe on the windward side and Sand Island on the south shore. HI_MTRC is designed to implement multiple short-duration, rapidly deployable and recoverable test sites across a range of environments around the island of Oʻahu to evaluate best practices and systems for MEC detection and assessment. Uncrewed systems were used to reduce costs, increase the spatial extent of the test site, reduce the time to perform specific tasks while simultaneously extending the duration of operations, and limit human exposure to the elements. Accomplishments of this effort include identifying and characterizing demonstration sites, developing approaches to rapidly deploy test sites, conducting engineering tests and a scaled deployment at one test site, improving geolocation information using a combination of swimmers, uncrewed systems and precise navigation approaches, and performing a tabletop exercise to evaluate an Optical Munitions Detector at one test site.

The HI_MTRC project demonstrated that a hybrid approach, combining complimentary capabilities of swimmers and uncrewed systems, successfully produced multiple rapidly deployable test sites with a range of seafloor and environmental conditions, covering hundreds of square meters. The HI_MTRC effort also highlighted the benefits of frequent, repetitive field work to assess technology performance under variable conditions.

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munitions test range; uncrewed systems; seafloor mapping; tabletop exercise

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ACRONYMS AND ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
AED	Automatic External Defibrillator
ARL	Applied Research Laboratory
cm	centimeter
COE	College of Engineering
CONOPS	Concept of Operations
CORS	Continuously Operating Reference Station
COTS	Commercial-off-the-Shelf
COVID-19	Corona Virus Disease 2019
DAR	Division of Aquatic Resources
DLNR	Department of Land and Natural Resources
DMM	Discarded Military Munitions
DoD	Department of Defense
ESA	Endangered Species Act
ESTCP	Environmental Security Technology Certification Program
FFF	Fused Filament Fabrication
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
HI_MTRC	Hawai‘i Munitions Test Range Complex
HIMB	Hawai‘i Institute of Marine Biology
IDA	Institute for Defense Analysis
in	inch/inches
kg	kilograms
km	kilometers
kts	knots
LiDAR	Light Detection And Ranging
LoRa	Long Range
m	meter
m^2	square meter
MCBH	Marine Corps Base Hawai‘i
MEC	Munitions and Explosives of Concern
METC	Maritime Education and Training Center
MHz	MegaHertz
mm	millimeter

NERR	National Estuarine Research Reserve
nm	nanometer
NOAA	National Oceanic and Atmospheric Administration
OMD	Optical Munitions Detector
PETG	Polyethylene Terephthalate Glycol-Modified
PNNL	Pacific Northwest National Laboratory (PNNL)
PVS	Polynesian Voyaging Society
ROS	Robot Operating System
ROV	Remotely Operated Vehicle
RTCM	Radio Technical Commission for Maritime Services
RTK	Real-Time Kinematic
SERDP	Strategic Environmental Research and Development Program
SSS	Sidescan Sonar
TTX	Tabletop Exercise
UH	University of Hawai‘i
UAV	Uncrewed Aerial Vehicle
UAS	Uncrewed Aircraft Systems
US	United States
USV	Uncrewed Surface Vehicle
UTM	Universal Transverse Mercator
UV	Ultraviolet
UXO	Unexploded Ordnance
UxS	Uncrewed Systems
UxV	Uncrewed surface vehicles
WAM-V	Wave Adaptive Modular Vessel
3-D	Three-Dimensional

ABSTRACT

The underwater environment presents unique challenges when developing technologies for the detection, classification, and remediation of munitions. Establishing underwater tests sites to conduct controlled assessments of MEC-related technologies in realistic environments is crucial in progressing toward operational status. The Applied Research Laboratory at the University of Hawaiʻi (ARL at UH) established the Hawaiʻi Munitions Test Range Complex (HI_MTRC) at two Oʻahu sites: Moku o Loʻe on the windward side and Sand Island on the south shore. HI_MTRC is designed to implement multiple short-duration, rapidly deployable and recoverable test sites across a range of environments around the island of Oʻahu to evaluate best practices and systems for MEC detection and assessment. Uncrewed systems were used to reduce costs, increase the spatial extent of the test site, reduce the time to perform specific tasks while simultaneously extending the duration of operations, and limit human exposure to the elements. Accomplishments of this effort include identifying and characterizing demonstration sites, developing approaches to rapidly deploy test sites, conducting engineering tests and a scaled deployment at one test site, improving geolocation information using a combination of swimmers, uncrewed systems and precise navigation approaches, and performing a tabletop exercise to evaluate an Optical Munitions Detector at one test site.

The HI_MTRC project demonstrated that a hybrid approach, combining complimentary capabilities of swimmers and uncrewed systems, successfully produced multiple rapidly deployable test sites with a range of seafloor and environmental conditions, covering hundreds of square meters. The HI_MTRC effort also highlighted the benefits of frequent, repetitive field work to assess technology performance under variable conditions.

EXECUTIVE SUMMARY

Detection, assessment, and remediation of munitions and explosives of concern (also referred to as MEC at a specific location do not suit a “one-type-fits-all” approach due to the diversity of environmental parameters, and the volume, variety, and condition of MEC discarded or discharged. Furthermore, the underwater environment presents unique challenges compared to working with MEC on land.

Establishing underwater tests ranges to conduct controlled performance evaluations of MEC-related technologies in realistic environments is crucial for progressing toward operational status. Based on guidance provided by SERDP and ESTCP in their 2018 workshop report, “Underwater UXO Standardized Demonstration Sites,” the Applied Research Laboratory at the University of Hawaiʻi (also known as “ARL at UH”) established the Hawaiʻi Munitions Test Range Complex (HI_MTRC).

HI_MTRC was designed to implement multiple short-duration, rapidly deployable and recoverable test beds across a range of environments around the island of Oʻahu to evaluate best practices and systems for MEC detection, assessment and remediation. To date, HI_MTRC activities have been conducted at two sites on Oʻahu: Moku o Loʻe on the windward side and Sand Island on the south shore.

This project had several objectives:

- Identifying and characterizing demonstration sites,
- Developing approaches to rapidly deploy a test site,
- Conducting engineering tests and a scaled deployment at one test site,
- Improving geolocation information using a combination of swimmers, uncrewed systems and precise navigation approaches, and
- Performing a tabletop exercise to evaluate a technology of interest to SERDP and ESTCP at the Moku o Loʻe site.

The focus on using uncrewed systems was intended to reduce costs, increase the spatial extent of the test site, reduce the time to perform specific operations while simultaneously extending the duration of the demonstration, and limit human exposure to the elements. For example, uncrewed systems could rapidly deploy seeds and clutter for swimmers to precisely orient on the seabed while the uncrewed systems continued mapping the seafloor and monitoring the environment.

To identify and characterize test sites, ARL at UH deployed uncrewed surface vessels, or USVs, equipped with commercial-off-the-shelf sidescan and bathymetric sonars and other environmental sensors. The effectiveness of this approach was a function of wind and wave conditions, the size of the USV, the quality of the sonar or sensor, and whether a survey plan could be pre-programmed into the USV and automatically followed. ARL at UH also worked with ASTRALiTe to integrate their LiDAR into a payload carried underneath a multi-rotor uncrewed aircraft system and subsequently used to map a shallow, coralline boat channel. ARL at UH also purchased a sub-bottom profiling system to detect metal seeds on the seafloor and buried objects and integrated this system with one of the USVs.

To facilitate rapid deployment of munitions seeds, ARL at UH fabricated "The Deployer," a linear actuator mounted underneath the payload of a USV, to release a series of objects via remote control. Using automatic driving, seeds were safely released within 5 meters of desired locations at the ocean surface within minutes. Swimmers then precisely placed the seeds and measured their location using floats equipped with real-time kinematic Global Navigation Satellite System sensors, an approach developed by the Pacific Northwest National Laboratory.

The engineering tests and scaled demonstration identified strengths and weaknesses of using uncrewed systems to install a test bed. The average rate of seed deployment was an obvious strength, and it improved from 6.0 to 3.6 minutes/seed as the team gained experience. Once autonomous driving was instituted, the combined Deployer/USV successfully deployed seeds within a 5-meter radius of the planned position at the ocean surface 89% of the time with an average positional offset of 2.51 m. However, only 73% of the targets relocated on the seabed were within 5 meters of the planned position, presumably because of seed movement during descent through the water column. Only 33% of seeds deployed from USVs were successfully relocated. This was a result of the diminishing performance of the sidescan sonar, which has subsequently been replaced.

Geolocation information acquired using real-time kinematic Global Navigation Satellite System sensors was tied to a local base station that was surveyed into place for 48 hours and referenced to nearby geodetic markers. Field testing of this approach for gathering geolocation data produced centimeter-level positioning accuracy over a period of a week.

A tabletop exercise was designed for field implementation and evaluation of an Optical Munitions Detector at the HI_MTRC and hopefully will be used for future work to implement a field event.

The HI_MTRC project demonstrated that a hybrid approach, combining complimentary capabilities of swimmers and uncrewed systems, successfully produced multiple rapidly deployable test sites with a range of seafloor and environmental conditions, covering hundreds of square meters. The HI_MTRC effort also highlighted the benefits of frequent, repetitive field work to assess technology performance under variable conditions.

1.0 INTRODUCTION

1.1 BACKGROUND

Discarded military munitions (DMM) and unexploded ordnance (UXO), collectively referred to as munitions and explosives of concern (MEC), are found along every coast in the contiguous United States (US), the Hawaiian Islands, Guam and other US territories as well as inland waterways. Significant investment has been made by Department of Defense (DoD) and private industry to develop technologies and approaches to detect MEC and assess the effects of their constituents on the environment. The volume of known MEC, the diversity of environmental parameters at MEC sites, and the variety and condition of objects discarded or discharged preclude a "one-type-fits-all" approach to detect, assess and remediate MEC. Currently, several well-characterized demonstration sites exist for testing platforms, sensors and approaches related to MEC, but these sites are typically confined to one specific environment due to cost considerations. At a workshop on the development of standardized underwater demonstration sites ("test beds") conducted during the Strategic Environmental Research and Development Program (SERDP) and ESTCP Symposium on 29 November 2018, subject matter experts discussed developing a suite of demonstration sites for evaluating and comparing the efficacy of MEC tools in different settings. Based on guidance in the SERDP-ESTCP Final Report [2018], the Hawaiʻi Munitions Test Range Complex (HI_MTRC) was designed to implement multiple short-duration test beds around the island of Oʻahu across a range of environments. The goal is to create rapidly deployable and recoverable test beds that evaluate best practices and systems for MEC detection, assessment and remediation with the overarching objective of eventually expanding this approach to include harbors, canals, ponds, etc.

1.2 OBJECTIVE OF THE HI_MTRC PROGRAM

The goal of this effort is to develop a suite of test beds for evaluating and comparing the efficacy of MEC tools. Desirable attributes of HI_MTRC are that it: (i) provides quick and easy access to a variety of environments; (ii) includes the ability to efficiently and cost-effectively deploy and recover the range, targets and the technology being tested; and (iii) be operated and maintained by personnel experienced with field operations and systems engineering. Oʻahu, Hawaiʻi was selected as an excellent location because of its mild climate, underwater visibility, variety of littoral environments that are readily accessible over distances of kilometers (km), and proximity to relevant DoD stakeholders. Related objectives included: understanding permitting requirements for test range operations and platforms; evaluating the ability of uncrewed systems (UxS) to quickly and cost-effectively assist in deploying inert seeds within test beds; assessing seabed object geolocation precision using a combination of swimmers, real-time kinematic (RTK) Global Navigation Satellite System (GNSS) sensors and remotely operated vehicles (ROVs); and conducting a tabletop exercise (TTX) for evaluating an Optical Munitions Detector (OMD) at HI_MTRC.

1.3 REGULATORY DRIVERS

Public Law 109-364, section 314, requires the DoD to assess the impacts of munitions on the ocean environment.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The capabilities of multi-domain UxS for site characterization and target deployment were evaluated. The capabilities of uncrewed surface vehicles (USVs) to carry Commercial-off-the-Shelf (COTS) sonars and integrated a Light Detection And Ranging (LiDAR) sensor with a COTS Uncrewed Aircraft System (UAS) for site characterization within HI_MTRC were augmented. The use of UxS aimed to reduce costs, increase the spatial extent of the test bed, extend operating time and limit human exposure to the elements.

2.1.1 Uncrewed Surface Vehicles

While isolated in Hawaiʻi during the COVID-19 pandemic, USVs already owned by the University of Hawaiʻi (UH) including a 3-foot-long student-built USV (Figure 2.1) for site characterization and a 16-foot Wave Adaptive Modular Vessel (WAM-V) USV (Figure 2.2) to deploy targets were used by personnel from the Applied Research Laboratory (ARL) and UH (Appendix A). The WAM-V is a dual pontoon surface vehicle platform developed by Marine Advanced Research, Inc. The WAM-V base platform includes various features to accommodate sea state conditions at Douglas scale of 2 or less. These features include independently articulating pontoons, hinged buoyancy pods with an outboard transom mount for improved thruster stability and isolation, and a passively stabilized payload tray using adjustable suspension to accommodate various payload weights up to 200 kilograms (kg).

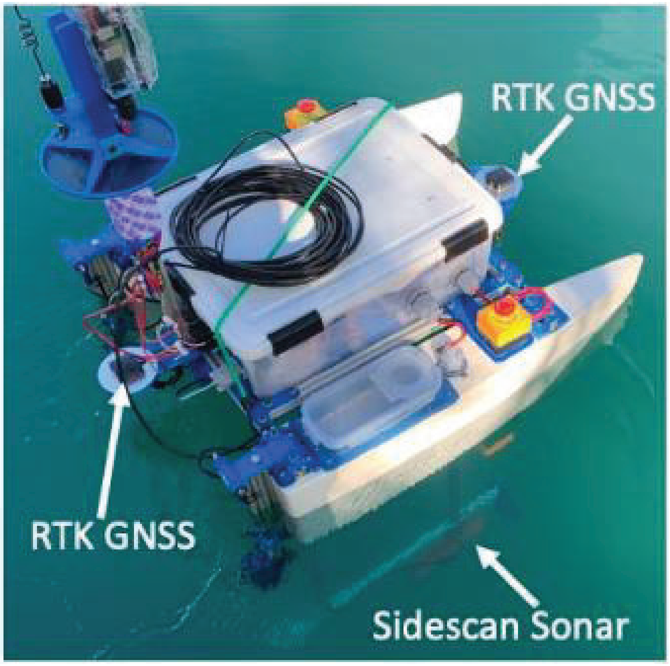


Figure 2.1. 3-foot-long Student-built USV with Tritech Starfish 990F Sonar and RTK GNSS Modules.

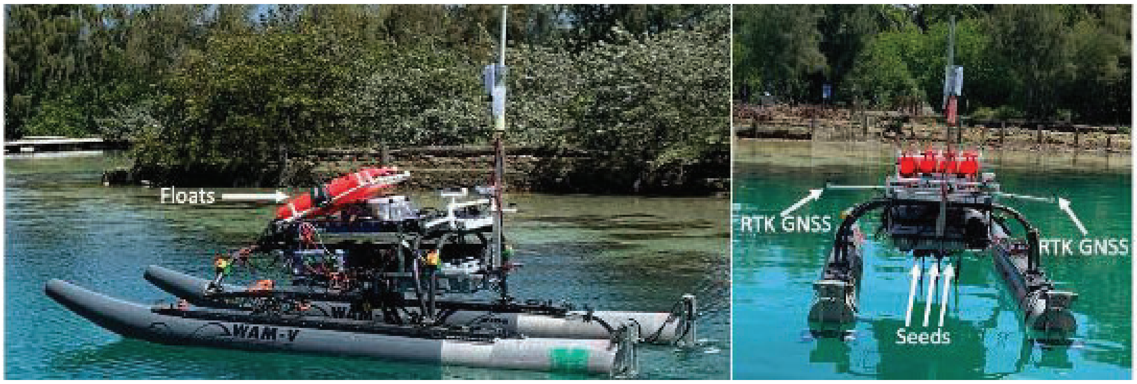


Figure 2.2. WAM-V Configured with RTK GNSS and Seeds Attached to Floats for Deployment.

2.1.2 Uncrewed Aircraft System

ARL at UH used a Skyfront Perimeter 8 gas-battery hybrid multi-rotor UAS with 5-hour endurance to conduct aerial mapping. The Skyfront Perimeter has a Pixhawk Autopilot with proprietary flight control software and flight qualities inherent to all multi-copter UAS such as hover and uniform movement control in all axes (Figure 2.3).

Figure 2.3. ASTRALiTe Edge Mounted Beneath the Skyfront Perimeter 8 UAS.

2.1.3 Mapping Sonars

In 2020 ARL at UH integrated two COTS seafloor mapping sensors, a Tritech Starfish 990F sidescan sonar and Imagenex DeltaT multibeam sonar, onto the student-built USV for site characterization. In 2021, a SyQwest sub-bottom profiling system which is a portable high-resolution marine sediment imaging instrument, was purchased and mounted on the WAM-V USV and operated at 10 kilohertz (kHz) to characterize shallow sediments and objects resting on the seafloor. Real-time kinematic (RTK) Global Navigation Satellite System (GNSS) sensors were incorporated into both USVs for vehicle navigation and orientation.

2.1.4 Mapping LiDAR

In August 2021, the ASTRALiTe Edge LiDAR, under funding by ESTCP, was mounted beneath the Skyfront Perimeter UAS and used for site characterization of a shallow boat harbor at one of the HI_MTRC sites.

2.1.5 Optical Munitions Detector

The OMD integrates monochrome and color cameras, a laser system, and underwater lights to map shallow water (less than 5-meter (m) depth) environments. Built and operated by Creare, Inc., the OMD uses structured light and structure from motion to extract optical information for detection and classification of MEC (Wilbur and Davis, 2021). The OMD was not deployed at HI_MTRC, but it was the focus of the TTX conducted in year 2.

2.2 TECHNOLOGY DEVELOPMENT

2.2.1 WAM-V modifications

For HI_MTRC, the WAM-V was modified to include 10.5 kilowatt-hours of battery capacity and 240 pounds of electric propulsion in differential configuration for a maximum speed of 11 knots (kts). A custom modular mounting rack based on the 80/20 T-slot extruded aluminum was added below the stock payload tray, allowing quick integration of custom sensor and actuator systems. Vehicle control was handled by an onboard computer running the Robot Operating System (ROS) to accommodate sensor payloads and perform basic autonomous tasks.

2.2.2 The “Deployer”

A deployment system built specifically for use on the WAM-V was designed and fabricated by the ARL at UH (Figure 2.4). The “Deployer” was configured to drop up to five 81-millimeter (mm) diameter targets. The main structure was constructed using 80/20 T-slot extruded aluminum. The blue U-shaped sockets were manufactured using polyethylene terephthalate glycol-modified (PETG) via fused filament fabrication (FFF) three-dimensional (3-D) printing, which exceeds the strength requirements for targets of interest and is cost effective for low-volume prototyping needs. Individual objects were suspended in each socket using cloth straps. The Deployer was designed for a maximum single object mass of 40 kg (200 kg total for the five-socket configuration). Two types of seeds were built as surrogates for 81-mm munitions: (i) 3-inch (in) nominal diameter, 12-in long, acrylonitrile butadiene styrene (ABS) tubes filled with stones that weighed 3 kg in air, and (ii) 3-in nominal diameter, 12-in long, galvanized steel tubes with 5-kg mass in air.

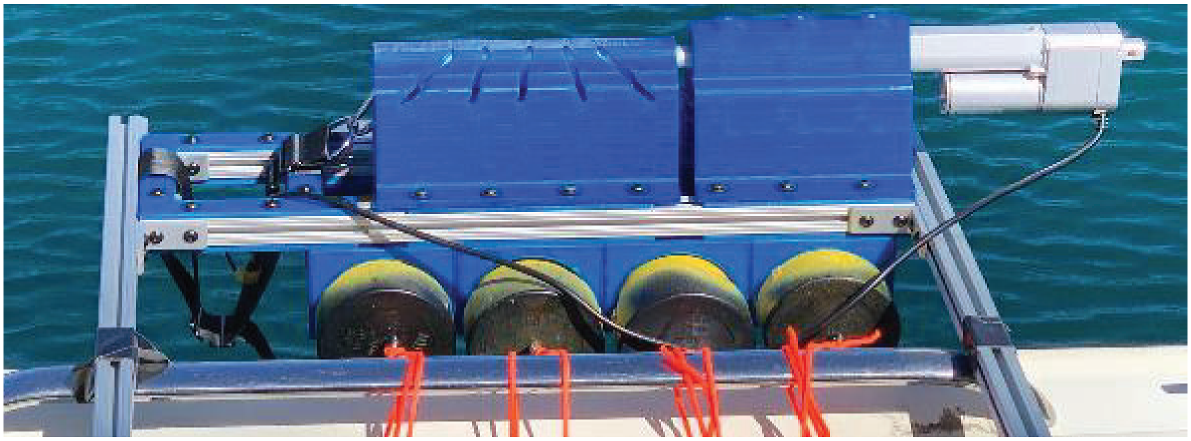


Figure 2.4. The Deployer Carrying Four ABS Seeds.

2.2.3 USV Navigation

Subscription-based RTK ground stations are unavailable in proximity to some HI_MTRC sites, so the ARL at UH developed a wireless interoperability system to provide RTK correction data from a second RTK GNSS module positioned at a ground station with visual line of sight to the USVs. The RTK GNSS system is based on the COTS u-blox ZED-F9P RTK module, which was demonstrated to produce centimeter- (cm-) level positioning accuracy with respect to a nearby base station (Appendix B). The wireless interoperability system connected two RTK modules onboard the USV with a single RTK module at the ground station. The ground station RTK GNSS sensor transmitted RTK correction data compliant to the Radio Technical Commission for Maritime Services (RTCM) communication protocol via a 915 megahertz (MHz) COTS RFM95W Long Range (LoRa) radio module. Using two RTK modules onboard the USV provided vehicle orientation data in addition to the cm-level position data.

Figure 2.5. RTK GNSS Ground Station (Foreground) in View of WAM-V with Three RTK GNSS Sensors Aboard.

2.2.4 RTK GNSS Floats for Geolocation

To improve the accuracy of geolocating targets during year 2 of this effort, RTK GNSS sensors were incorporated into waterproof containers and mounted inside floats (Figure 2.6a). Following the approach developed and tested at the Pacific Northwest National Laboratory (PNNL), the floats were tethered to weights that were placed adjacent to inert munitions replicas on the seabed (Figure 2.6b) by a swimmer (Figure 2.6c). A cam cleat was mounted underneath each float to allow the line attaching the float to the weight to be quickly tightened and reduce horizontal movement of the RTK GNSS sensors (Figure 2.6d). Following guidance from PNNL and Institute for Defense Analyses (IDA) personnel, RTK GNSS data were collected for each seed over a period of 2-3 minutes when the seeds were first deployed and again, hours later, prior to the seeds being recovered.

