Final Project Report
Manager Climate Corps
Pacific Islands Climate Adaptation Science Center

Project Title: Developing geospatial models in Hawaiian watersheds to mitigate erosion and climate change
Graduate Student: James Bartlett Melcher IV
Faculty Advisor: Rebecca Ostertag (UH Hilo, Biology)
Committee Members: Ryan Perroy (UH Hilo, Geography), Natalie Kurashima (Kamehameha Schools), Jené Michaud (UH Hilo, Geology)
Lead Institution: University of Hawaiʻi at Hilo
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Total Cost: $53,149.90

Project Summary
Soil erosion causes a cascading series of environmental problems, and in coastal settings the impacts are also felt in near-shore reef ecosystems through sedimentation and excess nutrient introductions (Figure 1). Managing landscapes to minimize and halt erosion is challenging, particularly in the face of changing climatic conditions and legacy effects from past land management decisions. In this project we generated high resolution geospatial datasets for two Hawaiian dryland landscapes currently subject to severe erosion, Keawanui on the island of Molokaʻi and Kailapa on Hawaiʻi Island (Figure 2). These watersheds were identified as priority locations of interest by our land manager partners, Kamehameha Schools (K.S.) on Molokaʻi, and the Kailapa Community Association and Department of Hawaiian Home Lands (DHHL) on Hawaiʻi.

High-resolution digital elevation models (DEMs) and orthomosaics of the study sites, derived from data collected using small unmanned aerial systems (sUAS) and a terrestrial light detection and ranging (lidar) laser scanner, will be used to identify erosion “hotspot” areas and better understand the movement of sediment across the landscape. These new data sets will also be used to produce habitat suitability and hydrology models. These models will be used to locate favorable habitat for the reestablishment of native vegetation cover by highlighting microtopographic features that are more likely to foster plant growth and provide resilience to drought (Questad et al. 2015) and to help locate areas best suited for the implementation of anti-erosion measures (Castillo et al. 2007).

Figure 1. The erosion of hillslope sediments into coastal waters. (Moloka'i photo credit Kimo Melcher, Hawai'i photo credit http://www.southkohalacoastalpartnership.com/projects.html)