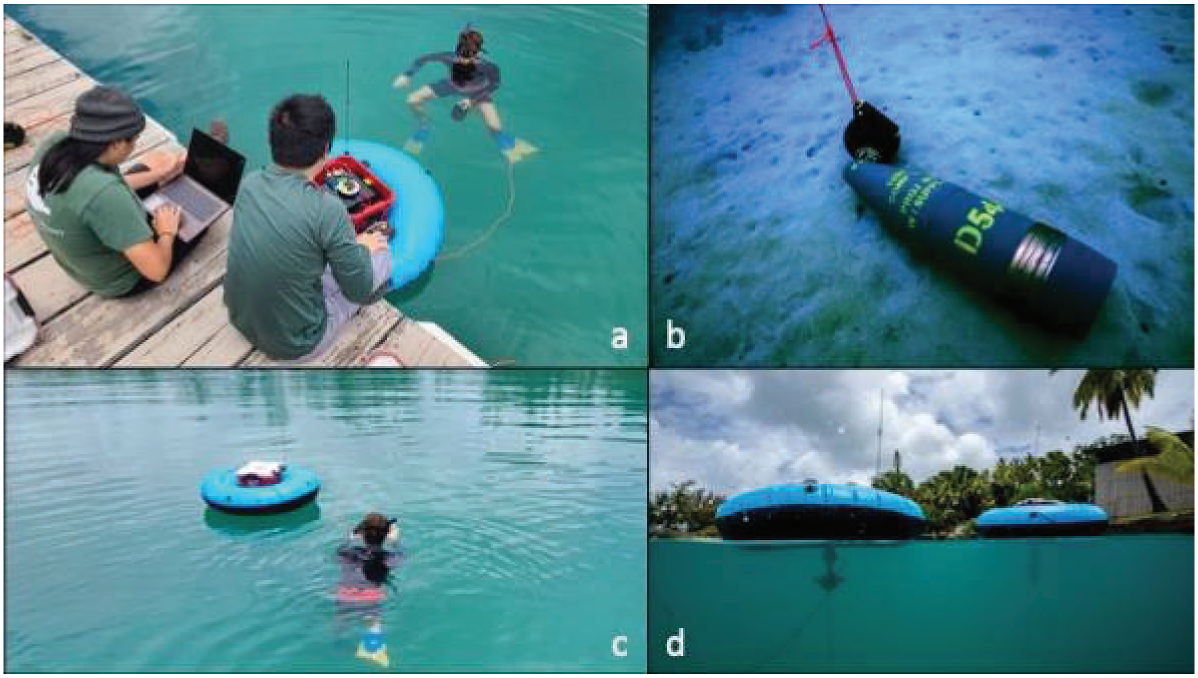


Figure 2.6. Floats with RTK GNSS Systems Were Used to Measure Seed Geolocation.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The primary advantages of using UxVs to support test bed installation are: (i) the increase in the spatial extent of test bed that can be deployed, (ii) the decrease in time required to deploy the test-bed, and (iii) the decrease in time required to characterize the test bed. USVs were used interoperably, with the WAM-V deploying objects while the 3-foot-long student-built USV recorded the WAM-V dropping objects using a COTS video camera and then mapped the location where the object was dropped immediately after the WAM-V moved away.

One limitation of using UxVs was that the desired geolocation accuracy for objects resting on or buried under the seabed surface could not be accomplished without assistance from humans. Additionally, humans must be used to deploy objects in proximity to coral so that the coral isn't damaged. Another limiting factor for using UxVs stems from the environmental conditions. Neither the UAS nor the 3-foot-long student-built USV performed effectively once the average wind speed increased above 20 kts; the WAM-V performed successfully in wind gusts up to 30 kts and sea state conditions up to Douglas scale 2 during field events lasting up to nine hours. In the future it would be instructive to compare how humans performed under similar conditions.

3.0 PERFORMANCE OBJECTIVES

The primary objective for year 1 was to conduct a mock demonstration at HI_MTRC, deploying a fixed number of seeds and clutter items using the WAM-V and the Deployer. The sidescan sonar (SSS) was mounted on WAM-V and 3-foot-long student-built USV to map the locations of the deployed objects. Another objective was to create a bathy/topo map of using ASTRALiTe's LiDAR integrated with ARL's Skyfront UAS. Lastly, a sub-bottom sonar was acquired for integration with the WAM-V to evaluate the ability of the system to detect objects buried in the seafloor.

The primary objectives for year 2 were to improve geolocation information using swimmers to verify the locations reported by the RTK GNSS system, and to conduct a tabletop exercise (TTX) for a technology that could potentially be evaluated in Hawaiʻi, the OMD (Appendix C).

3.1 USV SEED DEPLOYMENT TEST

The primary objective for the USV seed deployment test was demonstrating that the dropping mechanism could deploy a seed to an accuracy within a 5-m-radius circle of a target GNSS position. Once deployed, objects were to be geolocated with 1-m diameter precision. The horizontal offset between the target deployment location was measured and the location of the seafloor to quantify the drift of the object from surface to seafloor was identified. Five meters serves as an approximate threshold for the anticipated horizontal distance a deployed seed might migrate from a known surface location as it descends ~10 m through the water column in Kāneʻohe Bay.

3.2 UAS/LIDAR SURVEY

The primary objective of the UAS/LiDAR survey was to assess how deep the LiDAR could map bathymetry, especially in areas where the seafloor is dominated by mud. The waters around Hawaiʻi are typically very clear, but visibility is subject to oceanographic variability. A secondary objective was documenting the time required to survey a ~100,000 m^2 site using the integrated UAS/LiDAR.

3.3 USV SUB-BOTTOM SURVEY

The primary objective of the sub-bottom survey was to determine sediment layer thickness for seed burial. To achieve this objective, a SyQwest StrataBox HD was purchased and mounted underneath the WAM-V. An additional objective for this SyQwest sub-bottom profiler was to achieve penetration to a depth between 5 and 10 m below seafloor or down to where coral or bedrock are present if shallower than 5 m below seafloor.

3.4 SUMMARY OBJECTIVES AND PERFORMANCE METRICS

The activities described in Sections 3.1-3.3 were evaluated using pre-established metrics to characterize performance. These performance metrics are listed in Table 3.1.

Table 3.1. Summary Tasks and Performance Metrics

Task	Objective	Data Required	Success Criteria
Seed Deployment (3.1)	Deploy test seed items	Count of seeds deployed by WAM-V	Dropping mechanism deploys all seed items successfully
	Deploy seed items within 5-m-radius of planned target location	RTK GNSS Positioning of WAM-V at deployment	All targets are deployed within 5-m-radius planned target location
	Re-acquire deployed seeds using WAM-V with Starfish side-scan sonar (SSS)	RTK-enabled SSS mosaics	All deployed seeds are identified in Starfish sonar data and reported with 1-m radius positional accuracy
	Determine horizontal offset of seeds from deployed location with 5-m reference threshold	RTK GNSS Positioning of WAM-V and SSS mosaics	N/A
	Establish rate of seed deployment	Time of deployment recorded	N/A
LiDAR Survey (3.2)	Collect bathymetric LiDAR to 5 m water depth	ASTRALiTE UxS LiDAR data	Continuous bathymetric coverage to 5 m water depth
	Collect bathymetric LiDAR to 10 m water depth	Establish maximum depth of LiDAR soundings	Partial bathymetric coverage up to 10 m water depth
	Establish rate per 100,000 m^2	Determine effective coverage rate from flight time / area covered	N/A
Sub-bottom Survey (3.3)	Integration of SyQwest StrataBox Sub-bottom profiler to WAM-V instrument package	Sub-bottom profiles from SyQwest	SyQwest sub-bottom profiler is operational on WAM-V
	Sub-bottom profiles to 5 m depth below seafloor or to coral / bedrock substrate	Establish maximum effective depth of SyQwest profiles at field site	Continuous profiles to 5 m depth below seafloor or to coral / bedrock substrate

4.0 SITE DESCRIPTION

4.1 SITE SELECTION

4.1.1 Primary Test Bed – Moku o Lo‘e

Moku o Lo‘e, colloquially known as Coconut Island, was selected as the primary site for a test bed (Figure 4.1). The area outlined in red, ~350 m by 300 m, shows the location where the year 1 mock demonstration was conducted. Average daily conditions at this site are very low energy because of protections afforded by Kāne‘ohe Bay and Moku o Lo‘e. On the Douglas sea scale, the state of the sea is usually no higher than 2. The predominant trade winds blow from the northeast at speeds that typically do not exceed 20 kts. Water depths within the site are <15 m. This site was chosen for initial testing because its mild conditions would allow field operations to be conducted on a frequent and reliable basis.

Esri, HERE, Garmin, Earthstar Geographics, Resource Mapping Hawaii, GeoEye, Maxar

Figure 4.1. Primary Test Bed Site Located West of Moku o Lo‘e.

Moku o Lo‘e and its immediate vicinity are protected by layers of regulation. The National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management incorporated the He‘eia ahupua‘a (watershed), including Moku o Lo‘e and He‘eia Fishpond, into the He‘eia National Estuarine Research Reserve (NERR). Management of the NERR is via the State of Hawai‘i through the Hawai‘i Institute of Marine Biology (HIMB) and the State of Hawai‘i’s Department of Land and Natural Resources (DLNR). Each February HIMB provides the State of Hawai‘i with a list of equipment that it expects to deploy in the water around the island and is granted approval from the subsequent April 1st until March 31st of the following year.

4.1.2 Secondary Test Bed – Sand Island

Sand Island is located on the southern shore of O‘ahu, east of the Honolulu airport. The littoral zone around Sand Island is dominated by coral sand interspersed with clumps of muddy brown colored algae, *Avarainvillea amadelpha*. In the deeper (40 m) dredged channel that is part of Honolulu Harbor the coral sand is covered by a muddy silt. Figure 4.2 shows the area to the west of Sand Island where the secondary test bed site was located. The dimensions of the red box are ~400 m x 400 m.

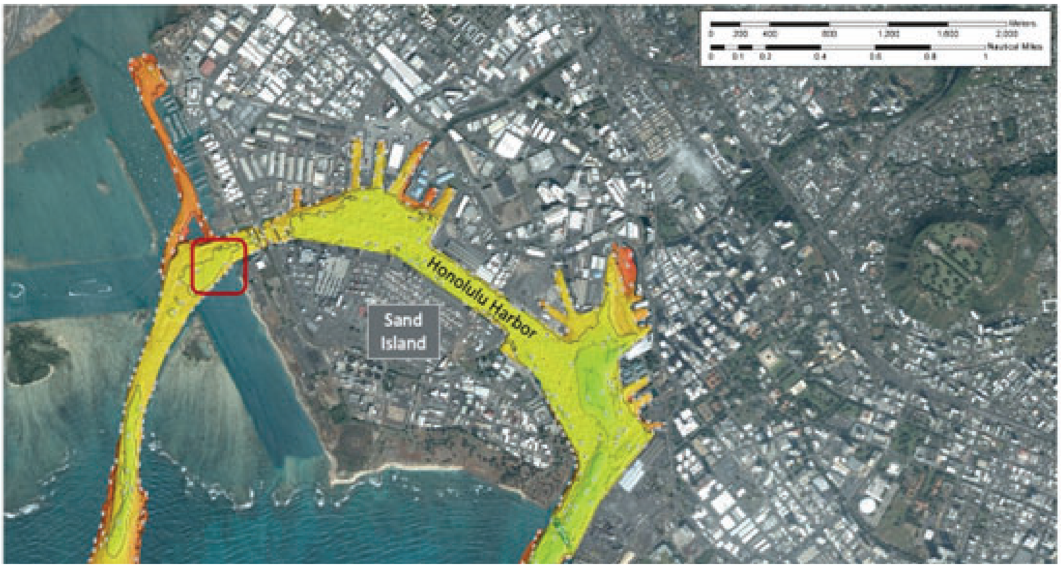


Figure 4.2. Secondary Test Bed Site (Red Box) Near Sand Island.

Average weather and oceanographic conditions at Moku o Lo‘e and Sand Island are similar. On the Douglas sea scale, the state of the sea is usually no higher than 2. The predominant trade winds blow from the northeast at speeds that typically do not exceed 20 kts. While Moku o Lo‘e receives precipitation 250 days per year on average, Sand Island sits leeward of O‘ahu’s Ko‘olau mountain range and is much drier as a result. The average annual rainfall for Kāne‘ohe Bay between 1991 and 2020 was 50.94 in; over the same time period the average annual rainfall for Waikiki was 20.65 in (NOAA National Centers for Environmental Information, retrieved from https://www.ncei.noaa.gov/products/us-climate-normals).

The Sand Island testing area is located near UH’s Maritime Education and Training Center (METC). The METC, which covers eight acres on Sand Island, includes classrooms, work bays, laboratories, offices, and a library. METC is located adjacent to O‘ahu’s southern shoreline with parking for cars and boat trailers. UH is permitted to conduct research, training and sailing classes in this area as long as the operations are of limited duration.

4.2 SITE HISTORY

Moku o Lo‘e is currently wholly owned by the State of Hawai‘i and has been operated and maintained by UH’s Hawai‘i Marine Lab, subsequently renamed HIMB, since the late 1940’s. A brief history of the island is available at: http://www.himb.hawaii.edu/about-us/history/. Moku o Lo‘e hosts world-class biological laboratory facilities.

The METC was established in July 1995 as part of the Honolulu Community College to support a two-year boat maintenance and repair program that would allow students to develop the skills to run a boat yard. Since 2002 the METC has partnered with the Polynesian Voyaging Society (PVS) to share traditional voyaging expertise globally. The METC also hosts UH sailing and water safety programs. A brief history of the METC and its PVS partnership is available at: https://archive.hokulea.com/index/partnerships/metc.html.

4.3 SITE CHARACTERISTICS

Moku o Loʻe and Sand Island are well-characterized because UH installs and maintains environmental sensors at the sites. UH also collaborates with state and federal agencies to collect and disseminate data of use to the residents of Hawaiʻi. Table 4.1 provides a brief summary of specific data types available for the primary and secondary test bed sites.

Table 4.1.Detailed Site Characteristics of Moku o Loʻe and Sand Island.

Data sources are provided.

	Moku o Loʻe (Coconut Island)	**Sand Island**
Agency Purview	NOAA National Estuarine Research Reserve System; State of Hawaiʻi DLNR	State of Hawaiʻi DLNR
Site Manager	HIMB	UH/Honolulu Community College
Physical Site Characteristics		
Depth Range (m)	0-18	0-40
Area (km^2)	>5.6	>2
Environment	Estuarine; lagoon; nearshore coastal	nearshore coastal
Sediment Type(s)	mud; patch reef; pavement; sand	sand; mud
Slope (°)	<5	<5 except at channel wall
Water Clarity	low-moderate turbidity	low-moderate turbidity
Site Monitoring and Data Availability		
Bathymetry	• Downloadable geographic information system (GIS) layers (down to 4m resolution): – http://www.soest.hawaii.edu/hmrg/multibeam/bathymetry.php – https://catalog.data.gov/dataset/gridded-bathymetry-of-kaneohe-bay-windward-side-oahu-main-hawaiian-islands-usa • Online Data Viewer: – https://www.pacioos.hawaii.edu/voyager/	• Downloadable bathymetry (down to 2m resolution): – http://www.soest.hawaii.edu/pibhmc/images/images-global/HonoluluHarbor_1to10000.jpg • Online Data Viewer: – https://www.pacioos.hawaii.edu/voyager/
Backscatter	• Partial coverage available from: – http://www.soest.hawaii.edu/hmrg/multibeam/backscatter.php	• None available
LiDAR (and Bathy LiDAR)	• Downloadable GIS layers: – https://histategis.maps.arcgis.com/apps/webappviewer/index.html?id=7c22201923084f749e6626e3e195de71	• Downloadable GIS layers: – https://histategis.maps.arcgis.com/apps/webappviewer/index.html?id=7c22201923084f749e6626e3e195de71
Benthic Classification	• Downloadable GIS layers: – http://planning.hawaii.gov/gis/download-gis-data/ • Online data viewer: – https://www.pacioos.hawaii.edu/voyager/	• Downloadable GIS layers: – http://planning.hawaii.gov/gis/download-gis-data/ • Online data viewer: – https://www.pacioos.hawaii.edu/voyager/

Table 4.1. Detailed Site Characteristics of Moku o Lo‘e and Sand Island. (Cont.)

	Moku o Lo‘e (Coconut Island)	**Sand Island**
Hydrodynamics	• Real-time observations and forecast models for waves, currents, sea surface temperature, salinity, and others found at: – https://www.pacioos.hawaii.edu/voyager/ – https://polar.ncep.noaa.gov/nwps/nwpsloop.php?site=HFO&cg=3 • Real-time and historical observations also at: – https://www.ndbc.noaa.gov/station_page.php?station=51210 – https://www.ndbc.noaa.gov/station_page.php?station=51207 – http://www.pacioos.hawaii.edu/regions/oahu/	• Real-time observations and forecast models for waves, currents, sea surface temperature, salinity, and others found at: – https://www.pacioos.hawaii.edu/voyager/ • Real-time and historical observations also at: – http://www.pacioos.hawaii.edu/regions/oahu/
Meteorological	• Real-time and historical observations at: – https://www.ndbc.noaa.gov/station_page.php?station=mokh1 – http://www.pacioos.hawaii.edu/weather/obs-mokuoloe/ • Forecasts models available at: – https://www.pacioos.hawaii.edu/voyager/	• Real-time and historical observations at: – https://www.pacioos.hawaii.edu/voyager/ • Forecasts models available at: – https://www.pacioos.hawaii.edu/voyager/
Permitting		
Acoustics	No explicit prohibition on acoustics	No explicit prohibition on acoustics
Ground Disturbance	• *Within Reserve:* – No explicit prohibition to ground disturbance activities unless activities result in collection of aquatic life. *(State of Hawaii Special Activity Permit SAP 2020-25)* • *Outside of Reserve (DLNR purview):* – Under existing permitting (no additional permit required): ▪ Negligible ground disturbance activities, defined as small gauges and monitoring devices, and/or deployed <30 consecutive days – Permitted through DLNR via Site Plan Approval: ▪ Ground disturbance activities, such as coring and excavation, and/or deployed for greater than 30 consecutive days *(State of Hawaii §13-5-22)*	• Negligible ground disturbance activities, defined as small gauges and monitoring devices, and/or deployed <30 consecutive days • Permitted through DLNR via Site Plan Approval: – Ground disturbance activities, such as coring and excavation, and/or deployed for greater than 30 consecutive days *(State of Hawaii §13-5-22)*
Sensor Deployment	See Ground Disturbance Permitting details	See Ground Disturbance Permitting details
Operational Support and Logistics		
Site Access	• Via HIMB vessel fleet	• Via METC vessel fleet
Shore-side Facilities	• HIMB facilities (Moku o Lo‘e)	• METC facilities
Vessel Support	• HIMB fleet, including: – 17' Boston Whaler – 22' Boston Whaler Outrage – 22' Boston Whaler Guardian – 40' support vessel (*Honu Kai*)	• UH Marine Center – 22' Boston Whaler – 40' support vessel (*Kaunānā*) • Local commercial charters
Scuba Diver Support	UH Scientific Diving Team	UH Scientific Diving Team

4.4 MUNITIONS CONTAMINATION

There is no known munitions contamination at Moku o Loʻe or Sand Island. Another shallow water munitions disposal site adjacent to Oʻahu that could be incorporated into HI_MTRC is Ordnance Reef. Ordnance Reef is a shallow-water disposal site where conventional munitions were disposed in water depths <100 m. Ordnance Reef has been the focus of numerous studies and technology demonstrations conducted by NOAA, the U.S. Army and UH (DeCarlo et al., 2007; Carton et al., 2012; Reyer et al., 2012; UH, 2014).

5.0 TEST DESIGN

5.1 DEMONSTRATION OVERVIEW

The ARL at UH conducted three engineering tests and one final field demonstration at Moku o Lo‘e and Sand Island during the first 14 months of this project. The engineering tests occurred at Moku o Lo‘e on May 10th and June 25th, 2021 and at Sand Island on July 15th, 2021. The final field demonstration followed on July 29th, 2021. The engineering tests identified operational challenges that led to modified approaches for the final field demonstration. An engineering test of a recently purchased SyQwest sub-bottom sonar was conducted on October 8th, 2021.

The engineering tests involved deploying acoustic reflectors, ABS and metal seeds, and various clutter objects, which culminated in the collection of twelve seeds and seven clutter items (Figure 5.1) that were deployed using the WAM-V and the Deployer during the final field demonstration. The July 29th field demonstration focused primarily on measuring the speed of deployment and the relative accuracy of geolocation data for seeds and clutter items when deployed at the ocean surface and when detected on the seabed. Each deployed object was attached to a float to facilitate recovery.

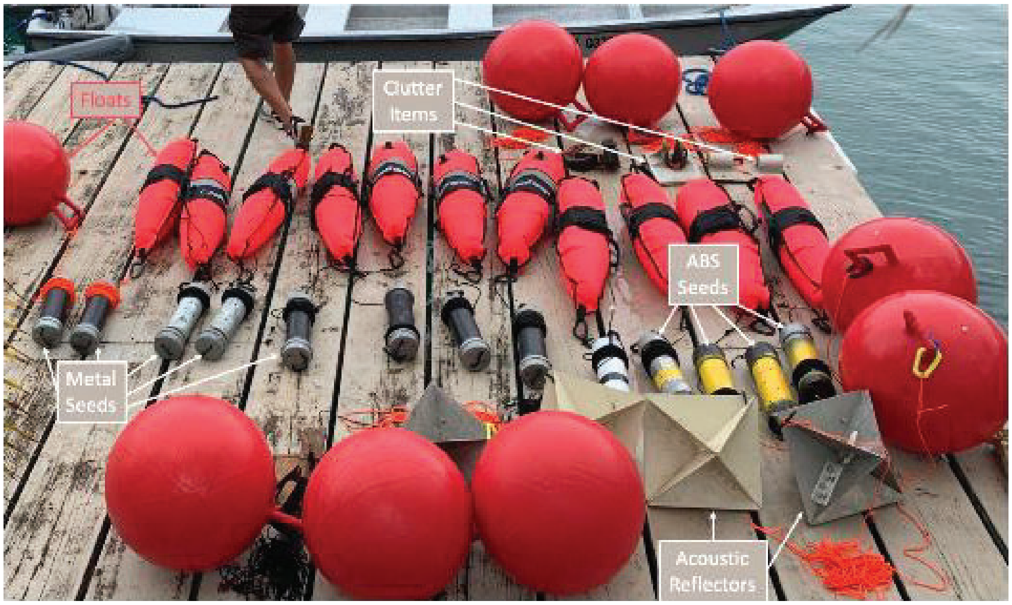


Figure 5.1. Seeds and Clutter Items Deployed During the Final Field Demonstration.

5.2 SITE PREPARATION

A test grid was established for the engineering tests and final field demonstration at the Moku o Lo‘e test site (Figure 5.2). The test grid was 150 m x 150 m and composed of one hundred 15 m by 15 m cells with an area of 225 m^2 grid cells. Each cell was given a number identifier and the cells for deploying seed and clutter items were selected using a random number generator. The goal was to deploy seed and clutter items as close as possible to the centroid position of the selected cells. The randomly generated locations where seeds or clutter were intended to be dropped are referred to as “target” locations in this report.

The RTK GNSS locations recorded at the time each object was released from the Deployer are "drop" locations. A primary objective of the field demonstration was to place drop locations within a 5-m radius of the target locations.

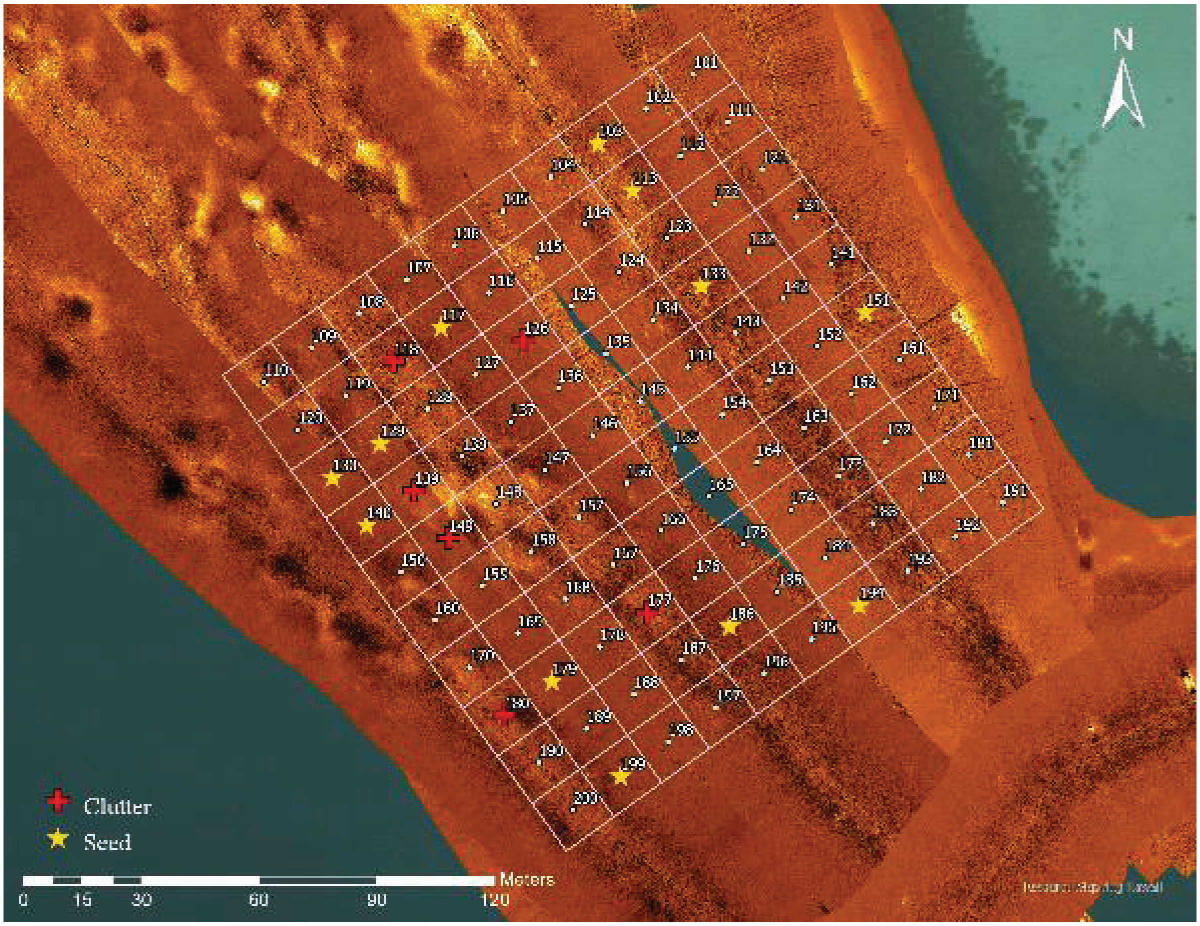


Figure 5.2. Field Demonstration Test Grid with Randomly Selected Locations for Seed and Clutter Items.

5.3 DATA COLLECTION

During the engineering tests and field demonstration at Moku o Lo‘e, the WAM-V equipped with the Deployer was manually (May 10th) or automatically (June 25th and July 29th) driven to target locations to deploy a seed or clutter item. The drop location of the WAM-V was recorded whenever an object was released for comparison to the target location. Clutter items were manually deployed from the support boat after maneuvering adjacent to the RTK GNSS positioning system mounted on either the port or starboard side of the WAM-V. After all seeds in the Deployer were released, the WAM-V returned to the dock for reloading. This process was repeated until as many as one dozen seeds were deployed. The rate of seed deployment was calculated based on the recorded deployment times. Once all objects were deployed, a SSS survey was conducted using the RTK-GNSS-enabled Starfish 990F sonar. The WAM-V was steered over the test grid to map deployed tested items in the environment.

For the engineering tests at Sand Island, a swimmer deployed the seeds on the seafloor and then the WAM-V maneuvered over the targets from multiple approach angles to conduct a SSS survey using the RTK-GNSS-enabled Starfish 990F sonar and a sub-bottom sonar survey using the SyQwest profiler.

6.0 DATA ANALYSIS AND PRODUCTS

Seed deployment was analyzed for five primary objectives:

1) Successful deployment of all seed and clutter items
2) Seed/clutter item deployed within 5-m radius of planned location
3) Seed/clutter item identified in Starfish 990F SSS data with ~1m radius precision
4) Seed/clutter item horizontal offset from deployed location with 5-m reference threshold
5) Establish a seed deployment rate

Additionally, an examination of whether the ultimate resting place of the seed/clutter items was within 5-m of the planned location was conducted, but this was not initially proposed as a performance metric.

6.1 TARGET SELECTION FOR DETECTION

To reacquire deployed test items, SSS surveys sonar data were processed using Chesapeake Technologies, Inc. SonarWiz 7 software. The sonar data was bottom-tracked and gain corrected to produce a sidescan mosaic. The seed and clutter items were identified from the sonar software and locations recorded and exported for geographic information system (GIS) analysis. The target location and drop location for each item were overlaid on the mosaic to assist in reacquiring the item in the sonar mosaic (Figure 6.1).

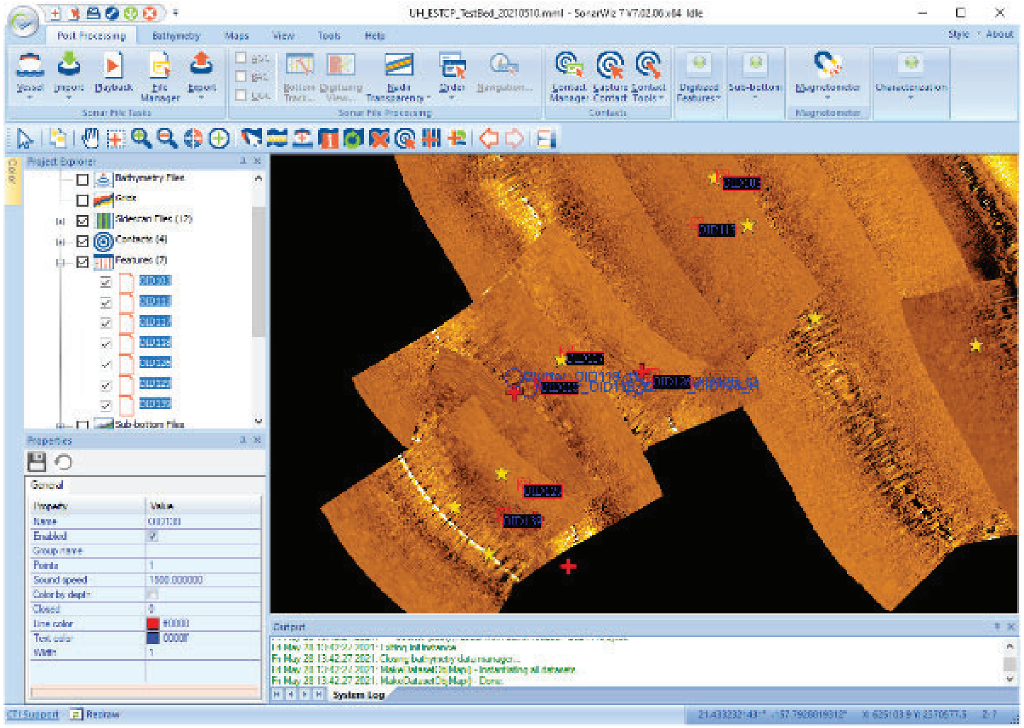


Figure 6.1. Screenshot of the SonarWiz Software Showing the May 10th Side-scan Mosaic with Target Locations Indicated.

Two clutter items (blue circles) were reacquired.

6.2 PERFORMANCE ANALYSIS METHODOLOGY

For the engineering tests and field demonstration at the Moku o Loʻe test site, the time and RTK GNSS location were recorded at the time each object was released into the ocean. The rate of seed deployment was calculated from the recorded deployment time. The recorded positions were converted to Geographic Information System (GIS) layers in ESRI ArcPro. The drop locations were compared to the target locations to determine the distance between expected and actual. Reflective objects in the SSS near either target or drop locations, hereafter referred to as "reacquired targets," were identified and incorporated into SSS shapefiles that were imported into the GIS and compared to the drop locations to estimate how far seed/clutter items drifted before settling on seabed. Finally, the locations of reacquired targets in the SSS data were compared to target locations. The resulting distances are summarized in Section 7.

6.3 DATA PRODUCTS

Data products produced include SSS mosaics, sub-bottom profiles, spreadsheets of GNSS locations for test item deployment and seabed locations, and GIS shapefiles of test grid, target drop locations, actual drop locations, sonar target locations, and sonar mosaics.

7.0 PERFORMANCE ASSESSMENT

7.1 10MAY2021 ENGINEERING TEST

Due to issues with timing and logistical constraints, the full suite of seed (twelve items) and clutter (six items) were not deployed during the May 10th engineering test. Four seed and three clutter items were deployed. Additionally, issues with manually driving the WAM-V to the target location and entanglement of the recovery lines on the WAM-V impacted the seed deployment rate.

7.1.1 Drop Distance from Target Location

The results from the May 10th engineering test are shown in Table 7.1. Color coding indicates test performance relative to the 5-m radius objective. The color gradation highlights the degree to which the test result exceeded (green) or failed (red) the 5-m target and is consistent across all tables in this section. The objective of dropping the seed and clutter within a 5-m radius of the target location was achieved for two of seven items. Of the remaining five items, four were deployed within 8.1 m of the target location, and one was more than 10 m from the target location.

Table 7.1. Distance Between Target and Drop Locations for the May 10th Engineering Test.

Target	Type	Target Latitude	Target Longitude	Drop Latitude	Drop Longitude	Distance from Target Location (m)
OID103	Seed	21.43333572	-157.79233614	21.43339400	-157.79232199	6.62
OID113	Seed	21.43322508	-157.79225258	21.43323565	-157.79238642	12.24
OID117	Seed	21.43291214	-157.79272523	21.43294713	-157.79272100	3.90
OID118	Clutter	21.43283391	-157.79284339	21.43285291	-157.79278150	6.75
OID126	Clutter	21.43287974	-157.79252351	21.43287272	-157.79250825	1.76
OID129	Seed	21.43264504	-157.79287799	21.43261836	-157.79281628	7.04
OID139	Clutter	21.43253440	-157.79279443	21.43255521	-157.79286907	8.07

While deploying within the 5-m envelope was achieved for two targets, deploying the seeds from the WAM-V under remote control proved difficult. The USV pilot was provided with heading information from the shore-based party and had to balance wind, currents, and the delay between sending the deploy command and the time for the actuator to release the seed.

7.1.2 Reacquiring Test Items

SSS imagery was collected only over the areas where seeds and clutter were deployed on May 10th. In the May 10th SSS data two of the three clutter items were relocated, but none of the four seeds were reacquired in the SSS imagery. Tests later conducted with the targets (section 7.3) indicate that the material (ABS) and cylindrical shape of the seeds were not optimal for acoustic detection by a traditional SSS system. The paracord attached to the items for recovery also could not be resolved in the SSS data. The following analysis focuses on the two clutter items that could be reacquired. The target locations, drop locations, and SSS target locations for the two clutter items are shown in Figure 7.1.

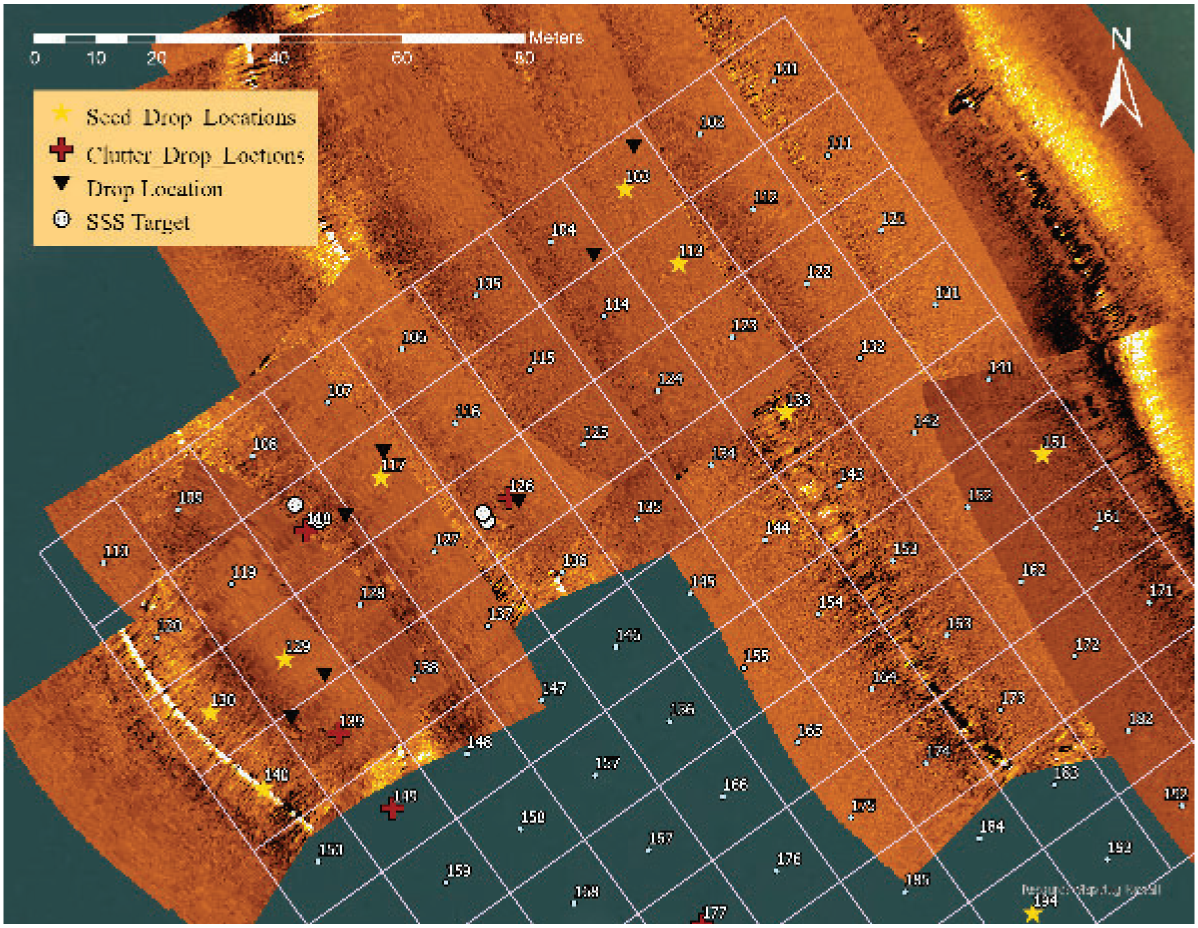


Figure 7.1. Drop Locations and SSS Targets Identified for the May 10th Engineering Test.

7.1.3 SSS Map Location versus Drop Location

In the May 10th engineering test, both clutter items reacquired were seen on two separate sonar transects. The location of the items in the SSS imagery is determined from the slant-range corrected sonar mosaic and compared the recorded drop location to depict how far the item drifted laterally from the ocean surface to the seafloor ~12 m below. The results are shown in Table 7.2. For clutter in grid cell 118, the SSS locations showed more variability, with one location within the 5-m radius and one location outside of the desired 5-m radius. For clutter in grid cell 126, the SSS locations were geolocated within 1 meter of each other, but were 6 m from the drop location. The offset between recorded test item locations on separate sonar transects is likely due to inaccuracies in WAM-V orientation or position combined with offsets in the picked target location from manual digitization in SonarWiz.

Table 7.2. Distance Between Drop Location and SSS Map Location for the May 10th Engineering Test.

Target	Type	Latitude	Longitude	Distance from Drop Location (m)
OID118	Clutter	21.43286880	-157.79284614	8.47
OID118	Clutter	21.43284393	-157.79280917	4.40
OID126	Clutter	21.43284276	-157.79254359	5.93
OID126	Clutter	21.43285428	-157.79255019	6.07

7.1.4 SSS Map Location versus Target Location

The SSS locations for the clutter items were also compared to the original target location. The results for the May 10th engineering test are shown in Table 7.3. The seed items were discovered to be closer to the desired target location than to the drop location. The clutter in grid cell 118 was located within the 5-m target radius in both sonar transects. The clutter in grid cell 126 was recorded just within the 5-m target radius in one transect, but just outside the 5-m target radius on the second pass.

Table 7.3.Distance Between Target Location and SSS Map Location for the May 10th Engineering Test.

Target	Type	Latitude	Longitude	Distance from Target Location (m)
OID118	Clutter	21.43286880	-157.79284614	4.60
OID118	Clutter	21.43284393	-157.79280917	2.54
OID126	Clutter	21.43284276	-157.79254359	5.16
OID126	Clutter	21.43285428	-157.79255019	4.91

7.1.5 Seed Deployment Rate

On May 10th, manually maneuvering the WAM-V to the first and second target locations took at least 17 minutes. The process entailed the shore-based team radioing a heading to the WAM-V pilot in the support boat and telling the pilot to stop the WAM-V thrusters when the platform, which was transmitting its RTK-GNSS position, was a few meters away from the target location. Because the shore-based team had no knowledge of the wind and currents in Kāneʻohe Bay, this method of steering the WAM-V was imprecise. After the first seed was deployed, the decision was made to maneuver the WAM-V “close enough” to the target location and record the drop location. While this improved the rate at which objects were deployed, it was obvious during the field test that the distances between the target and drop locations was too great. Seed deployment rate for the seven items deployed during the engineering test on May 10th is shown in Table 7.4. Drop times are listed in Hawaiian Standard Time, 24-hour format. The time to deploy for the first object is not listed as it includes the transit from the dock to the field area.

Table 7.4.Seed Deployment Rate for the May 10th Engineering Test.

Type	Time	Difference/Rate (minutes)
Seed	1247	-
Seed	1304	17
Seed	1306	2
Seed	1311	5
Clutter	1318	7
Clutter	1320	2
Clutter	1323	3
AVERAGE		**6.0 minutes**

7.2 25JUNE2021 ENGINEERING TEST

7.2.1 Drop Distance from Target Location

For the June 25th engineering test, the WAM-V was configured to autonomously drive to the target location. Seeds were released via remote control at the target location. This method greatly improved speed of deployment and increased positional accuracy. Of the 18 items successfully deployed, only two items were deployed at drop locations outside of a 5-m radius of the target location. The average drop location was only 3.26 m from the target location (Table 7.5).

Table 7.5. Distance Between Target and Drop Locations for the June 25th Engineering Test.

Target	Type	Target Latitude	Target Longitude	Drop Latitude	Drop Longitude	Distance from Target Location (m)
109	Clutter	21.43286630	-157.79304511	21.43285135	-157.79306219	2.44
112	Clutter	21.43330332	-157.79213441	21.43329920	-157.79216110	2.81
116	Seed	21.43299038	-157.79260707	21.43297080	-157.79262041	2.57
118	Seed	21.43283391	-157.79284339	21.43282630	-157.79293586	9.62
127	Seed	21.43280151	-157.79264167	21.43276711	-157.79265264	3.97
145	Seed	21.43273671	-157.79223822	21.43265560	-157.79227777	9.87
149	Seed	21.43242377	-157.79271087	21.43240997	-157.79270850	1.55
163	Clutter	21.43267191	-157.79183478	21.43265801	-157.79185952	2.99
165	Seed	21.43251545	-157.79207110	21.43249030	-157.79206975	2.79
168	Seed	21.43228074	-157.79242559	21.43228245	-157.79243431	0.92
171	Seed	21.43271775	-157.79151489	21.43271893	-157.79152312	0.86
176	Seed	21.43232658	-157.79210571	21.43232732	-157.79212098	1.59
177	Seed	21.43224834	-157.79222387	21.43222073	-157.79219009	4.65
180	Seed	21.43201363	-157.79257836	21.43199551	-157.79260421	3.35
182	Clutter	21.43252888	-157.79154950	21.43250551	-157.79156988	3.34
191	Clutter	21.43249648	-157.79134777	21.43250004	-157.79137266	2.61
201	Seed	21.43236726	-157.78998474	21.43235487	-157.78998724	1.40
201	Clutter	21.43236726	-157.78998474	21.43237120	-157.78999651	1.30

7.2.2 Reacquiring Test Items

A complete SSS mosaic was generated for the Moku o Lo‘e demonstration site on June 25th. Three of six clutter items and two of twelve seeds were relocated in the SSS imagery. Although materials (e.g., metal tape, hose clamps, tacks) were added to the outside of the ABS seeds to increase their acoustic reflectivity, the ability to detect seeds did not improve. As on May 10th, the paracord attached to the items for recovery was not resolved in the SSS data. The target locations, drop locations, and SSS target locations for the three clutter and two seed items reacquired during the June 25th field experiment are shown in Figure 7.2.

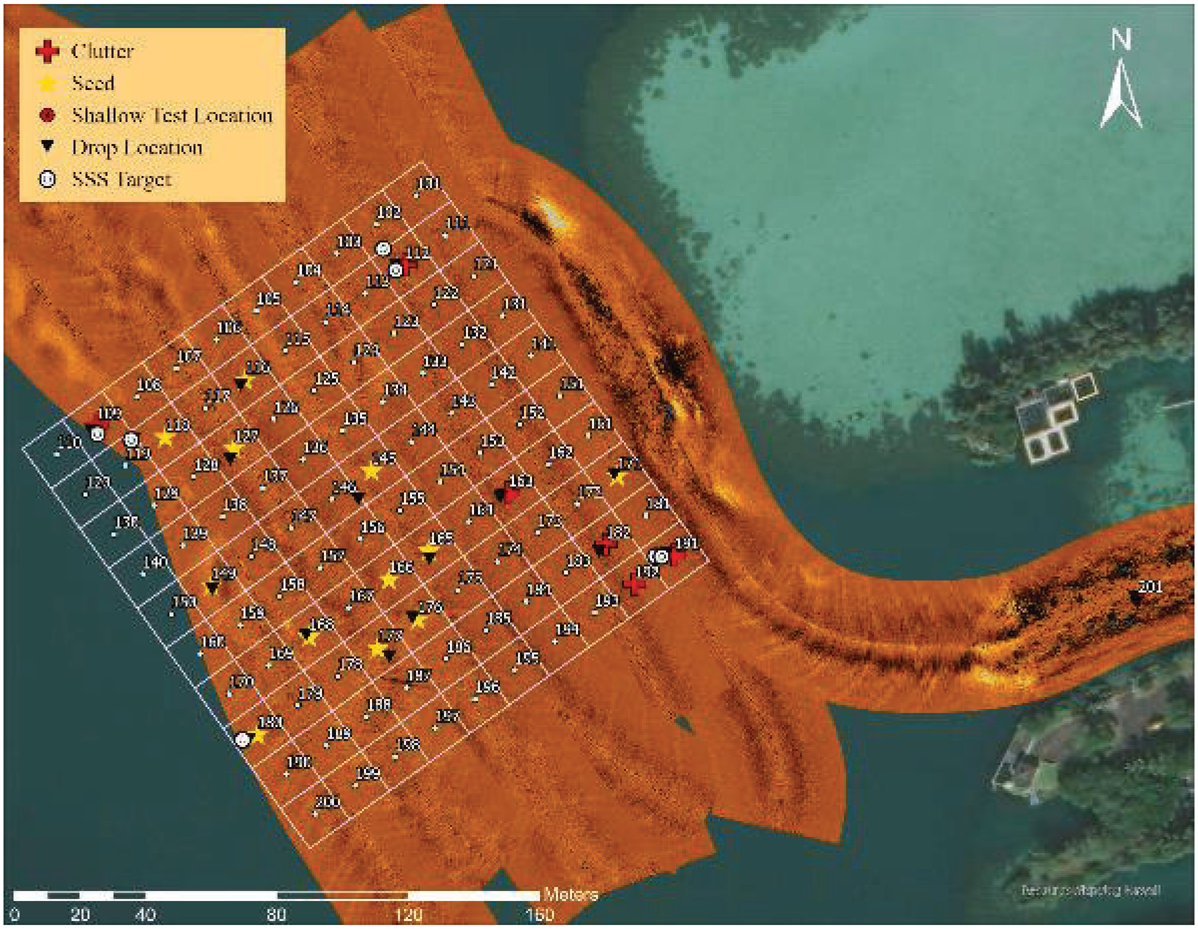


Figure 7.2. Engineering Test Grid for Moku o Lo‘e on June 25th Comparing Target and Drop Locations.

7.2.3 SSS Map Location versus Drop Location

In the June 25th engineering test, only two clutter items in grid cells 112 and 191 were imaged in two separate sonar tracks. The other three objects reacquired in SSS data either fell outside of overlapping sonar transects, in the nadir gap of overlapping transects, or could not be resolved in other transects. The location of the items in the SSS imagery is determined from the slant-range corrected sonar mosaic and compared to the drop location to depict how far the item drifted laterally from the ocean surface to the seafloor ~12 m below.

The results are shown in Table 7.6. For clutter in grid cell 112, the SSS locations showed one location within the 5-m radius and one outside the 5-m radius. For clutter in grid cell 191, the SSS locations were geolocated within one meter of each other, and within 2 m of the drop location. All remaining reacquired objects were found within a 5-m radius of their drop location.

Table 7.6.Distance Between Drop Location and SSS Map Location for the June 25th Engineering Test.

Target	Type	Latitude	Longitude	Distance from Drop Location (m)
109	Clutter	21.43283982	-157.79214770	3.72
112	Clutter	21.43328471	-157.79218391	2.13
112	Clutter	21.43334401	-157.79138915	5.49
118	Seed	21.43282236	-157.79260833	0.78
180	Seed	21.43199535	-157.79302860	0.43
191	Clutter	21.43249086	-157.79137124	1.99
191	Clutter	21.43248979	-157.79292960	1.14

7.2.4 SSS Map Location versus Target Location

The results of comparing SSS locations for the clutter items to the target location for the June 25th engineering test are shown in Table 7.7. In contrast to the May 10th engineering test, the seeds were not located closer to the target location than the drop location. Clutter in grid cell 109 and the seed in grid cell 180 fell within the 5-m radius. The seed in grid cell 118 exceeded 11 m from the target location, which is largely due to the initial 9.6 m offset between the drop location and the target location. Clutter in cells 112 and 191 each had one SSS target pick within the 5-m radius and one outside the 5-m radius. Both items were initially dropped within 5 m of the target location, which suggests that the items drifted before impacting the seabed.

Table 7.7. Distance Between Target Location and SSS Map Location for the June 25th Engineering Test.

Target	Type	Latitude	Longitude	Distance from Target Location (m)
109	Clutter	21.43283982	-157.79214770	2.56
112	Clutter	21.43328471	-157.79218391	3.33
112	Clutter	21.43334401	-157.79138915	8.23
118	Seed	21.43282236	-157.79260833	11.40
180	Seed	21.43199535	-157.79302860	4.89
191	Clutter	21.43249086	-157.79137124	5.79
191	Clutter	21.43248979	-157.79292960	3.94

7.2.5 Seed Deployment Rate

On June 25th the WAM-V autonomously steered itself to target locations. Four round-trip WAM-V excursions were required to drop eighteen objects: three seeds on the first excursion, two seeds and three clutter items on the second excursion, five seeds on the third excursion and two seeds and two clutter items on the final excursion. The time between the first and second excursion was 55 minutes. The time between the second and third excursion, which included lunch and tour of Moku o Loʻe for Department of Defense personnel observing the experiment, was 1 hour and 45 minutes. The time between the third and fourth excursion was 14 minutes. The timing of the final two objects dropped was impacted by motor problems in one of the WAM-V thrusters, so the average seed deployment rates for June 25th have been calculated with and without the last two values (Table 7.8). Drop times are listed in Hawaiian Standard Time, 24-hour format. The time to deploy the first object in each excursion is not listed as it includes the transit from the dock to the field area. Excursions are color-coded.

Table 7.8.Seed Deployment Rate for the June 25th Engineering Test.

Type	Time	Difference/Rate (minutes)
Seed	1037	-
Seed	1040	3
Seed	1051	11
Clutter	1146	55-minute break
Seed	1148	2
Seed	1157	9
Clutter	1205	8
Clutter	1214	9
Seed	1359	1 hour & 45-minute break
Seed	1401	2
Seed	1403	2
Seed	1405	2
Seed	1408	3
Clutter	1422	14-minute break
Seed	1424	2
Clutter	1430	6
Seed	1442	12
Clutter	1507	25
AVERAGE		**6.0 minutes**
AVERAGE (modified)		**4.92 minutes**

7.3 15JULY2021 ENGINEERING TEST

Limited ability to detect ABS seeds during the June 25th field experiment, even after the seed exteriors had been altered with reflective materials (e.g., metal tape, hose clamps, tacks) was concerning. The project team formulated several hypotheses regarding this outcome:

- Seeds were being buried in mud in the initial demonstration site within Kāne‘ohe Bay.
- ABS targets were poorly reflective.
- The Starfish 990F sonar, when operated from the WAM-V, was limited to mapping ranges less than the ~10 m depths expected at the initial demonstration site.

On July 15th the Starfish 990F sonar was fastened to the underside of the central modular mounting rack onboard the WAM-V. Four seeds, two steel and two ABS, were connected in 2-foot (ft) intervals in a “ladder” formation (Figure 7.3) and deployed at variable depths by a swimmer. The RTK-GNSS set-up typically used at Moku o Lo‘e was moved to the rectangular area located near Sand Island (Figure 4.2). The primary objectives of this field exercise were to:

- Change the geological setting to evaluate whether the muddy conditions in Kāne‘ohe Bay were obscuring objects deployed on the seafloor in the SSS data, and
- Compare the reflectivity of ABS and galvanized steel seeds of similar dimension.

Seeds were deployed at depths of 4, 7 and 13 meters by a swimmer using a dive watch to measure water depth. The “ladder” was connected to a float by paracord for easy recovery and to provide a general location reference at the ocean surface. After the seeds were successfully deployed and details of their distribution and depth were documented, the WAM-V conducted multiple short transects past the float to assess whether the Starfish 990F SSS could effectively map the objects at each water depth. The WAM-V was alternately operated under its own power and was towed to evaluate noise levels introduced when running the USV’s motors. Because the motion of the vehicle was more erratic than usual, SSS mosaics for the Sand Island tows were not produced but nevertheless identified the targets in the real-time waterfall data display and captured screenshots of targets in the SSS data.

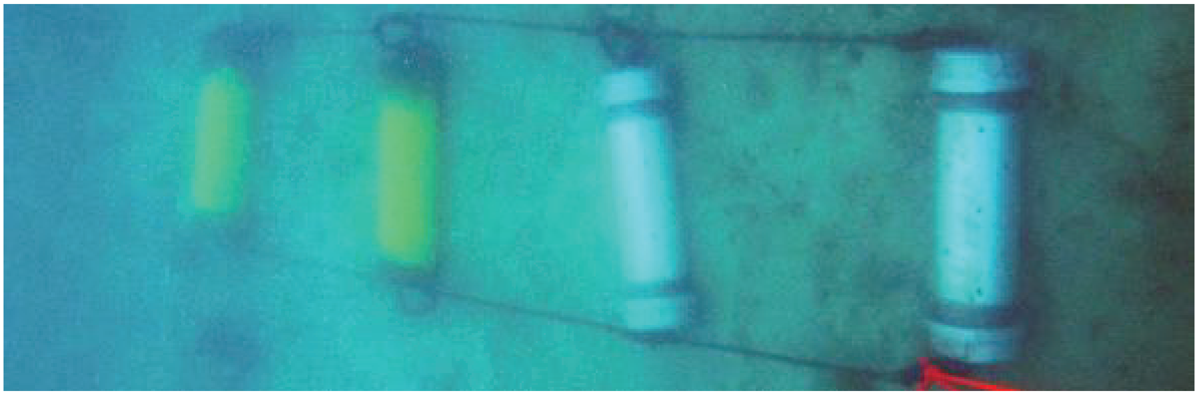
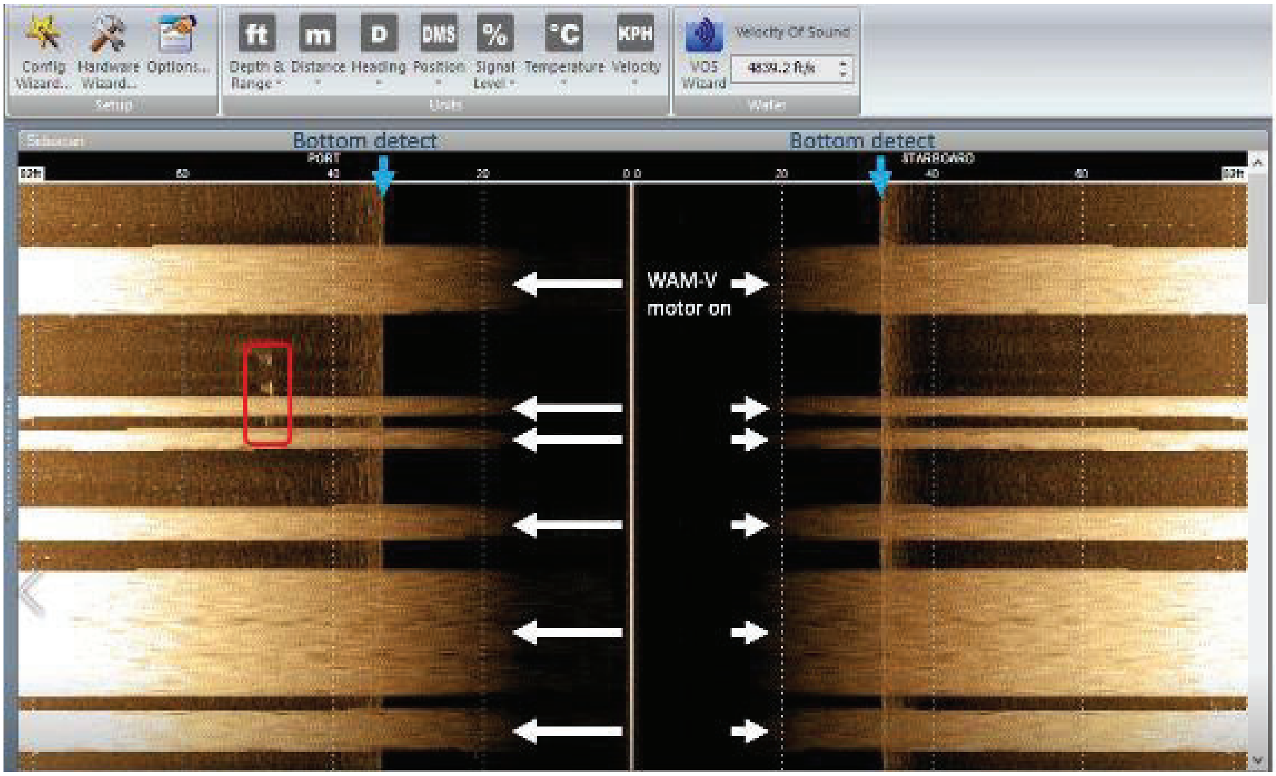


Figure 7.3. ABS and Steel Seeds Deployed in “Ladder” Formation Near Sand Island on July 15th.

Figure 7.4. WAM-V, Support Boat and RTK-GNSS Base Station Deployed at Sand Island.

Figure 7.5 shows a screenshot of the waterfall display produced in real time by the Starfish 990F sonar system display software. These data were acquired at the deepest location (40 feet), but because the Starfish was mounted about 5 feet beneath the WAM-V, the bottom is detected in the port and starboard side data at a range of about 35 feet (blue arrows). During the time these data were collected, the WAM-V motors were intermittently turned on and off, resulting in bands of brighter data values (white arrows) where the signal:noise ratio was significantly reduced. This banding can be mitigated by data post-processing, but during the field exercise it was much harder to identify the ladder of targets when the WAM-V motors were operating. When the motors were turned off, the shore-based observers were consistently able to recognize the seeds, although at this maximum test depth it appears that the metal seeds generated stronger reflections than the ABS seeds (red rectangle).



Velocity Of Sound 4839.2 ft/s

Figure 7.5. Screenshot of Starfish Sonar Waterfall Display Acquired During the July 15th Engineering Test.

Analysis of the interference formed the basis of a Master's degree student thesis that was recently published (Santos and Trimble, 2022).

7.4 29JULY2021 FIELD DEMONSTRATION

7.4.1 Drop Distance from Target Location

The WAM-V was configured to automatically drive to target locations on July 29th and seeds were released via remote control when the WAM-V reached each location. Time to deploy seed and clutter objects decreased by moving to drop locations automatically. Drop accuracy also improved - only two out of 19 total items were deployed outside of a 5-m radius of the target location. The average drop distance to the target location decreased to 2.51 m from the 3.26 m average that was derived during the June 25th engineering test (Table 7.9).

Table 7.9.Distance Between Target and Drop Locations for the July 29th Final Demonstration.

Target	Type	Target Latitude	Target Longitude	Drop Latitude	Drop Longitude	Distance from Target Location (m)
109	Clutter	21.43286630	-157.79304511	21.43287301	-157.79305443	1.22
112	Clutter	21.43330332	-157.79213441	21.43330787	-157.79217628	4.37
116	Seed	21.43299038	-157.79260707	21.43297245	-157.79261862	2.32
118	Seed	21.43283391	-157.79284339	21.43283391	-157.79284340	1.99
127	Seed	21.43280151	-157.79264167	21.43279580	-157.79265885	1.89
145	Seed	21.43273671	-157.79223822	21.43272565	-157.79229832	6.35
149	Seed	21.43242377	-157.79271087	21.43241154	-157.79273424	2.77
163	Clutter	21.43267191	-157.79183478	21.43267037	-157.79185211	1.81
165	Seed	21.43251545	-157.79207110	21.43251234	-157.79208568	1.55
166	Seed	21.43243721	-157.79218927	21.43242613	-157.79220219	1.82
168	Seed	21.43228074	-157.79242559	21.43228288	-157.79244243	1.76
171	Seed	21.43271775	-157.79151489	21.43270339	-157.79153920	2.98
176	Seed	21.43232658	-157.79210571	21.43232666	-157.79212285	1.78
177	Seed	21.43224834	-157.79222387	21.43224298	-157.79225033	2.81
180	Seed	21.43201363	-157.79257836	21.43201353	-157.79260038	2.28
182	Clutter	21.43252888	-157.79154950	21.43253156	-157.79156277	1.41
191	Clutter	21.43249648	-157.79134777	21.43250845	-157.79136347	2.10
192	Clutter	21.43241825	-157.79146594	21.43240415	-157.79151476	5.30
201	Clutter	21.43236726	-157.78998474	21.43237535	-157.78999142	1.13

Reacquiring Test Items

For the final July 29th field experiment, five of eight clutter items and three of twelve seeds were reacquired in the SSS imagery. Although eight of the original ABS seeds were replaced by steel seeds between June 25th and July 29th, the ability to detect seeds did not improve. The target locations, drop locations, and SSS target locations for the five clutter and three seed items reacquired during the July 29th final demonstration are shown in Figure 7.6.

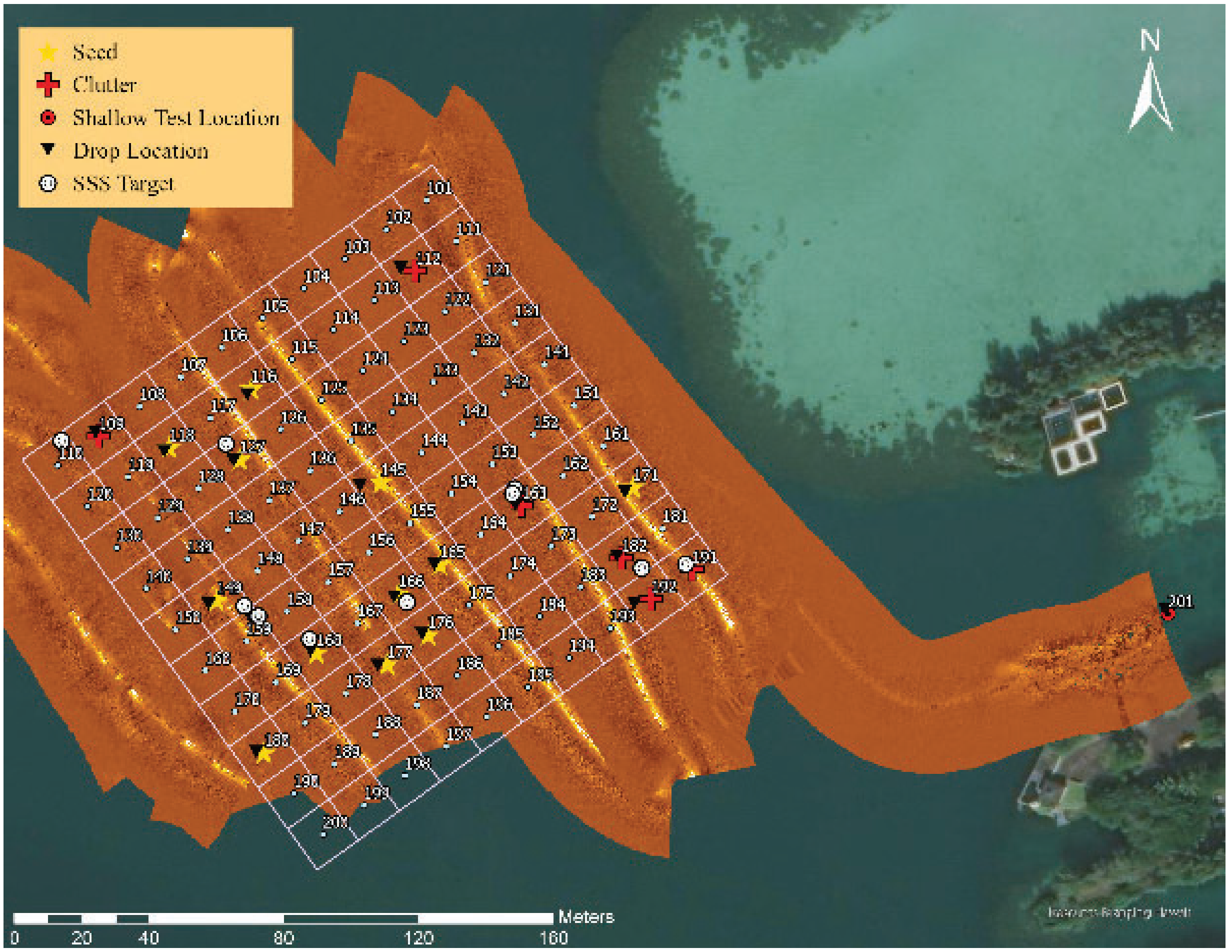


Figure 7.6. Demonstration Test Grid for Moku o Lo‘e on July 29th Comparing Target and Drop Locations.

SSS Map Location versus Drop Location

In the SSS imagery collected during the July 29th final demonstration, clutter in grid cell 163 was imaged in three separate passes, as was a randomly placed clutter item near cell 159. Other targets either fell outside of overlapping sonar transects, in the nadir gap of overlapping transects, or could not be resolved in other transects. The location of the items in the SSS imagery is determined from the slant-range corrected sonar mosaic and compared to the recorded drop location to depict how far the item drifted laterally. The results are shown in Table 7.10. For clutter in grid cell 163, the SSS locations fell between 3.67 and 5.04 meters from the drop location. For the randomly dropped clutter object, the SSS locations ranged from 2.81 to 3.49 meters from the drop location. Three of the six remaining test items were found within a 5-m radius of their recorded drop location.

Table 7.10. Distance Between Drop Location and SSS Map Location for the July 29th Final Demonstration.

Target	Type	Latitude	Longitude	Distance from Drop Location (m)
109	Clutter	21.43285089	-157.79313728	10.29
127	Seed	21.43283914	-157.79266663	5.66
N/A	Clutter	21.43237620	-157.79257669	2.81
N/A	Clutter	21.43240386	-157.79261729	3.49
163	Clutter	21.43269941	-157.79184578	3.69
163	Clutter	21.43271240	-157.79184004	5.04
163	Clutter	21.43269911	-157.79184644	3.67
166	Seed	21.43241069	-157.79215123	4.02
168	Seed	21.43231326	-157.79243131	3.76
182	Clutter	21.43249746	-157.79147769	8.08
191	Clutter	21.43250704	-157.79135179	0.36

SSS Map Location versus Target Location

Results for the July 29th field demonstration are shown in Table 7.11. Performance was similar to the June 25th engineering test. Clutter in grid cell 191 was recorded within the 5-m radius. Clutter in grid cell 109 exceeded 11 m from the target location despite only a 1.22 m offset between the drop location and the target location. This suggests the item either drifted or was pulled after deployment by the surface buoy that was attached to the object to facilitate recovery. Clutter in cell 163 had one SSS target pick within the 5-m radius and one outside the 5-m radius. In all, five of the nine reacquired targets fell within the 5-m target radius.

Table 7.11. Distance Between Target Location and SSS Map Location for the July 29th Final Demonstration.

Target	Type	Latitude	Longitude	Distance from Target Location (m)
109	Clutter	21.43285089	-157.79313728	11.13
127	Seed	21.43283914	-157.79266663	6.11
N/A	Clutter	21.43237620	-157.79257669	N/A
N/A	Clutter	21.43240386	-157.79261729	N/A
163	Clutter	21.43269941	-157.79184578	4.32
163	Clutter	21.43271240	-157.79184004	5.27
163	Clutter	21.43269911	-157.79184644	4.33
166	Seed	21.43241069	-157.79215123	3.54
168	Seed	21.43231326	-157.79243131	4.49
182	Clutter	21.43249746	-157.79147769	6.71
191	Clutter	21.43250704	-157.79135179	2.46

Seed Deployment Rate

On July 29th the WAM-V automatically steered itself to target locations. Three round-trip WAM-V excursions were required to drop nineteen objects: four seeds and five clutter items on the first excursion, four seeds and three clutter items on the second excursion, and four seeds on the final excursion. The time between the first and second excursion was 26 minutes. The time between the second and third excursion was 22 minutes. During the first excursion an ROV was deployed twice: (i) to image a steel seed that was entangled in paracord in the water column, and (ii) to re-image the same seed after it had been untangled, redeployed and settled on the bottom (Table 7.12). The average seed deployment rates for July 29th have been calculated with and without the ROV-impacted values. Drop times are listed in Hawaiian Standard Time, 24-hour format. The time to deploy the first object in each excursion is not listed as it includes the transit from the dock to the field area. Excursions are color-coded.

Table 7.12. Seed Deployment Rate for the July 29th Final Demonstration.

Type	Time	Difference/Rate (minutes)
Clutter	1031	-
Clutter	1036	5
Seed	1048	12
Seed	1103	15
Seed	1109	6
Seed	1113	4
Clutter	1116	3
Clutter	1118	2
Clutter	1121	3
Clutter	1147	26-minute break
Seed	1151	4
Seed	1154	3
Seed	1156	2
Seed	1158	2
Redeploy	1200	2
Clutter	1204	4
Seed	1226	22-minute break
Seed	1235	9
Seed	1237	2
Seed	1240	3
AVERAGE		**4.76 minutes**
AVERAGE (modified)		**3.6 minutes**

7.5 AUGUST2021 LIDAR ENGINEERING TEST

On August 17, 2021 the ASTRALiTe Edge LiDAR was mounted beneath the Skyfront Perimeter Unmanned Aerial Vehicle (UAV; Figure 7.7) and tests were conducted to verify that the UAV could safely and successfully carry the LiDAR while it acquired high quality data.

Figure 7.7. ASTRALiTe Edge Mounted Beneath the Skyfront Perimeter 8 UAV.

On August 18th several seeds, corner reflectors and clutter objects were deployed within the shallow (<5 m deep) boat channel at Moku o Lo‘e by swimmers to see if they could be detected underwater in the LiDAR point cloud data. The flight plans were designed to incorporate sufficient overlap per transect line while flying at an altitude of 30 m. The flight area was covered twice, offset 90º from each other to reduce the impact of shadowing from high-relief structures. The boat channel survey covered 22,415 m^2 and took 31 minutes to complete with the UAS operating at 4 m/s. The Skyfront ground control system showed visuals from a mounted camera and UAV’s location in near real-time (Figure 7.8) with a wide-angle perspective from the UAV (lower left), and the grid pattern survey and UAS position and status (upper right). The resulting topo-bathymetric map is shown in Figure 7.9.

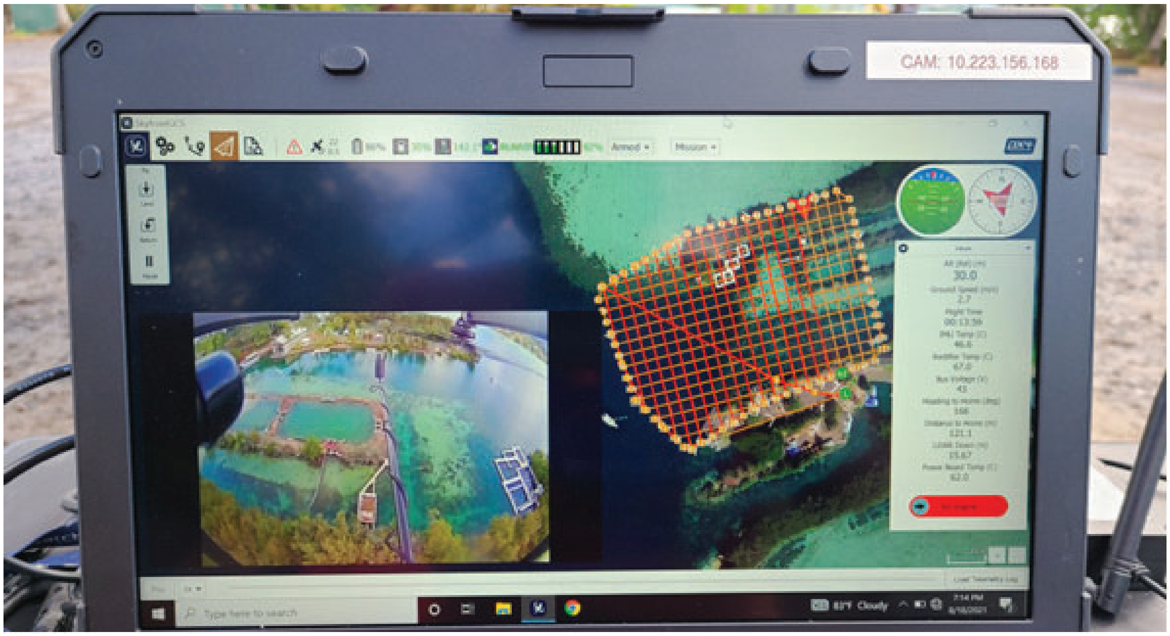


Figure 7.8. Real-time Display during ASTRALiTe LiDAR Operations on August 18, 2021.

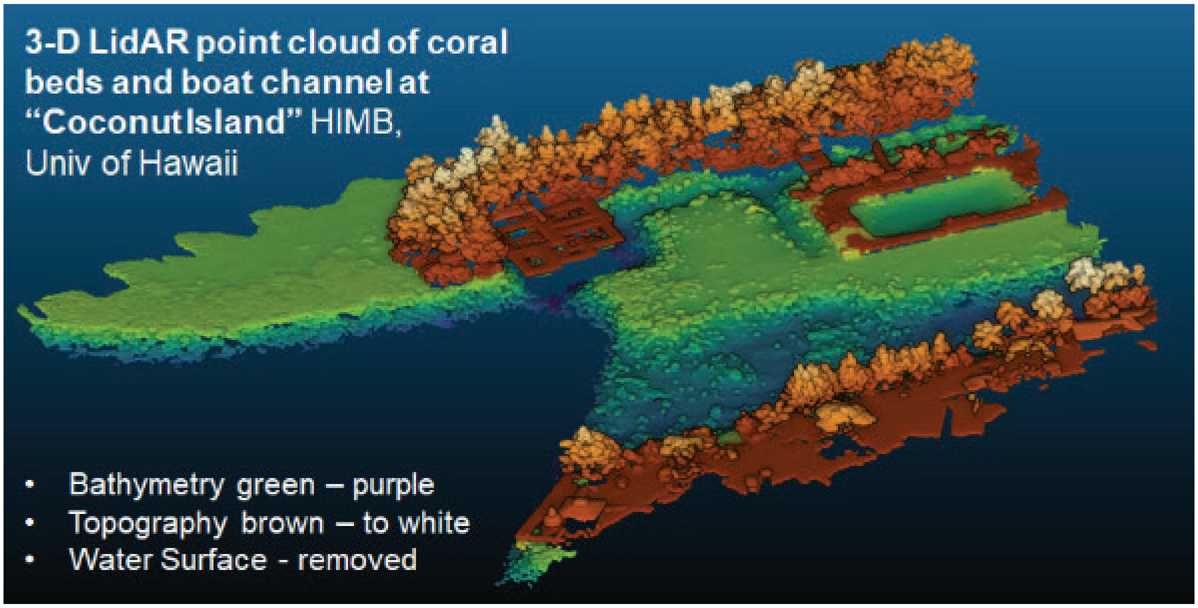


Figure 7.9. ASTRALiTe Topo-bathymetry Map from the August 18th Field Trial.

Figure 7.9 shows coral colonies in the deeper (dark blue) and shallower (green) portions of the boat channel and surrounding land and trees (brown, red, orange, white). The V-shaped data gap in the center-left portion of the image corresponds to locations where the water depth drops to >5 m and the LiDAR was unable to map the muddy seabed surface. High turbidity at the time of the survey due to an incoming tide may have decreased the depth penetration of the LiDAR, although further processing may allow data visualization slightly deeper than currently shown.

While detecting seeds and clutter objects was not a specific objective of the LiDAR survey, demonstrating the ability to detect known objects in LiDAR point clouds would be of significant benefit to future HI_MTRC and other underwater test ranges.

7.6 08OCTOBER2021 SUB-BOTTOM SONAR ENGINEERING TEST

The October 8th engineering test at Sand Island was designed to evaluate the performance of the SyQwest sub-bottom profiler, which had recently been purchased and configured for integration into the WAM-V (Figure 7.10a) to detect objects resting on or buried under the surface of the seafloor. For this SyQwest sonar test, two ABS and two metal targets were strung together in a ladder configuration for rapid deployment. The seeds were placed at various depths on the seabed by a swimmer (Figure 7.10b). While the swimmer attempted to bury the seeds, underwater photographs of the experiment show that the maximum burial depth achieved was only a few cm. As such, this engineering test only evaluated the ability of the SyQwest sub-bottom profiler to detect objects that were proud on the seafloor.

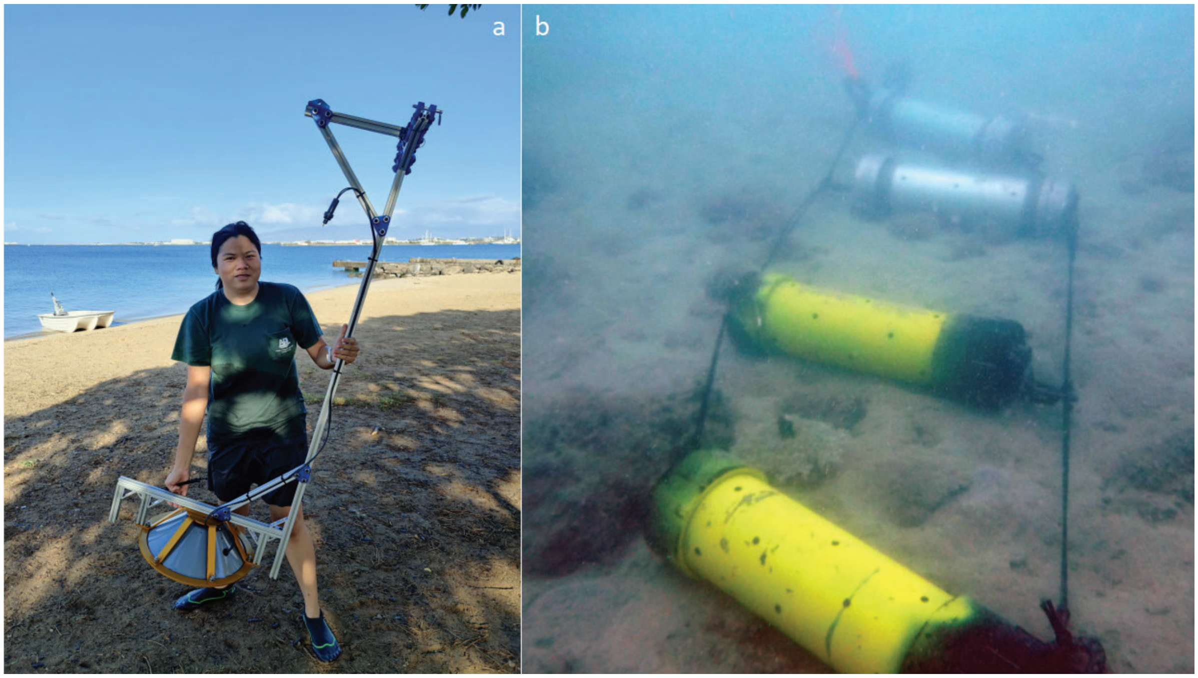


Figure 7.10. a) SyQwest Sub-bottom Profiler and WAM-V Mount, and b) Seeds on the Seafloor.

Interference issues previously noted as impacting the SSS data quality were observed in the profiles collected by the SyQwest sub-bottom profiler (Figure 7.11), but the SyQwest was nevertheless able to detect the seeds on the seafloor.

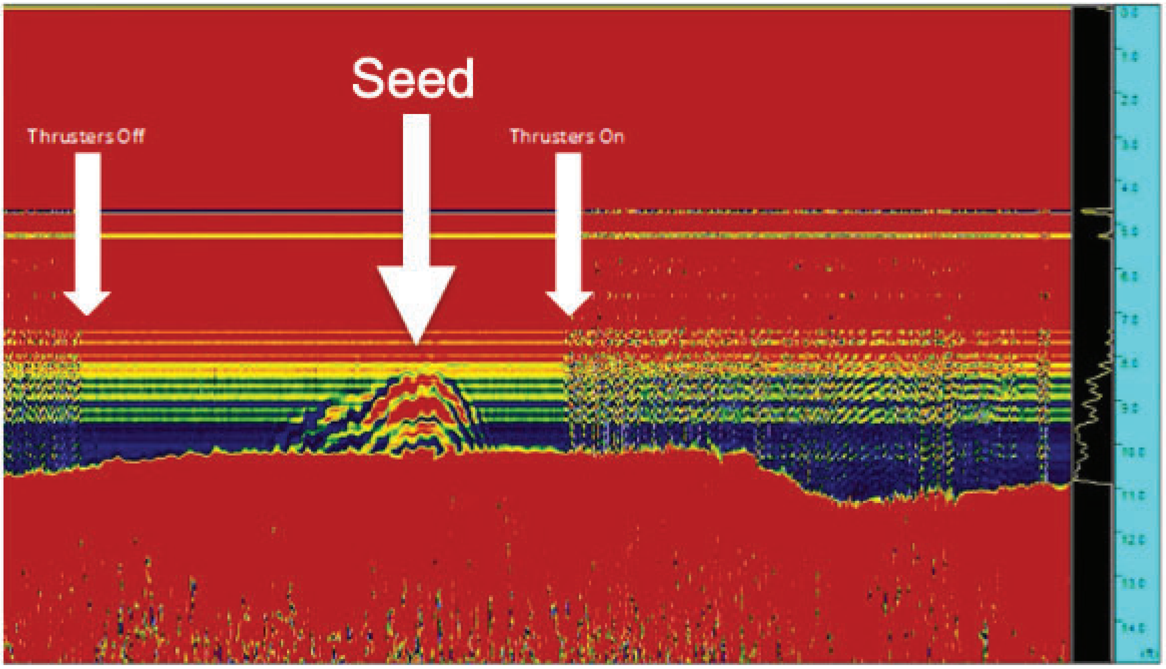


Figure 7.11. Parabolic Return in SyQwest Sonar Data that Correlated with Seed Location.

Subsequent to the October 8th engineering test, the HI_MTRC team was advised to focus on: (i) improving geolocation accuracy and (ii) conducting a TTX to support testing of the OMD in Hawai‘i. The former effort is described in Section 2 of this report; the latter is summarized in Section 9 and detailed in Appendix C.

8.0 2022 TABLETOP EXERCISE

A TTX was conducted to imagine how to assess the performance of the OMD at HI_MTRC. The comprehensive TTX report is included in Appendix C.

The OMD integrates monochrome and color cameras, a laser system, and underwater lights to map shallow water (less than 5 m depth) environments. The OMD uses two approaches, structured light and structure from motion, to extract optical information for detection and classification of MEC.

Using guidance from Creare, Inc., the OMD developer and the scoring team from IDA, the HI_MTRC team identified three categories of requirements necessary for test range operators to conduct successful field experiments and demonstrations: administrative (permits, procurement and storage), technical (deployment, measurement, monitoring, performance assessment), and logistical (shipping and coordinating resources).

Two separate field events were proposed: an engineering test and the technical demonstration. The objective of the engineering test is to allow technologists and site operators to conduct a trial exercise to identify and fix issues that might impact the technical demonstration. The technical demonstration will then assess the ability of the OMD to detect and classify MEC and clutter objects in a shallow coralline environment. The small boat harbor at the HI_MTRC site was selected as it has the desired depth and typically excellent water clarity and offers excellent facilities and support to conduct field events. Because live coral is found throughout the small boat harbor, test site installation will be conducted by swimmers. UxVs may be used to characterize the seabed depending upon operating conditions and water clarity.

Limitations of the approach, potential threats/hazards, safety and security, and logistics for travel, storage and asset preparations were considered.

The TTX report recommends that the OMD assessment take place in six phases, which include setup, transit to test range, equipment preparation, field event (deployment and data acquisition), breakdown of operation, and transit off range.

Environmental monitoring will be conducted prior to and during the engineering test and technical demonstrations. Approximately twelve seeds will be deployed by swimmers in the engineering test (calibration) area and up to twice that number in the technical demonstration (blind test) grid. The geolocation accuracy of the seeds will be assessed using RTK GNSS floats during the deployment and recovery efforts at the completion of the calibration/blind test. An SSS will be used to characterize the site before, during and after the exercise to provide additional information on the seafloor topography and position of the seeds. Finally, underwater video will be recorded during all phases of the field event to document the surroundings of each seed and to ensure recovery of all items at the end of the event.

The HI_MTRC team will provide environmental data and project notes collected throughout the duration of the engineering test and testing demonstration periods to the IDA team. Geoposition data will be transmitted to the IDA team and OMD principals. All data will be transmitted via secure internet protocol. Additionally, upon request, data analysis and an independent assessment of the project from HI_MTRC's perspective may be provided.

9.0 MPLEMENTATION ISSUES

Three categories of implementation issues for HI_MTRC were identified: environmental permitting, technological risks of creating, operating and maintaining a test range in the variable environments of Hawaiʻi and environmental factors. One goal of the TTX for OMD was to drill down into these issues.

9.1 ENVIRONMENTAL PERMITTING

Sensors that were used during this project were approved based on sharing technical specifications with regulators or did not require permits because they were deployed at distance from live corals for durations of less than one day. However, the potential exists that future demonstrations will require equipment to remain in place for longer duration or use active systems with power levels of concern to environment managers.

9.1.1 Land Disturbance

The State of Hawaiʻi requires site plan approvals (HAR Title 13 Chapter 5-22) and/or Special Activity Permits (HRS 187A-6) for:

- placing objects on the seafloor for more than 30 days, or
- if the disturbed substrate is composed of live rock or coral, or
- if the drop location is within a Marine Life Conservation District, which does not allow people to take, alter, deface, destroy, possess, or remove any sand, coral, rock, or other geological feature, or specimen.

Depending on the desired duration of the demonstration site deployment, authorization could take months to acquire.

9.1.2 Active Acoustics

The State of Hawaiʻi defers to federal regulations regarding impacts of active acoustics on marine wildlife. Based on the known sensor statistics for systems owned and intended to be used in the near future, NOAA has determined there is no reasonable anticipated risk of causing take of marine mammals, thus, Marine Mammal Protection Act incidental take authorization (16 U.S.C. 1371 Sec. 101) will not be required. If required for other sensors, an incidental take authorization would take 5-8 months to process.

9.2 TECHNICAL CHALLENGES

During year 1, technical challenges were encountered that would not ultimately affect the operation and maintenance of the HI_MTRC, but if left unresolved could limit progress in developing a hybrid approach that allows UxS to support humans in deploying a test range. For example, year 1 tests showed an inability to consistently reacquire deployed objects in the SSS data. Figure 9.1 shows a comparison of SSS imagery collected in December 2020, June 2021, and July 2021. The December data were collected when the Starfish 990F SSS was mounted on the 3-foot-long student-built USV. The data clearly depict a rough (coralline) texture in the small boat harbor (blue arrow), several point reflectors in the deeper part of Kāneʻohe Bay (white circles) and mottled texture near the patch reefs in the northern part of the survey area (green arrow).

Six months later, during the June 25, 2021 survey, the Starfish 990F SSS was mounted on the WAM-V, and the depiction of these three features had changed. The texture in the small boat harbor (blue arrow) is still visible, but arguably subdued. The mottled texture near the patch reefs is barely visible (green arrow), and the point reflectors cannot be detected. The SSS data from the July 29, 2021 survey show even less texture; the coralline terrain in the boat harbor (blue arrow) is significantly less rough in appearance.

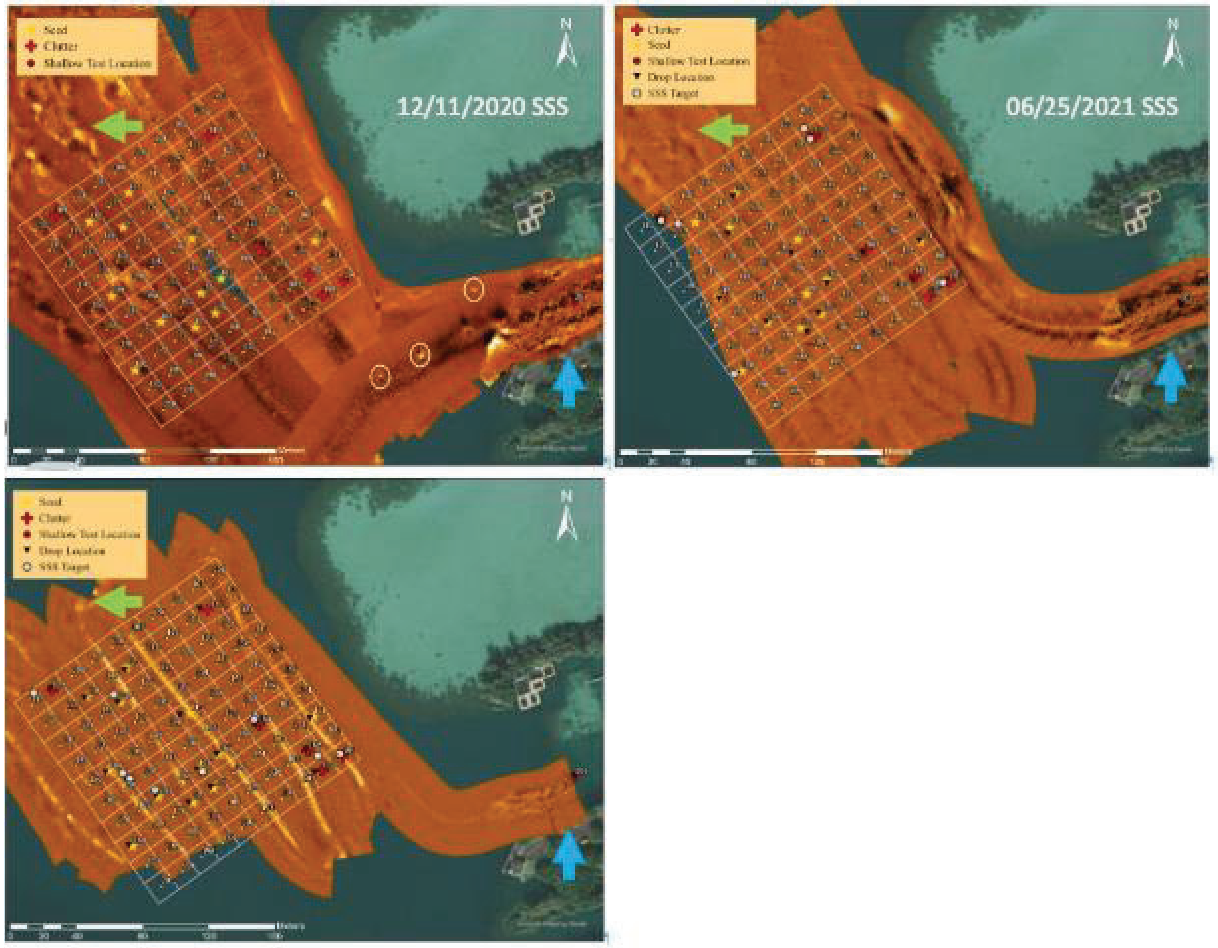


Figure 9.1. Comparison of Starfish 990F SSS Data Collected in December 2020, June 2021 and July 2021.

The hypothesis is that the diminishing information quality in the SSS could have two causes: either (i) the Starfish sonar is failing, or (ii) there is a source of systematic noise associated with the WAM-V that is swamping acoustic returns. A different seafloor mapping system to improve environmental characterization will be used in the future.

The engineering tests revealed issues with the Deployer dropping seeds consistently and the process of loading new targets onto the WAM-V. The drop failure and seed reloading process for the Deployer were addressed by oversizing the U-shaped sockets cradling the seeds, which reduced friction, and streamlining the quick-release strap components, which made the Deployer easier to load.

During HI_MTRC testing, floats were attached to the seeds and clutter items to make them easier to recover. The engineering tests identified line management to be a problem, with tangled lines preventing seeds from reaching the seabed. Line management was resolved by winding the line around the targets, which unraveled as the seed sank, reducing tangling. For future technology demonstrations it is anticipated that lines might be used to geolocate objects at the beginning and end of a technology demonstration, although the floats will be removed while the technology is being assessed.

Tests of the RTK GNSS system met the requirements necessary to determine the geolocation of the USV within a meter, although this result depended on the separation distance between RTK GNSS boards mounted on the vehicle.

The COTS sonars used during the engineering tests and final field demonstration had mixed results. The Imagenex DeltaT multibeam sonar was designed for deeper water and higher altitudes, and the data that it produced were far inferior to the shallow bathymetry data from the ASTRALiTe LiDAR. Data quality from the Tritech Starfish 990F sidescan sonar degraded over the two-year period of performance of this project. The cause of this degradation was not investigated because, through a separately funded project, ARL at UH acquired an unmanned underwater vehicle (UUV) with a mounted Edgetech 450/900 kHz sidescan sonar system that is expected to be used in the future to provide high-resolution reflectivity data for the seafloor. Only one experiment was conducted in which the SyQwest sub-bottom profiling system was integrated into the WAM-V. Given the limited testing time, it is expected that performance will improve with additional experimentation, calibration and experience.

The ASTRALiTe LiDAR was integrated with the Skyfront Perimeter UAS within a day, and the two were rapidly able to map shallow, coralline seafloor. The only limitation for using the integrated UAS/LiDAR system was wind speed; operations were only conducted when the average wind speed was below 20 kts.

9.3 ENVIRONMENTAL FACTORS

As with all test sites in marine settings, the environment presents challenges to installing, operating and recovering the test range. As stated previously, wind speeds higher than 20 kts made it challenging to control the 3-foot-long student-built USV and drive it in straight lines. While WAM-V USV operated effectively in sea state conditions at Douglas scale 2 and wind gusts up to 30 kts, the TTX underscored the importance of continually monitoring weather conditions, which change rapidly in Hawai‘i, and making sure the whole team agrees on when and how to stop operations quickly so that neither personnel nor equipment are at risk.

10.0 SUMMARY

10.1 YEAR 1 ACCOMPLISHMENTS

Year 1 efforts for the development of the Hawaiʻi Munitions Test Range Complex focused on two tasks: 1) identification and characterization of the demonstration site, and 2) scaled deployment of a demonstration site. Despite hurdles created by the pandemic, these tasks were completed within 14 months.

Moku o Loʻe was selected as the primary demonstration site. To begin site characterization, an RTK GNSS with a small student-built USV equipped with a high-resolution side-scan sonar was successfully tested and integrated. Using the student-built USV, the site at Moku o Loʻe was documented and mapped with high-resolution SSS. The RTK GNSS and sonar package were then successfully integrated into the larger WAM-V USV and autonomous driving capability was added to improve the WAM-V's navigational performance. A seed deployment mechanism mounted on the WAM-V was developed and the ability to deploy seed items using the "Deployer" was successfully demonstrated on repeated occasions.

During year 1 ARL at UH documented the placement of seeds on the seafloor using either swimmers equipped with diving watches or via a small ROV and surface floats.

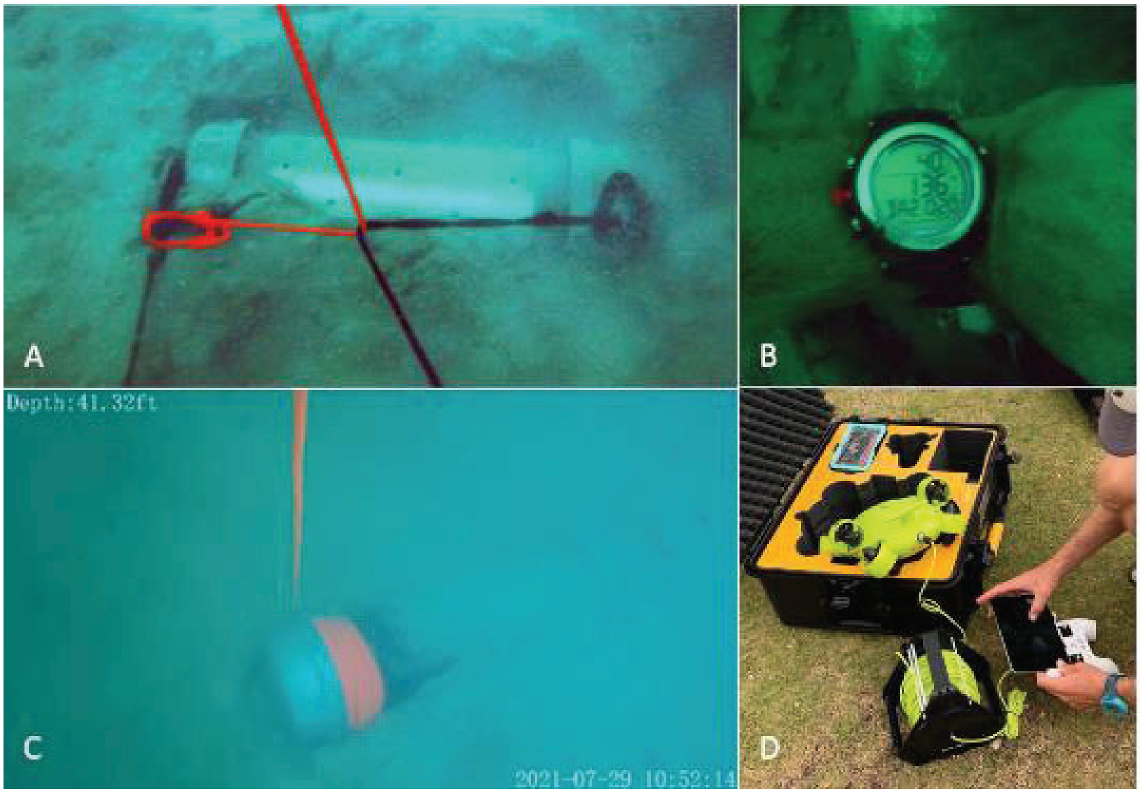


Figure 10.1. A: Steel Seed Nested in Sediment at Sand Island. B: 40-foot Water Depth Shown on Watch Directly Above Seed. C: Steel Seed Nested in Sediment in Kāneʻohe Bay at a Depth of 41.32 Feet. D: ROV used to Acquire Video in C.

Several performance objectives were identified for the scaled deployment of the test bed. The results of the engineering tests and field demonstration, which were designed to assess the ability of UxVs to install a test bed, were analyzed using these metrics (Table 10.1). The LiDAR and sub-bottom components were completed in year 2 of the effort due to technical complications and procurement delays.

Table 10.1. Summary Tasks and Performance Metrics

Task	Objective	Success Criteria	Performance	Conclusion
Seed Deployment (3.1)	Deploy test seed items	Dropping mechanism deploys all seed items successfully	All 12 seeds and 6 clutter items were successfully deployed on the final 2 field tests (first field test was aborted due to manual operation of WAM-V)	Pass
	Deploy seed items within 5-m radius of reported GNSS position	All targets are deployed within 5-m radius planned target location	Autonomously driven: 89.1% deployed within 5-m-radius of planned target location	Marginal Pass
	Re-acquire deployed seeds using WAM-V with Starfish side-scan sonar	All deployed seeds are identified in Starfish sonar data and reported with 1-m radius positional accuracy	Seed items were difficult to distinguish in sonar with 33% detection rate	Fail
	Determine horizontal offset of seeds from deployed location with 5-m reference threshold	N/A	73% of detected seeds were within 5-m radius of deployment location with a mean offset of 4.36 m	Pass
	Establish rate of seed deployment	N/A	3.6 min best-case rate of deployment	Pass
LiDAR Survey (3.2)	Collect bathymetric LiDAR to 5 m water depth	Continuous bathymetric coverage to 5 m water depth	LiDAR survey was conducted on August 18, 2021 with 100% data coverage to 5 m depth	Pass
	Collect bathymetric LiDAR to 10 m water depth	Partial bathymetric coverage up to 10 m water depth	Data for depths deeper than 5 m were sparse	Fail
	Establish rate per 100,000 m^2	N/A	Actual: 22,415 m^2 mapped in 31 minutes. Est: 138 minutes to map 100,000 m^2	Pass
Sub-bottom Survey (3.3)	Integration of SyQwest StrataBox Sub-bottom profiler to WAM-V instrument package	SyQwest sub-bottom profiler is operational on WAM-V	SyQwest Sub-bottom profiler integration was completed and tested on October 8, 2021	Pass
	Sub-bottom profiles to 5 m depth below seafloor or to coral / bedrock substrate	Continuous profiles to 5 m depth below seafloor or to coral / bedrock substrate	No objects were buried to test the penetration ability of the SyQwest sub-bottom profiler	Fail

The first objective of the seed deployment was demonstrating the ability to deploy all seed items using the WAM-V Deployer. Using autonomous driving, the intended twelve seed items were successfully deployed using the WAM-V. At least six clutter items were also successfully deployed using manual methods. This objective was met based on the criteria in Table 10.1.

The second objective tested the ability to deploy seeds within a 5-m radius of the planned position. Once autonomous driving was instituted, the WAM-V achieved an 89.1% rate of deployment within 5 m of the target position. The average positional offset was 2.51 m for the July 29th demonstration. The objective was to achieve a 100% rate of targets within 5 m, but the high rate of success and low overall average distance supports a marginal pass. As the autonomous driving is refined on the WAM-V, better performance is anticipated.

The third objective was the ability to relocate the seed items within a 1-m radius of uncertainty in geolocation. This objective was not met. The diminishing performance of the Starfish 990F SSS over time rendered identification of targets in the sonar difficult. Only 33% of targets were successfully relocated.

The fourth objective of the seed deployment was to determine the horizontal offset of the seeds from the deployed location. It was anticipated that the horizontal drift of the targets in the >10 m of water at Moku o Lo‘e would be 5m or less. The results showed that 73% of the targets relocated were within 5-m of the recorded deployment position. The mean overall offset was less than 5 m (4.36m). No success criterion was specified for this objective, but a mean horizontal offset was successfully determined.

The final objective of the seed deployment test was to establish a rate of seed deployment. The average rate of deployment (adjusted for breaks in activities) improved over the course of the 3 field tests from 6.0 minutes to 4.92 minutes to a minimum of 3.6 minutes per seed with the incorporation of autonomous driving and refinement of deployment methodology. The rapid rate of seed deployment is viewed as a success.

Several summary observations were made throughout the engineering tests and final demonstration. Primarily, the seed deployment rate and the ability to deploy within a 5-m radius of the target location improved drastically with the incorporation of autonomous driving in the WAM-V. Less than 30% of targets were placed within 5 m of the target location when remotely driving the WAM-V and logistical issues increased the seed deployment time, limiting the total number of seeds deployed (e.g., May 10th results). Autonomous driving rendered the WAM-V easier to handle, improved the deployment rate by more than 1.6x, and improved the drop accuracy from 28.6% to 89.1%.

10.2 YEAR 2 ACCOMPLISHMENTS

Year 1 efforts focused on: 1) conducting a LIDAR survey of the small boat harbor at Moku o Lo‘e, 2) integrating the SyQwest StrataBox HD sub-bottom profiler into the WAM-V and collecting data over seeds, 3) improving geolocation data in shallow-water settings following an approach pioneered by PNNL, and 4) conducting a TTX for the OMD. The performance objectives for tasks 1 and 2 were analyzed using the metrics in Table 10.1. The geolocation data were collected and assessed during experiments on February 25, 2022 and April 22, 2022 with the expectation of repeatable precision that showed <1 m of variability. No performance objectives were required for the TTX, which was a thought experiment for a future field program.

The first objective of conducting a LiDAR survey was accomplished on August 18, 2021. The LiDAR successfully mapped coral colonies throughout the Moku o Loʻe boat channel, where the water is <5 m deep. In deeper regions the LiDAR was unable to detect the seafloor, perhaps due to turbidity or the soft, muddy bottom. The LiDAR maps were generated very rapidly, with an estimated rate of approximately 2.25 hours to map a 100,000 m^2 region.

The second objective was to integrate a SyQwest sub-bottom profiler into the WAM-V and map the seafloor and shallow subsurface. On October 8, 2021 the SyQwest StrataBox HD sub-bottom profiler successfully tracked the seafloor and identified proud objects during its one and only field trial at Sand Island. The measured depths were consistent with previous depth measurements and pre-existing bathymetric data of the Sand Island test site. Due to a shift in priorities, no experiments were conducted with the SyQwest sub-bottom profiler to see if it could detect objects buried by more than a few cm of sediment.

The third objective of improving geolocation data using floats equipped with RTK GNSS sensors was demonstrated on multiple occasions over periods of several hours for water depths up to four meters (Figure 10.2).

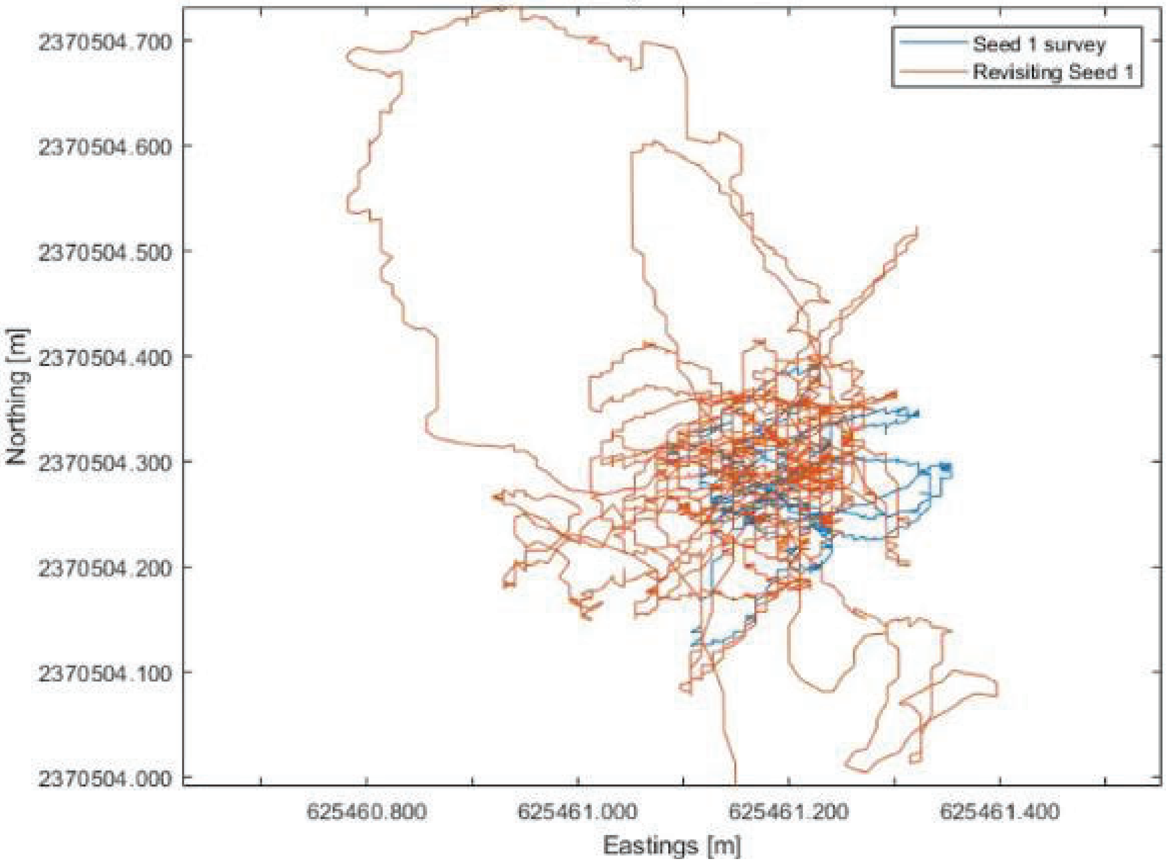


Figure 10.2. Comparison of RTK GNSS Geolocation Data for a Seed Over a Period of Hours.

The fourth objective, conducting a TTX for the OMD, was a thought experiment that revealed multiple important considerations for testing that will be addressed in the future.

10.3 ROOM FOR IMPROVEMENT/FUTURE WORK

Throughout this project the concept of best practices for deploying and recovering a test range in diverse settings evolved significantly. Initially the objective was to deploy and recover a test range using only UxVs, but through testing and evaluation it became clear that a hybrid model, in which UxVs support human operators, was a better approach. UxVs can rapidly and (generally) safely deploy objects within 5 meters of a desired location at the ocean surface, but precisely locating and orienting objects requires human abilities. This is particularly true in settings where protected fauna reside. Because UxVs have the potential to operate with longer endurance, less risk and greater spatial coverage than humans, a hybrid approach that employs UxVs for broad distribution with human operators adding the fine-tuning is recommended.

Other areas for improvement include purchasing higher quality sensors, reducing electrical and mechanical interference between sensors and platforms, incorporating irregularly shaped clutter objects into the automatic deployment system, increasing the number of objects that can be deployed from a USV to reduce the time spent reloading the dropping mechanism(s), and ruggedizing the UxVs to perform better in more active wind and ocean environments.

The hope for future work is to implement a field event that follows the blueprint described in the TTX for the OMD technology.

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APPENDIX A POINTS OF CONTACT

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Josh Levy	ARL at UH 2800 Woodlawn Drive Suite 263 Honolulu, HI 96822	808.956.0431 levyjosh@arl.hawaii.edu	Logistics, UAS pilot, boat operator, swimmer, diver
Kainani Santos	ARL at UH 2800 Woodlawn Drive Suite 263 Honolulu, HI 96822	808.956.0431 kainani.santos@arl.hawaii.edu	Graduate Student Mechanical Engineer
Carter DuVal	Naval Research Lab Code 7354 1005 Balch Blvd Stennis Space Center, MS 39529	228.688.4182 Carter.duval@nrlssc.navy.mil	Consultant (Data Processing & Analysis, GIS, Field Planning)

APPENDIX B RTK GNSS PERFORMANCE ANALYSIS

B.1. Geopositioning

Effective use of demonstration sites requires that site operators be able to accurately determine the geographic position of an object. For this project, the goal is to achieve geopositional accuracy of ~0.5 m. There are several methods to geographically locate underwater objects; RTK GNSS was chosen to achieve the required positional accuracy. Unfortunately, Hawaiʻi does not have public access to the RTK networks that are scattered across the continental United States, so in 2020 the ARL at UH built this capability. The high precision GNSS-RTK modules used are the SparkFun GNSS-RTK2 ZED-F9P boards. The complete system includes one board on the base station and two boards on the USV. The two boards are located as far apart as possible on the vehicle to form a dual-RTK system for the vehicle that provides detailed information about vehicle position and orientation (primarily yaw) during survey operations.

Testing of the RTK GNSS system has primarily been conducted on land using personnel and a variety of motor vehicles. While the RTK GNSS system can be mounted on the small USV, the team knew that the offset between the two boards on such a small platform would produce data that were not very precise. Therefore, the RTK GNSS system was installed and tested using vehicles that were similar in length to the 16-foot WAM-V. The accuracy and precision of the system measured during a December 2020 parking lot excursion are shown in Figure B.1 with a vector map indicating vehicle heading during the first few tracks of the deployment in Figure B.2.

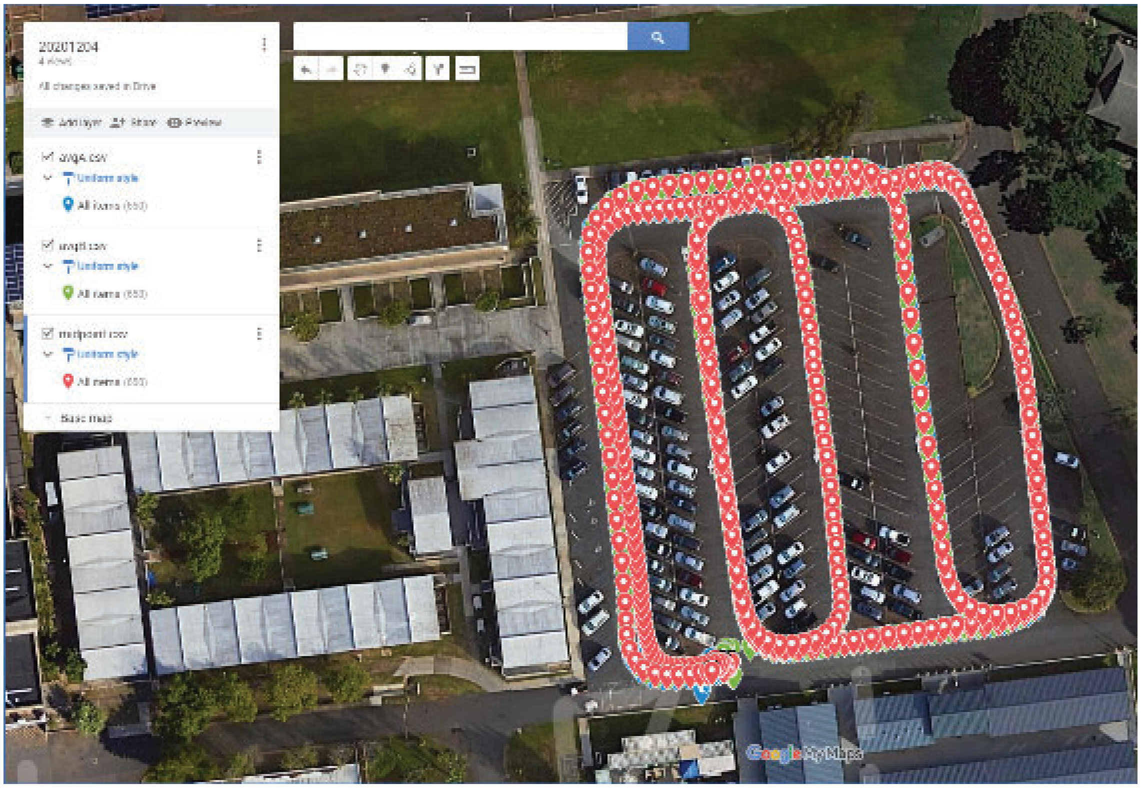

Figure B.1. Map of Locations from December 2020 RTK GNSS Test.

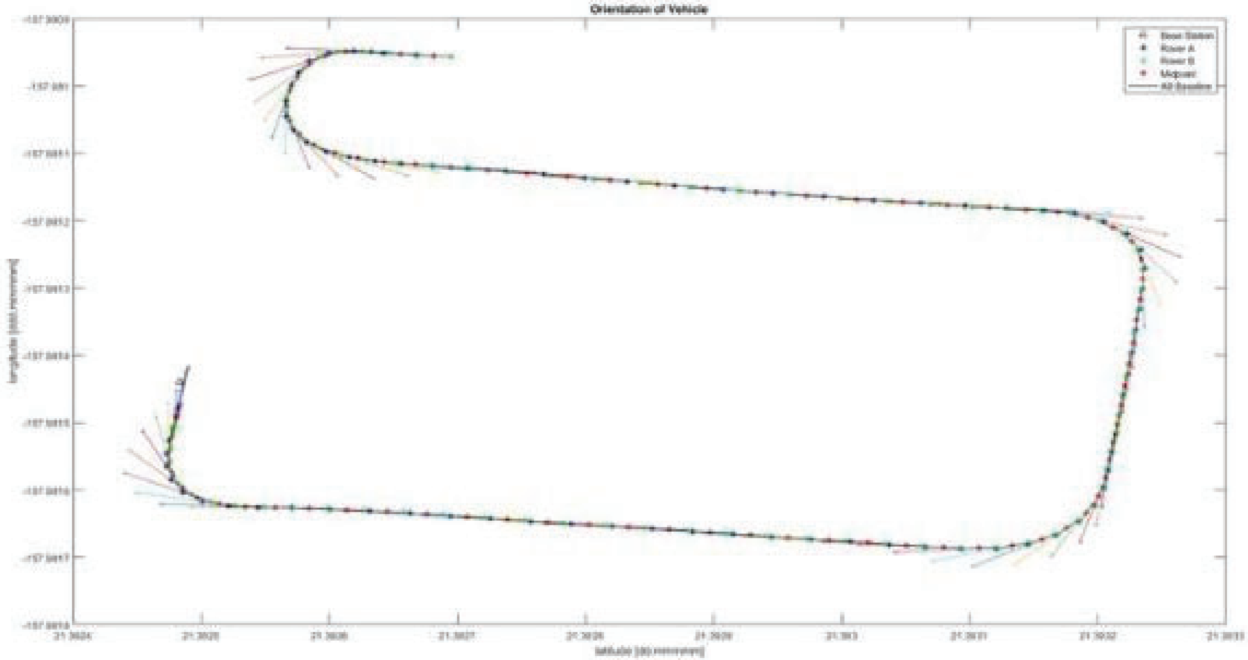

Figure B.2. Graphs of Vehicle Heading Derived from RTK GNSS Boards Mounted on the Test Vehicle.

At the request of ESTCP, the performance of the RTK GNSS was revisited to determine the quantitative performance metrics of the system. Three different aspects of the positioning performance of the RTK modules were validated: (1) absolute Earth-centric positioning accuracy, (2) positioning precision (repeatability), and (3) positioning accuracy with respect to the base station.

Absolute Earth-centric positioning accuracy

Absolute earth-centric positioning accuracy describes the closeness of a latitude-longitude measurement from the RTK module against a known true latitude-longitude ground truth with respect to the global Earth-centric coordinate system. As with most measurement systems, absolute accuracy over the full measurement scale is the most challenging parameter to achieve, and the certainty of the accuracy measurement is limited by the accuracy of the ground truth measurement.

Ground truth measurements of latitude-longitude are available via well-documented National Geodetic Survey (NGS) geodetic markers; however, geodetic markers compliant to the most current horizontal position surveying standards – North American Datum of 1983 (NAD83) and World Geodetic System of 1984 (WGS84) – *do not* claim positioning accuracy figures with respect to a GNSS-based measurement system; rather, they claim accuracy with respect to nearby networked Continuously Operating Reference Station (CORS) (whose locations *define* ground truths) and local geodetic marker system. Because NAD83 and WGS84 standards are primarily based on local surveying techniques that are then are augmented by GNSS, one should not anticipate sub-meter agreement between geodetic markers and non-WGS84 GNSS data.

Despite this, absolute accuracy performance is still worth knowing, particularly for appreciating the error between two independently collected GNSS surveys that have not been calibrated to a known ground marker. Agreement between geodetic ground markers and independently collected GNSS surveys is likely to improve as NGS transitions to the upcoming North American-Pacific Geopotential Datum of 2022, which *will* be primarily based on GNSS data.

To analyze absolute positioning accuracy, two nearby NGS NAD83-compliant geodetic ground markers with excellent sky access were surveyed: "HCTC 96" at 21.3118 N, -157.89952 W (Figure B.3) and "KEEHI 7" at 21.33019 N, -157.89916 W (Figure B.4). Because this test analyzes absolute accuracy, no RTK base station was used as this would reference the position data with respect to the RTK base station instead of the absolute Earth-centric datum. Satellite data were collected until the RTK module reported a horizontal dilution of precision of 0.5 m or less, i.e., the repeatability of the current measurements fall within a 0.5 m variance, then the latitude and longitude data were recorded and compared against the geodetic marker latitude and longitude.

Figure B.3. HCTC 96 NGS Geodetic Marker.

Figure B.4. KEEHI 7 Geodetic Marker.

Positioning precision

Positioning precision describes the statistical repeatability of measurements, particularly after systematic changes to the measuring modality. High measurement precision is essential for successfully re-locating a previously located object of interest in a survey area. There are multiple well-known systematic error causes in satellite positioning systems: satellite clock error, changes in upper atmosphere (ionosphere), receiver clock error, changes in observed satellites and their known orbits, lower atmosphere, and multipath interference. Because these systematic errors tend to change slowly over hour-level time scales, sub-meter precision is achievable by standalone GNSS modules over minute-level time scales; however, this sub-meter precision cannot be assumed for long time scales (often months or years for survey sites). RTK technology corrects for these systematic errors by collecting satellite data from a ground station RTK module that is assumed stationary (and can be assigned a calibration latitude-longitude if desired). Systematic biases measured by the stationary RTK module are sent to the measuring RTK module in the form of "correction data" which corrects the measuring RTK position data to cm-level precision, even over arbitrarily long time scales.

To analyze positioning precision, a portable survey site was set up on UH Mānoa campus on the roof of a large, flat parking structure. Four orthogonal "corners" of the survey area were selected for validating precision, and the RTK ground station was setup in a location in line-of-sight of all four corners. A top-down orthogonal view of the survey area indicating the location of the base station and four corners (blue markers) is presented in Figure B.5. The survey area on the two days of experimentation is shown in Figure B.6 and Figure B.7.

Figure B.5. UH Zone 20 Parking Structure; Location of the Positioning Precision Survey Area.

Figure B.6. Positioning Precision Survey Area Viewed from Corner 3 on May 04, 2021, 1830 HST.

Figure B.7. Positioning Precision Survey Area Viewed from Corner 4 on May 06, 2021, 1300 HST.

The base station RTK module collected GNSS data until a standalone horizontal dilution of precision of < 0.5 m was achieved, which took roughly 20 minutes. The latitude and longitude were recorded and set as the calibration coordinates for the RTK base station module in fixed RTK mode. Once the measuring RTK module entered "RTK Fixed" mode (all correction data received from the RTK base station module and high-quality 3D satellite lock), it was moved precisely to each corner and the measurements at each corner were recorded. Images of the placements of the RTK module are shown in Figure B.8. The measuring RTK module was then powered off and powered on again, and the four-corner measurement process was repeated a second time.

Figure B.8. Placing the RTK Module Antenna at Each Corner.

Corner 1 top right, corner 2 top left, corner 3 bottom left, corner 4 bottom right.

To replicate the conditions emulating a major change in systematic biases, this experiment was repeated on a second day, at the different time during the day. This ensured changes in the previously mentioned sporces of error, as well as human error in setting up and positioning the RTK base station module and data recording. The latitude and longitude data recorded at each corner were then compared against data from the previous experiment to define the precision (repeatability) of the measurements.

<u>Positioning accuracy with respect to the base station</u>

Absolute earth-centric positioning accuracy describes the closeness of a latitude-longitude measurement from the RTK module against a known true latitude-longitude ground truth with respect to the global Earth-centric coordinate system.

Positioning accuracy with respect to the base station describes the closeness of a latitude-longitude measurement from the RTK module against a ground truth measurement with respect the calibrated latitude-longitude *defining* the position of the RTK ground station module. This can be thought of as the "local accuracy" of the measurements, as opposed to the "global accuracy" of the absolute Earth-centric positioning accuracy described earlier. Because the measurement scale is calibrated with respect to the local operating range of the RTK base station module, this local accuracy should be much closer to measured ground truths than the absolute Earth-centric positioning accuracy. The measured ground truth distances between each corner were measured using a wheeled measuring tool, as shown in Figure B.9. The measured ground truth measurements were then compared against calculated distances between the latitude-longitude satellite data taken at each corner.

Figure B.9. Wheeled Measuring Tool Used to Measure the Distance Between the Four Corners.

B.2. RTK GNSS Performance

Absolute Earth-centric positioning accuracy

Table B.1. Documented vs. Measured Latitude-Longitude Data from Geodetic Markers and Position Error.

	Latitude	Longitude	Error between measured vs. documented [m]
HCTC 96 documented position	21.33118°	-157.89952°	-
KEEHI 7 documented position	21.33019°	-157.89916°	-
HCTC 96 measured via RTK	21.33122827°	-157.8995408°	5.78 m
KEEHI 7 measured via RTK	21.33023465°	-157.8991821°	5.46 m

The single RTK module was accurate to approximately 6 m of the HCDC 96 and KEEHI 7 geodetic latitude-longitude markers. As previously mentioned, GNSS positioning should not be expected to achieve sub-meter absolute accuracy to geodetic markers, as the NAD83 geodetic marker system only claims high accuracy with respect to the nearest CORS network and nearby local markers, and the RTK module cannot take advantage of any RTK-correction technology in this measuring modality.

<u>Positioning precision</u>

Table B.2. Compiled Latitude-Longitude Data from Each Corner During Each Trial.

	Latitude	**Longitude**	**Δ Latitude vs. trial 1 converted to [cm]**	**Δ Longitude vs. trial 1 converted to [cm]**
trial 1 corner 1	21.29578082°	-157.8179396°	-	-
trial 1 corner 2	21.29568775°	-157.8168713°	-	-
trial 1 corner 3	21.29592802°	-157.816847°	-	-
trial 1 corner 4	21.29602052°	-157.8179162°	-	-
trial 1 corner 5	21.29578043°	-157.8179397°	-	-
trial 2 corner 1	21.29578054°	-157.8179397°	-3.09 cm	-1.05 cm
trial 2 corner 2	21.29568763°	-157.8168713°	-1.29 cm	-0.490 cm
trial 2 corner 3	21.29592791°	-157.816847°	-1.26 cm	0.0181 cm
trial 2 corner 4	21.29602061°	-157.8179162°	1.03 cm	-0.611 cm
trial 2 corner 5	21.29578042°	-157.8179397°	-0.103 cm	0.116 cm
trial 3 corner 1	21.29578056°	-157.8179397°	-2.85 cm	-1.08 cm
trial 3 corner 2	21.29568746°	-157.8168713°	-3.16 cm	-0.703 cm
trial 3 corner 3	21.29592784°	-157.8168469°	-2.03 cm	0.568 cm
trial 3 corner 4	21.29602046°	-157.8179164°	-0.688 cm	-2.68 cm
trial 3 corner 5	21.29578023°	-157.8179398°	-2.27 cm	-1.81 cm
trial 4 corner 1	21.29578069°	-157.8179395°	-1.50 cm	0.610 cm
trial 4 corner 2	21.29568767°	-157.8168713°	-0.836 cm	-0.351 cm
trial 4 corner 3	21.29592781°	-157.8168471°	-2.39 cm	-0.973 cm
trial 4 corner 4	21.29602056°	-157.8179163°	0.420 cm	-1.78 cm
trial 4 corner 5	21.29578012°	-157.8179397°	-3.48 cm	-0.314 cm
Mean over all five corners			**-1.57 cm**	**-0.702 cm**

*** Note: Corner 5 is identical to corner 1 but was recorded twice when completing the rectilinear survey.**

Over the approximately 110 x 25 m survey area, the RTK system was precise to an equivalent mean latitude repeatability of 1.6 cm and mean longitude repeatability of 0.70 cm on five controlled data points over four trials on two different days of data collection. This precision is on the same order of magnitude of experimental setup error and demonstrates that this positioning system can locate objects down to cm-level precision, even after setting up and breaking down the calibration base station over arbitrarily long time periods.

Positioning accuracy with respect to the base station

Table B.3. Positioning Accuracy of Corner Lengths with Respect to the RTK Base Station.

	Manually Measured Distance Between Corners [m]	Calculated Distance Between Corners Based on RTK Latitude-Longitude Data [m]	Error [m]
corner 1 to corner 2	111.684	111.088	0.596
corner 2 to corner 3	26.797	26.816	-0.019
corner 3 to corner 4	111.735	111.187	0.548
corner 4 to corner 5	26.797	26.806	-0.009

The RTK system was accurate to approximately 0.6 m of the manually-measured lengths between the four corners of the survey area. It should be noted that accuracy evaluated against a measured length expresses the error in the measurement system and the flat earth conversion (latitude-longitude [degrees] to x-y [m]). Based on these results, the positioning length accuracy with respect to the base station is one decimeter or better. The ARL at UH will continue to document geolocation as objects are deployed within the Demonstration Site to increase the sample size for analysis purposes.

APPENDIX C TABLETOP EXERCISE FOR THE OPTICAL MUNITIONS DETECTOR

C.1. Tabletop Exercise Overview

Objective

SERDP and ESTCP instigated four test ranges to assess the performance of innovative technologies and approaches for detecting unexploded ordnance and discarded military munitions, collectively referred to as MEC throughout this report. These SERDP/ESTCP-selected test ranges are distributed from Hawaiʻi to Italy to evaluate MEC-detection technologies across a variety of environments. ESTCP recommends that test site managers conduct a TTX with technology developers prior to assessment at their site. This report describes a TTX for evaluating an OMD at HI_MTRC operated by the ARL at UH.

Requirements for Conducting Test Site Demonstrations

Using guidance from the OMD developer and the scoring team, the HI_MTRC team identified three categories of requirements necessary for test range operators to conduct successful field experiments and demonstrations: administrative, technical, and logistical.

Administrative Requirements

- Identifying appropriate technologies for the test site
- Obtaining environmental permits required to operate assessed technology
- Procuring surrogate MECs and clutter objects appropriate for assessment
- Arranging secure storage for operational equipment

Technical Requirements

- Deployment and retrieval of MECs and clutter objects
- Precisely geolocating deployed MECs and clutter objects
- Supporting technologists as they prepare and integrate their equipment
- Coordinating supplementary vessels and personnel for deployment and recovery of calibration and test sites, as needed
- Monitoring environmental conditions before, during, and after field activities
- Supporting independent assessment of technology performance

Logistical Requirements

- Monitoring regulations/policies for travel to the State of Hawaiʻi
- Assisting technologists with shipping equipment to/from Hawaiʻi
- Identifying travel and housing options for technologists
- Identifying sources of spares/consumables in support of field operations
- Coordinating movement of technology to Moku o Loʻe
- Coordinating storage for equipment at technologist-prescribed specifications
- Coordinating workspace/power/internet for technologists at test range

C.2. Design of the TTX

Demonstration Technology

The technology selected for this TTX is the OMD, built and operated by Creare, Inc., which integrates monochrome and color cameras, a laser system, and underwater lights to map shallow water (less than 5 m depth) environments. The OMD uses two approaches, structured light and structure from motion, to extract optical information for detection and classification of MEC (Wilbur and Davis, 2021). Structured light uses triangulation of a light source and camera to reconstruct a 3-D scene while structure from motion combines multiple images over the same area to reconstruct the scene in 3-D using stereo-vision techniques.

Project Participants and Roles

Technology Developer

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HI_MTRC Team

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Scoring and Assessment

Daniel Kolodrubetz, IDA
Jacob Bartel, IDA

Sponsors and Observers

To be determined

Exercise Scenario

Dates and Duration

Dates are to be determined. The technology developer and scoring team recommended two separate field events: an engineering test and the technical demonstration. The former event is anticipated to require two days, while the technical demonstration is expected to take at a minimum, one week: one day for technology integration, one day for measurements and pre-testing, multiple days to adjust the system based on test results, and one day for the technical demonstration.

Objective

The objective of the engineering test is to allow technologists and site operators to conduct a trial exercise to identify and fix issues that might impact the technical demonstration. The engineering test can be conducted days or months in advance of the technical demonstration.

The objective of the technical demonstration is to assess the ability of the OMD to detect and classify MEC and clutter objects in a shallow coralline environment.

Capabilities Being Demonstrated

The technical demonstration will assess the ability of the OMD to detect MEC that is proud on the seafloor in a shallow-water environment with good water clarity. The small boat harbor at the HI_MTRC site has the desired depth and typically excellent water clarity. The seafloor in the small boat harbor is a hard coralline substrate with patches of live coral that will act as natural clutter in addition to man-made clutter objects that will be deployed (Figure C.1).

Figure C.1. Satellite Image of the Small Boat Harbor for the OMD Assessment.

Limitations of the Approach

Limitations of the technical demonstration include:

- Working in a ~200 m^2 area with detection halos of 2-3 m around each target/clutter object.

- Changing environmental conditions (e.g., rain, wind, tides) that may impact system performance; for example, by making it harder to operate the survey vessel or decreasing water clarity.
- Vessel traffic near Moku o Lo‘e generating wakes that affect sensor/platform motion.

Threats/Hazards

- Severe weather conditions (i.e., wind conditions above 30 kts, lightning) would result in cancellation of testing.
- Health risks to personnel (e.g., COVID-19 outbreak) could result in cancellation of testing.
- Failure of components could result in delays until resolved.
- Availability of platforms (e.g., Boston whaler, USV) could result in delays until resolved.

Exercise Planning Team

Prior to execution the concept of operations (CONOPS) will be reviewed by all parties: ESTCP, IDA, Creare and ARL at UH, hereafter referred to as the Exercise Planning Team. This team will direct allocation of resources by HI_MTRC site managers and OMD technologists to foster a successful field exercise.

C.3. TTX Details

This section provides a detailed thought experiment for conducting the engineering test and technical demonstration and explicitly links technologist objectives, scoring requirements and HI_MTRC site manager activities.

Assumptions

Assumptions for conducting the technical demonstration will be discussed and agreed upon by the performers. Example assumptions include how much time to allot for the engineering test and technical demonstration, how much time to plan for contingencies, and alternative plans that can be implemented in case technical or logistical issues arise. The first priority of the field events is to evaluate the OMD team’s capabilities, plans, systems and processes in a way that allows accurate, and independent evaluation by the IDA. A secondary priority is assessing the capabilities of the HI_MTRC site and team to conduct technical demonstrations.

Objectives

Engineering Test

The objectives of the engineering test are listed in Table C.1. Each objective is linked to a core capability that is necessary to achieve mission success. The objectives and core capabilities are identified by the Exercise Planning Team.

Table C.1. Objectives and Core Capabilities for Engineering Test.

Demonstration Objective	Primary Core Capability (OMD Team)	Secondary Core Capability (HI_MTRC Team)
Transporting OMD and auxiliary equipment to HI_MTRC site.	Ability to have OMD and auxiliary equipment in a transportable state appropriate for air/sea shipment. Ability to re-assemble and deploy the OMD within a set time period.	Ability to coordinate support vehicles for transportation to/from test site.
Deployment of personnel and equipment for engineering test.	Ability to transition OMD and auxiliary equipment into operational configuration with or without assistance from HI_MTRC personnel.	Ability to deploy test site objects as needed. Ability to support OMD engineering test.
Engineering test of OMD.	Ability to integrate with ARL at UH geo-positiong systems to collect object location data during engineering test. Ability to collect sensor data during deployment.	Ability to collect environmental data during engineering test. Ability to collect near real-time geolocation data.
Post-test dissemination of data.	Ability to retrieve data from equipment for post-processing with or without assistance from HI_MTRC personnel.	Ability to disseminate geolocation and environmental data to OMD team.
Transporting OMD and auxiliary equipment from HI_MTRC site.	Ability to transition OMD and auxiliary equipment into a transportable state with or without assistance from HI_MTRC personnel.	Ability to recover test site objects that may have been deployed.

Technical Demonstration

The objectives of the technical demonstration are listed in Table C.2. Each objective is linked to a core capability that is necessary to achieve mission success. The objectives and core capabilities are identified by the Exercise Planning Team.

Table C.2. Objectives and Core Capabilities for Technical demonstration.

Demonstration Objective	Primary Core Capability (OMD Team)	Secondary Core Capability (HI_MTRC Team)
Transporting OMD and auxiliary equipment to HI_MTRC site.	Ability to have OMD and auxiliary equipment in a transportable state appropriate for air/sea shipment. Ability to re-assemble and deploy the OMD within a set time period.	Ability to coordinate support vehicles for transportation to/from test site.
Deployment of personnel and equipment for technical demonstration.	Ability to transition OMD and auxiliary equipment into operational configuration with or without assistance from HI_MTRC personnel.	Ability to rapidly deploy test range seeds, clutter, and auxiliary equipment. Ability to collect geolocation data for deployed objects.
Technical demonstration of OMD capabilities.	Ability to integrate with ARL at UH geo-positioning systems to collect location data during technical demonstration. Ability to collect sensor data during deployment.	Ability to collect environmental data during technical demonstration in support of scoring objectives.
Post-demonstration dissemination of data.	Ability to retrieve data from equipment for post-processing with or without assistance from HI_MTRC personnel.	Ability to re-acquire geolocation data for deployed objects. Ability to disseminate geolocation and environmental data as appropriate to technologists and scoring team.
Transporting OMD and auxiliary equipment from HI_MTRC site.	Ability to transition OMD and auxiliary equipment into a transportable state with or without assistance from HI_MTRC personnel.	Ability to recover deployed seeds, clutter, and auxiliary equipment.

Permitting

Moku o Lo‘e and its immediate vicinity are protected by a few layers of regulation. National Oceanic and Atmospheric Administration's Office for Coastal Management incorporated the He‘eia ahupua‘a (watershed), including Moku o Lo‘e and the He‘eia Fishpond, into the He‘eia National Estuarine Research Reserve (NERR). Management of the NERR is via the State of Hawai‘i through HIMB and the State of Hawai‘i's DLNR. The waters surrounding Moku o Lo‘e are home to Central North Pacific Green Sea Turtles, which are listed as threatened under the Endangered Species Act (ESA).

DLNR has determined that no permits are required for placement of objects on the seafloor if the duration of the placement is less than 30 days. The expectation is that the OMD test will not require objects to be on the seafloor for 30 days or more.

The State of Hawai‘i’s Division of Aquatic Resources (DAR) and NOAA were contacted regarding the use of the laser that is integrated into the OMD with the concern being potential exposure risk to animals listed under the ESA. Per the email communications, if the activity is funded by a federal entity, NOAA must consult with the federal agency through the Section 7 ESA. The initial consultation could result in three outcomes; 1) A determination that risk of exposure to any listed species is almost zero, which would require no further responsibility to consult, 2) a determination that actions are ‘not likely to adversely affect’ listed species, which would require an informal consultation, or 3) a determination that actions are “likely to adversely affect” listed species, which will result in a full consultation and an incidental take statement to proceed with operations. DAR, who will be kept informed of the conversations with NOAA, will defer to federal conclusions and does not require a separate state permit. There is no potential for harm to fauna resulting from use of the remaining components (i.e., cameras, lights) of the OMD.

Participant Responsibilities

Technology Developer: pre-event planning; ship equipment to/from Hawai‘i; mobilize the OMD within an agreed upon time frame; transition OMD and auxiliary equipment into operational configuration; integrate with ARL at UH-provided vessels and/or geo-positioning systems to collect data during technical demonstration; collect sensor data during deployment; provide acquired data to scoring team for analysis; demobilize equipment.

HI_MTRC Demonstration Site Team: pre-event planning; receive equipment and transport to test side; install the test range as agreed upon for the engineering test and technical demonstration; provide support vessel and geo-positioning systems; support Technology Demonstrators in their efforts to integrate systems; collect environmental data before, during and after the field events; provide acquired data to scoring team for analysis; assist with demobilization of equipment and transport off Moku o Lo‘e.

Scoring Team: pre-event planning; observe technical demonstration; analyze sensor and environment data; provide independent assessment of technical performance.

Field Event Structure

Phase 0: HI_MTRC Setup – Prepare applicable test range equipment.

Table C.3. Checklist of Actions to Be Taken During Test Range Set Up.

Action	Description
Confirm TTX event	Determine dates with technologist (i.e., arrival to Hawaiʻi, setup of technology at field, engineering test, field experimentation, closeout, departure from State)
Confirm TTX with field site	Provide notice to HIMB for water use and access to power/tools
Coordinate and confirm support logistics	Provide notice to support USV support team, support boat from HIMB, and vehicles to transport equipment
Confirm readiness and availability of HI_MTRC	Verify operation of equipment managed by HI_MTRC team, assess condition of field, and check weather forecast
Distribute TTX CONOPS to involved groups	Provide version of CONOPS to teams
Deployment of HI_MTRC technology to field	Ensure all HI_MTRC technology is present at site (i.e., inert objects, survey equipment)
Support shipping/lodging of OMD team	Provide contact details for shipping providers, addresses for places of interest, and guidance for navigating between locations

Phase 1: Transit to range – Get necessary equipment on Moku o Loʻe.

Table C.4. Checklist of Actions to Be Taken During Phase 1 – Transporting Technology to Test Site.

Action	Description
Receive OMD items	HI_MTRC team to coordinate with OMD team to transport members/equipment to HIMB
Transport OMD items to HIMB	Transport technology through HIMB shuttle or from Heʻeia Boat Harbor
Secure OMD technology in a controlled storage area	Prepare location on HIMB for safe-keeping within OMD-defined storage conditions

Phase 2: Preparation of equipment – Setup of assets for intended roles and tasks.

Table C.5. Checklist of Actions to Be Taken During Phase 2 – Setting Up Assets.

Action	Description
Retrieve OMD technology	Transport OMD technology from HIMB storage location to working area
Deployment of requested amenities and capabilities to OMD team	Access to HIMB facilities (i.e., 120V plugs), HI_MTRC project engineer on standby
Confirm acceptable field conditions	Collect environmental survey data. Determine pass/fail for deployment of range and equipment based on environmental conditions

Phase 3: Field Event – Deployment of OMD and Data Acquisition.

Phase 3 is divided into actions for the engineering test and the technical demonstration.

Table C.6. Checklist of Actions to Be Taken During Phase 3 – Deployment and Data Acquisition.

Action	Description
Confirm field conditions	Determine pass/fail for deployment of range and equipment based on observed conditions
Engineering Test: HI_MTRC deployment of field	HI_MTRC team deploys a calibration field using recommendations of IDA team
Engineering Test: HI_MTRC characterization of field	HI_MTRC team generates a "ground truth" map of engineering field
Engineering Test: OMD deployment of technology on platform	OMD team configures technology for use on requested platform, with assistance from HI_MTRC project engineer, as needed
Engineering Test: OMD characterization of technology	OMD coordinates operation of technology in engineering field with assistance from HI_MTRC members, as needed
Technical Demonstration: HI_MTRC reconfiguration of field	HI_MTRC team rearranges calibration field into new configuration at the discretion of range director
Technical Demonstration: HI_MTRC characterization of field	HI_MTRC team generates a "ground truth" map of technical demonstration field
Technical Demonstration: OMD characterizes field	OMD coordinates operation of technology in demonstration field, with assistance from HI_MTRC members, as needed

Phase 4: Breakdown of operation – Recovery of equipment in field and transition into transportable state.

Table C.7. Checklist of actions to be taken during Phase 4 – Recovery of equipment/preparation for transport.

Action	Description
Recovery of OMD equipment	Remove OMD system from host platform and disassemble for desalination
Recovery of HI_MTRC deployed objects	Remove deployed inert objects from field and desalinate
Convert OMD equipment into storage configuration	OMD team coordinates any disassembly of equipment for storage at HIMB
Return HI_MTRC equipment to storage	HI_MTRC teams returns range equipment to storage

Phase 5: Transit off range – Get necessary equipment off Moku o Lo‘e.

Table C.8. Checklist of Actions to Be Taken During Phase 5 –Transport Equipment Back to O‘ahu.

Action	Description
Retrieve OMD items	Transport OMD equipment from HIMB storage area to boat access point
Transport OMD items to main island	Transport OMD items to HIMB shuttle dock or He‘eia Boat Harbor
Debrief	Debrief

Travel and Lodging

The island of O‘ahu in Hawai‘i is a convenient location for this project. Daniel K. Inouye International Airport ranks second in the category of airports handling between 20,000 and 50,000 flights annually and offers numerous daily flights to commute from the US mainland. A variety of accommodations are available, particularly in Waikiki. Additionally, small rooms are available for rent on Moku o Lo‘e on a first-come, first-served basis for personnel who prefer to not commute to the test location daily.

Shipping and Storage

Several shipping companies certified to handle sensitive equipment and hazardous materials are available on O‘ahu, including Fedex, DHL, Pasha Hawai‘i, and the United Parcel Service. Temporary equipment storage between delivery on O‘ahu and transport to the test site is available at the UH Marine Center, located at Pier 35, Honolulu Harbor, and the ARL at UH offices at Mānoa Innovation Center, 2800 Woodlawn Drive. Moku o Lo‘e is closed to the public and has 24-hour security provided by HIMB. The 29-acre Moku o Lo‘e has numerous storage areas scattered across the island.

HI_MTRC Asset Preparation

ARL at UH purchased eight inert MEC seeds, half of which will be left to soak in the waters around Moku o Lo‘e to bio-foul the surface of the seeds, while the others will be kept in a condition that is closer to original manufacture. ARL at UH developed a partnership with the Marine Corps Base Hawai‘i (MCBH), which resulted in an offer to use their stockpile of inert munitions casings for short-duration (<30 day) underwater experiments. Figure C.2 shows some of the MCBH seeds that can be available for use.

Figure C.2. Example Inert Munitions Available at MCBH for Field Experimentation at HI_MTRC.

Inert Products, LLC manufactures and sells realistic, inert ordnance aids to train DoD personnel and first responders to recognize and potentially mitigate explosive threats. For this project ARL at UH purchased two each of 105 mm projectiles, 155 mm projectiles, 60 mm mortar rounds and 81 mm mortar rounds (Figure C.3). One set of each projectile is kept in pristine condition, while the other is intended to be deployed for weeks to months around Moku o Loʻe to encourage biofouling by shallow-water tropical sea life.

Figure C.3. Inert Ordnance Aids Purchased for Use at HI_MTRC.

Safety and Security

HIMB has 24-hour site security, and an officer can be reached at 808-218-2014 (or after hours, Resident on duty 808-391-7158). All activities involving boat operations, swimmers and divers will be conducted following the HIMB Snorkeling and Breath-hold Diving Safety Guidelines and the HIMB Boating Safety Program Manual.

Swimmers assigned to placing seeds around the test site will only do so if sea conditions are calm (waves less than 3 feet and currents less than 0.5 kts). Each swimmer will wear mask, fins and snorkel, and will display a dive flag conforming to Hawaiʻi state regulations. Spotters will be positioned in boats and/or onshore near dive operations to alert any boating traffic of the presence of workers in the water.

Boats will be operated by authorized and qualified boat operators and will only be operated in safe weather conditions. Each boat will be equipped with the following: communication devices, personal floatation devices, signal flares, fire extinguishers, horn, anchor and line, oars/paddles, first aid kit, water bailing devices, dock lines, registration documents and chart/map of Kāneʻohe Bay.

In the event of a life-threatening emergency, 911 must be called, followed by calling HIMB security officer or the Resident on duty if after hours. The HIMB sponsor will arrange transportation to go to the Lilipuna pier, which is the designated meeting location for emergency services.

In the event of an injury on Moku o Loʻe, first aid kits are located in the lagoon pavilion, the lighthouse, in the lobby between the main office and the Pauley classrooms, and the marine safety office. Three automatic external defibrillator (AED) kits are located on the island: one outside the grad student residence, one in the New Pauley labs near the double glass doors in the middle of the building (between the Hagedorn lab and Core lab), and one in the lobby between the main office and the Pauley classrooms.

IDA Performance Requirements

ARL at UH personnel conferred with IDA scorers in March 2022 to discuss best practices for installing, monitoring, and recovering objects at a test site. Specific directives that ARL at UH will implement for OMD testing and demonstrations based on this discussion include:

- Use WGS84 for geolocation reference system.
- Use the Universal Transverse Mercator (UTM) coordinate system.
- Measure locations in northings and eastings (meters) to centimeter-level precision.
- Establish a reference point and survey its geolocation over multiple days prior to the event to assess GNSS data quality.
- Install objects using swimmers/divers for precision and to avoid coral damage.
- Deploy munitions targets at least 2xR distance apart, where R is the desired detection halo radius – typically 2-3 m.
- Randomize target locations.
- Deploy the calibration and blind grids at the same time.
- The approach developed by Pacific Northwest National Laboratory (PNNL), using floats to measure geolocation, should work well in the shallow boat harbor setting.
- Measure object geolocation for a few minutes right after deployment and right before recovery.

- Conduct engineering tests first, even months in advance of the demonstration.
- Collect environmental data for several days before and throughout the duration and recovery of the engineering tests and demonstration.
- Record qualitative assessments of all aspects of tests (e.g., logistics, onshore support, technological challenges, etc.)

Site Installation

Two operational areas will be delineated: approximately the right third of the boat channel for calibration/testing and the remaining two-thirds for the technical demonstration portion. This will allow these activities to be performed as two separate events (Figure C.4).

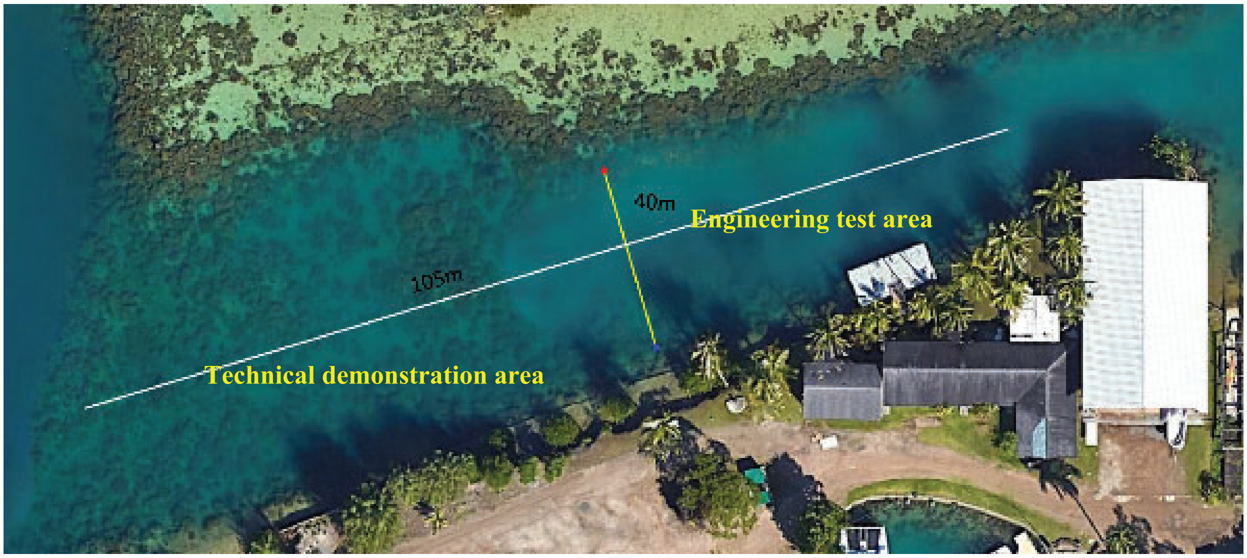
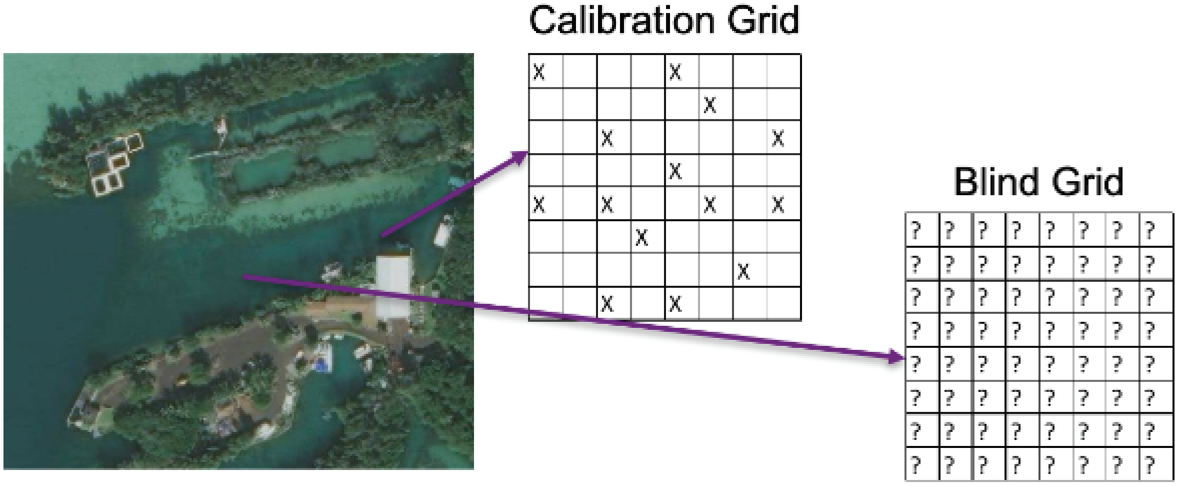


Figure C.4. Satellite Image of the Small Boat Harbor for the OMD Operational Areas.

The test site will be seeded manually by swimmers due to the shallow environment and the presence of live coral in the boat channel. Approximately twelve seeds will be deployed in the engineering test (calibration) area and up to twice that number in the technical demonstration (blind test) grid (Figure C.5). All items will be deployed on the seabed surface (proud) as the OMD cannot detect buried objects.



Calibration Grid

X				X			
					X		
		X					X
				X			
X		X			X		X
			X				
						X	
		X		X			

Blind Grid

?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?
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?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?
?	?	?	?	?	?	?	?

Figure C.5. Grid Images

The geolocation accuracy of the seeds will be assessed using RTK GNSS floats during the deployment and recovery efforts at the completion of the calibration/blind test using an approach pioneered by PNNL. RTK GNSS sensors are incorporated into waterproof containers and mounted inside floats (Figure C.6a) tethered to weights placed adjacent to the object on the seabed (Figure C.6b) by a swimmer (Figure C.6c). A cam cleat mounted underneath each float allows the line attaching the float to the weight to be quickly tightened to reduce horizontal movement of the RTK GNSS sensors (Figure C.6d) while acquiring geolocation data. During testing in the small boat harbor, this method enabled ARL at UH to confirm the location of the seeds to within a 1 m radius over a period of many hours.

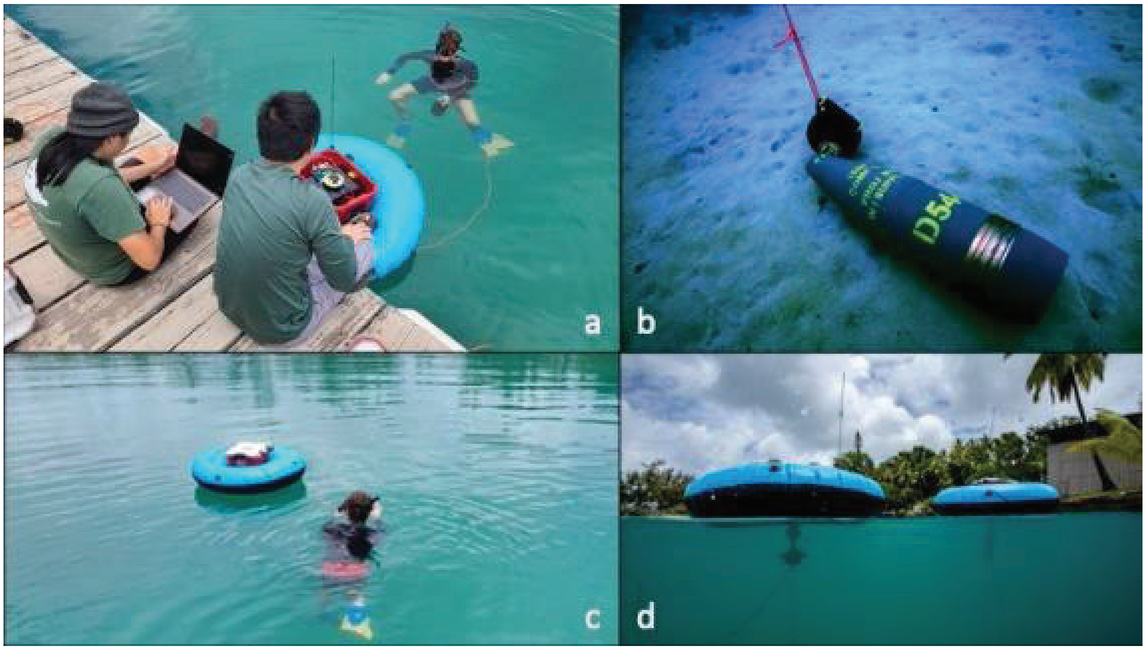

Figure C.6. Acquiring Geolocations Using RTK GNSS Sensors.

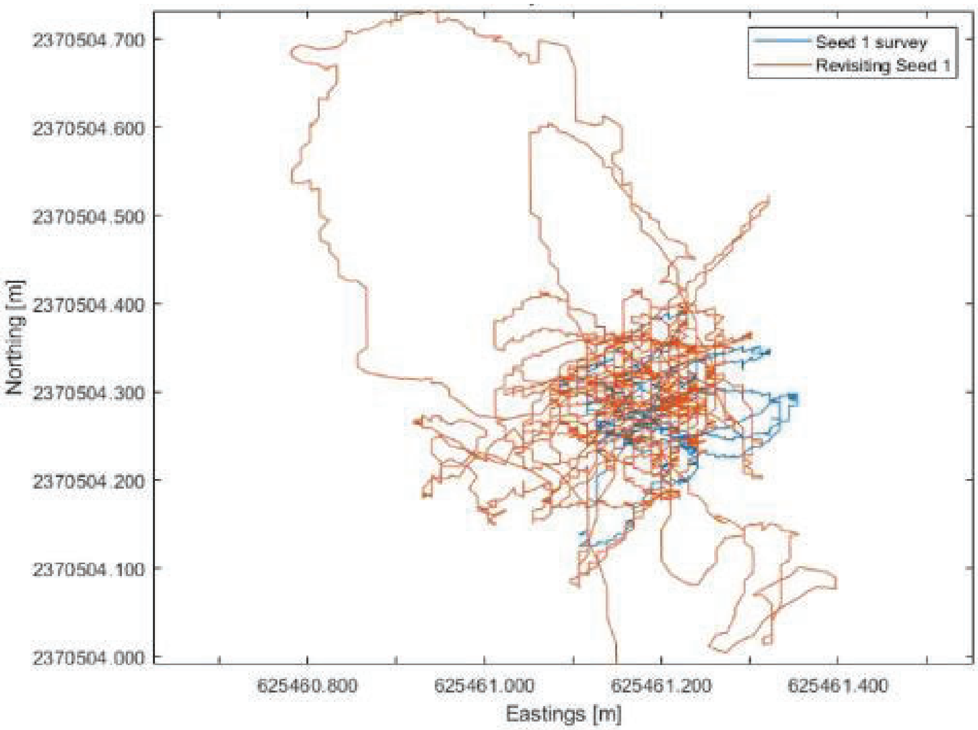

Figure C.7. Survey Data of Seed Location.

A SSS will be used to characterize the site before, during and after the exercise to provide additional information on the seafloor topography and position of the seeds.

Additionally, underwater video will be recorded during all phases of the field event to document the surroundings of each seed and to ensure recovery of all items at the end of the event.

Environmental Monitoring

Moku o Loʻe was chosen because its mild conditions allow field operations to be conducted on a frequent and reliable basis. The environments present are estuarine, lagoon and nearshore coastal with sediment types including mud, patch reef, pavement, and sand, producing low-moderate turbidity conditions. On an average day, conditions at the site are very low energy because of protections afforded by Kāneʻohe Bay and Moku o Loʻe. On the Douglas sea scale, the state of the sea is usually no higher than 2. The predominant trade winds blow from the northeast at speeds that typically do not exceed 20 kts. Water depths within the site are <15m.

Pre-Deployment Monitoring

Prior to deployment of equipment and crew, environmental site conditions will be monitored and collected by the HI_MTRC team. Recorded parameters and frequency are indicated in Table C.9.

In-Deployment Monitoring

The HI_MTRC team will monitor environmental conditions throughout the deployment phase in case conditions change significantly and become unsafe, triggering a stop-work situation.

Post-Deployment Monitoring

The HI_MTRC team will continue to monitor environmental conditions throughout the post-deployment and seed recovery phase in case conditions change significantly and become unsafe, triggering a stop-work situation.

Table C.9. Environmental Parameters

Parameter	Sampling Frequency	Collection Method	Data / Sensor Owner
Bathymetry	N/A	ASTRALiTe Bathymetric LIDAR	ARL at UH
	Upon Request	Bathymetric Sonar	ARL at UH
	N/A	Bathymetric Sonar	NOAA
	N/A	Collated Historical Bathymetry Datasets	HMRG
Backscatter	Upon Request	Tritech Starfish 990F	ARL at UH
	N/A	Collated Historical Bathymetry Datasets	HMRG
LIDAR	N/A	Airborne LIDAR	State of Hawaii
Sediment	Upon Request	Diver Sampling (penetrometer)	ARL at UH
	N/A	Historical data set	USGS
Bottom Type	N/A	Historical data set	State of Hawaii
Water Temp	Upon Request	CTD & Aqualink Buoy	ARL at UH
	6 min	Thermometer @ 1 m below MLLW	NOAA
Tides	6 min	Acoustic Water Level Sensor	NOAA
Salinity	Upon Request	CTD	ARL at UH
	3 hr	Buoy	UH
	1 hr	PacIOOS ROMS model	PacIOOS
Waves	Upon Request	Aqualink Buoy	ARL at UH
	10 min	Waverider Buoy	NOAA
Wind	Upon Request	Aqualink Buoy	ARL at UH
	6 min	Anemometer @ 10 m ASL	NOAA
Air Temp	6 min	Thermometer @ 3 m ASL	NOAA
Barometric Pressure	6 min	N/A	NOAA
Total Rainfall	1 hr	N/A	HIMB
PAR Flux Density and Radiation	1 hr	Eppley 295-385 nm ultraviolet (UV) radiometer LiCor 200SZ Pyranometer LiCor Quantameter (400-700 nanometer [nm])	HIMB
Sound speed	NA	NA	NA
Turbidity	NA	monochrome LED light (780-900 nm). detection angle 90 ±2.5°. FNU	USGS
Humidity	1 min	NA	NWS
Currents	NA	PacIOOS ROMS model	UH

Environmental Monitoring

Moku o Lo‘e can only be reached via watercraft. There is a shuttle boat that operates continuously weekdays, from 6:15 am to 5:30 pm. For large equipment transportation, the Honu Kai offers open deck space while the Ka Noelo Kai can simultaneously transport up to 48 passengers and several pallets of equipment.

The HIMB fleet includes smaller Boston Whaler vessels that are available to support field operations. Shore-side facilities with various equipment for repair and maintenance of boats is available at HIMB. All vessels are equipped with safety kits (first aid, flares, fire extinguishers, etc.).

The OMD equipment has previously been operated in the configuration depicted in Figure C-8. ARL and Creare personnel also discussed the potential of installing the OMD on uncrewed surface vehicles (UxVs) owned and operated by ARL at UH, but this integration may involve a significant amount of engineering. If desired, ARL at UH can provide support with UxVs, but the expectation is this would increase the cost and duration of the effort.

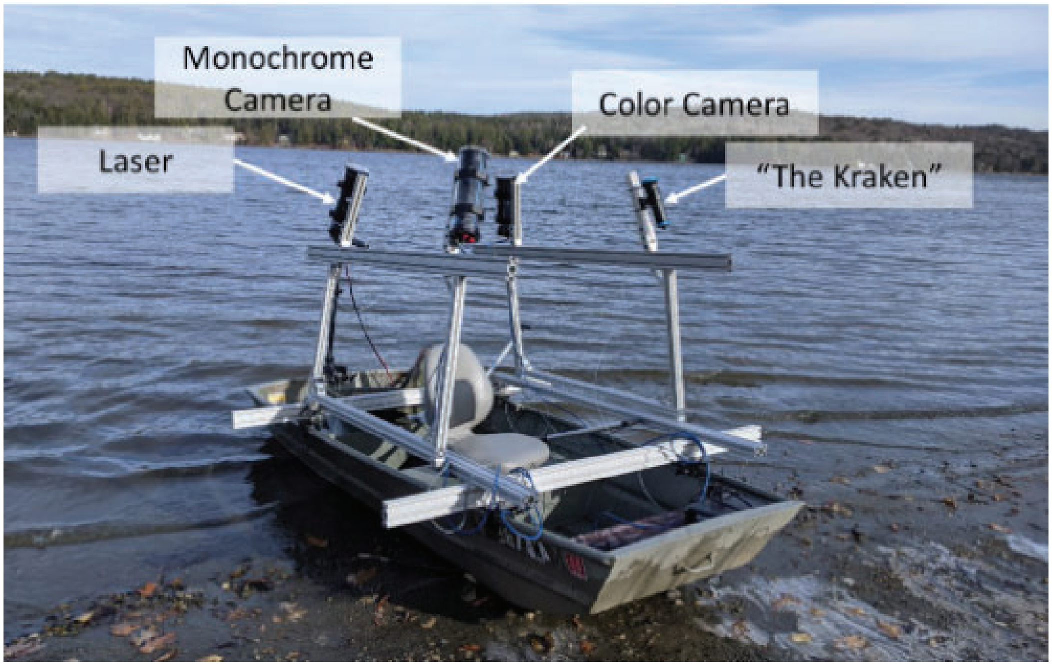

Figure C.8. Example of Vessel that Can Be Used to Mount and Transport the OMD.

HIMB offers wireless internet connection and 110- and 220-volts power. HI_MTRC will ensure that internet and Wi-Fi access are available to OMD team members for the duration of the demonstration. Data storage and transfer will be accomplished via secure internet transfer.

C.4. Post-Demonstration Performance Analysis

Overview

The ARL at UH will provide information to support the IDA in the OMD performance assessment. Information provided by ARL at UH to IDA will include environmental conditions, geolocation data for seeds and anecdotal information describing difficulties and successes during the test.

Test Bed Deployment

Conditions that are being monitored and may be unfavorable to deployment of the test bed are listed in Table C-10. Any condition exceeding the threshold triggers a stop-work situation.

Table C.10. Thresholds for Environmental Parameters

Parameter	Frequency	Threshold
Waves	10-minute frequency from NOAA or upon request from the ARL at UH	Less than 0.5 m
Wind	6-minute frequency from NOAA or upon request from the ARL at UH	Less than 20 knots
Rain	Conditions will be observed visually, as it occurs	Heavy rain and/or visibility deemed insufficient for safe operations
Lightning	Conditions will be observed visually and upon hearing thunder	Operations to be suspended until 30 minutes after the last strike

Site characterization will be documented and mapped using a high-resolution SSS that will provide information about the bottom texture at sub-meter resolution throughout the test site.

Underwater video equipment mounted on an uncrewed vehicle will be used to document the initial conditions of the reef and seafloor.

Demonstration

The demonstration will take place if the wave height is less than 0.5 m, the wind speed less than 20 kts, no heavy rain is present, visibility is deemed sufficient for safe operations, and no lightning is detected.

The geolocation of all seeds deployed at the test site will be recorded using RTK GNSS set up in continuous recording mode at a frequency of one hertz.

Following deployment of the seeds, a SSS survey of the site will be performed.

Underwater video will be recorded to document the surrounding and orientation of each surrogate as it is deployed in the grid.

Test Bed Recovery

The deployed seeds will be recovered if the wave height is less than 0.5 m, the wind speed less than 20 kts, no heavy rain is present and visibility is greater than 10 m, and no lightning is detected. This effort is anticipated to take less than one day to complete.

Since water currents displace the seeds, the geolocation of all seeds deployed at the test site will be recorded at the end of the test using RTK GNSS to determine if seeds moved between the deployment and completion of the test. A comparison of the initial and final RTK GNSS data will be available to assess any displacement.

Underwater video will be recorded at the end of the exercise to document that all seeds have been recovered.

Data Transfer

The HI_MTRC team will provide environmental data collected for a to-be-determined period before the engineering tests and demonstration, and throughout the duration of the engineering tests and testing demonstration periods to the IDA team. The geolocation data will be transmitted to the IDA team and the OMD principals. Project notes that may include logistics such as site access and transport/storage of equipment along with daily field notes will also be shared with IDA. Additionally, upon request, data analysis and an independent assessment of the project from HI_MTRC's perspective can be provided.

Data includes SSS mosaics, spreadsheets of GNSS locations for test item deployment and seabed locations, and global information system (GIS) shapefiles of test grid, drop locations, sonar target locations, and sonar mosaics.

The HI_MTRC is equipped to transfer data via remote access using fast, encrypted and DoD-approved protocols.