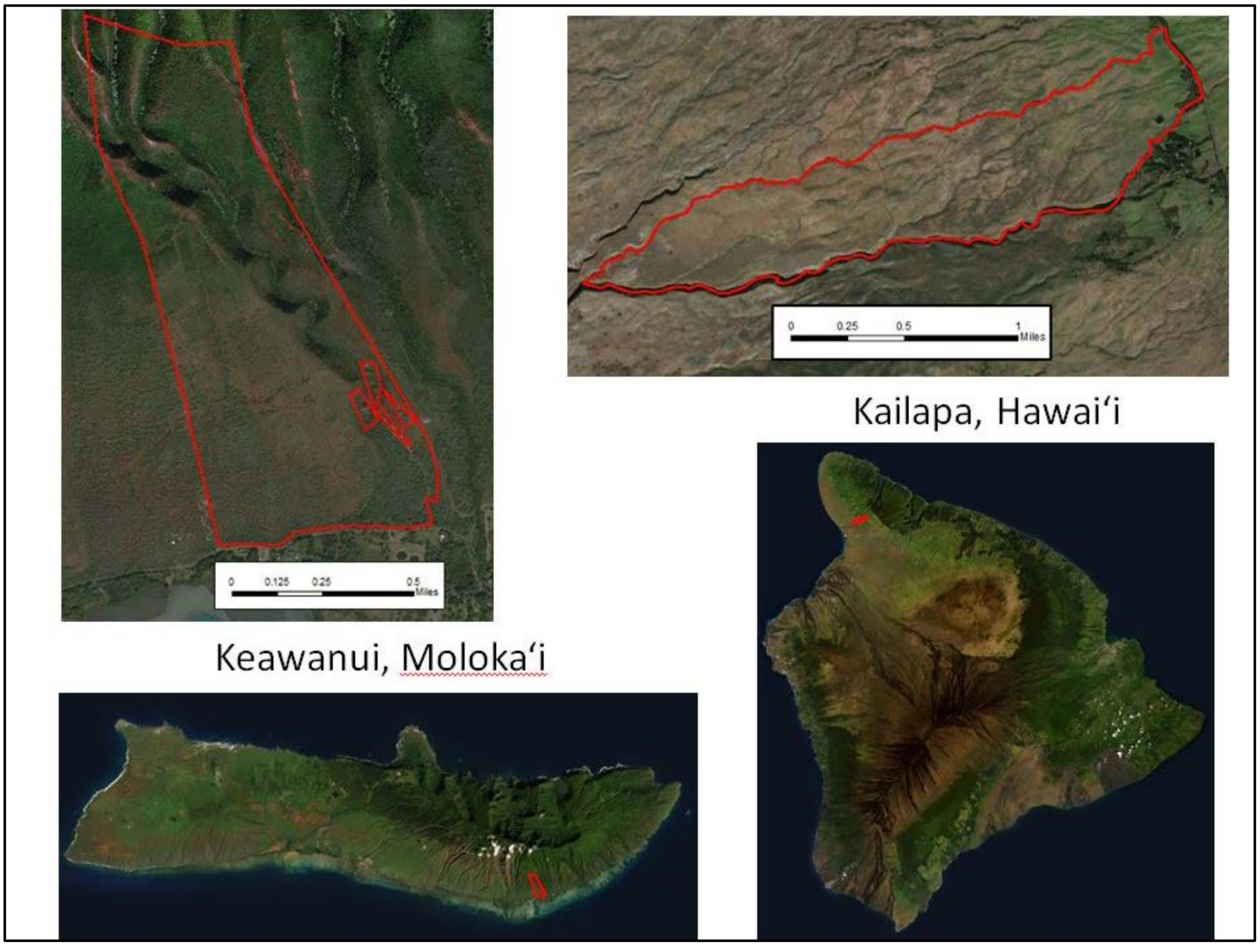

Figure 2. Two leeward semi-arid landscapes were chosen with land managers who were eager to address issues of flooding and soil erosion. Both sites are being managed and actively grazed with one of them on Molokaʻi (K.S.) and the other on Hawaiʻi island (DHHL).

Technical Summary

The impacts of anthropogenic land use change have increased the natural rate of soil erosion far beyond anything previously observed (Wilkinson and McElroy 2006). Remedying the situation will require an intentional and concentrated effort. This project generated orthomosaics and topographical maps for two actively managed watersheds to benefit ongoing and future conservation efforts. Beyond identifying erosion "hot spot" areas and creating habitat suitability and hydrology models, these data can also be used to calculate vegetation cover, identify invasive species, and determine topographic features of interest (Jenson and Domingue, 1988).

The technical aspects of this project are broken down into five steps: selecting and marking the ground control points (GCPs), gathering survey-grade coordinates of the GCPs, collecting aerial imagery and lidar data, producing orthomosaics and DEMs, and then developing and analyzing models to focus restoration efforts using these data as inputs. Each aspect is collected in a multi-step process as outlined below.

GCPs are identifiable man-made or natural features used as tie-points to constrain and position derived maps and models and give them accurate real world coordinates. GCPs allow the user to make defensible and reliable distance and volumetric measurements from the final geospatial layers, and can be used to confidently compare different datasets collected over time. Installing GCPs consisted of securing permissions from landowners, traversing the site to locate large immovable objects within the landscape that had flat unobscured surfaces, and painting markers big enough to be seen and identified in aerial images (Figure 3A).

The survey-grade geographic coordinates measured for this project were collected using a pair of Trimble R10 Integrated Global Navigation Satellite System differential GPS units (Figure 3B). Coordinates were collected by stationing one of the units over a base point where it continuously operated while another mobile roving unit was used to gather positional data of GCPs (Stombaugh et al. 2005). The rover unit was placed over each GCP and activated for thirty minutes, allowing sufficient data to be collected to give precise (< 5 cm positional error) coordinates. GPS data were post-processed using Trimble Business Center software.

Aerial imagery was taken using a DJI Matrice 200 and DJI Inspire 2, equipped with a DJI Zenmuse X5S camera (Figure 4). The sUAS was flown at a height of 80m for the majority of the site, 100m over steep gulches where elevation data might be less accurate in order to prevent a potential drone crash. Individual photographs taken with the X5S camera at these altitudes cover an area of ~50m by 70m which give each pixel a resolution of ~2cm. Flight plans were made on an Apple iPad using the Maps Made Easy application, where altitude and camera information was used to calculate the positioning and timing of photos (Figure 5). Once all of the photos and GCP information for a site has been gathered in the field we then begin the process of generating orthomosaics and DEMs using Pix4Dmapper (Figure 6).

Figure 3. Over the course of the summer, interns Andrade and Haase were instructed on the assembly procedures for the Trimble R10 and the Trimble SX10. **A** GCPs were marked on easily visible flat surfaces. **B** Andrade attaches the R10 receiver onto a tripod assembly. **C** Haase levels a Trimble R10 360 prism to position SX10 Lidar unit. **D** Andrade arranges the Trimble SX10.

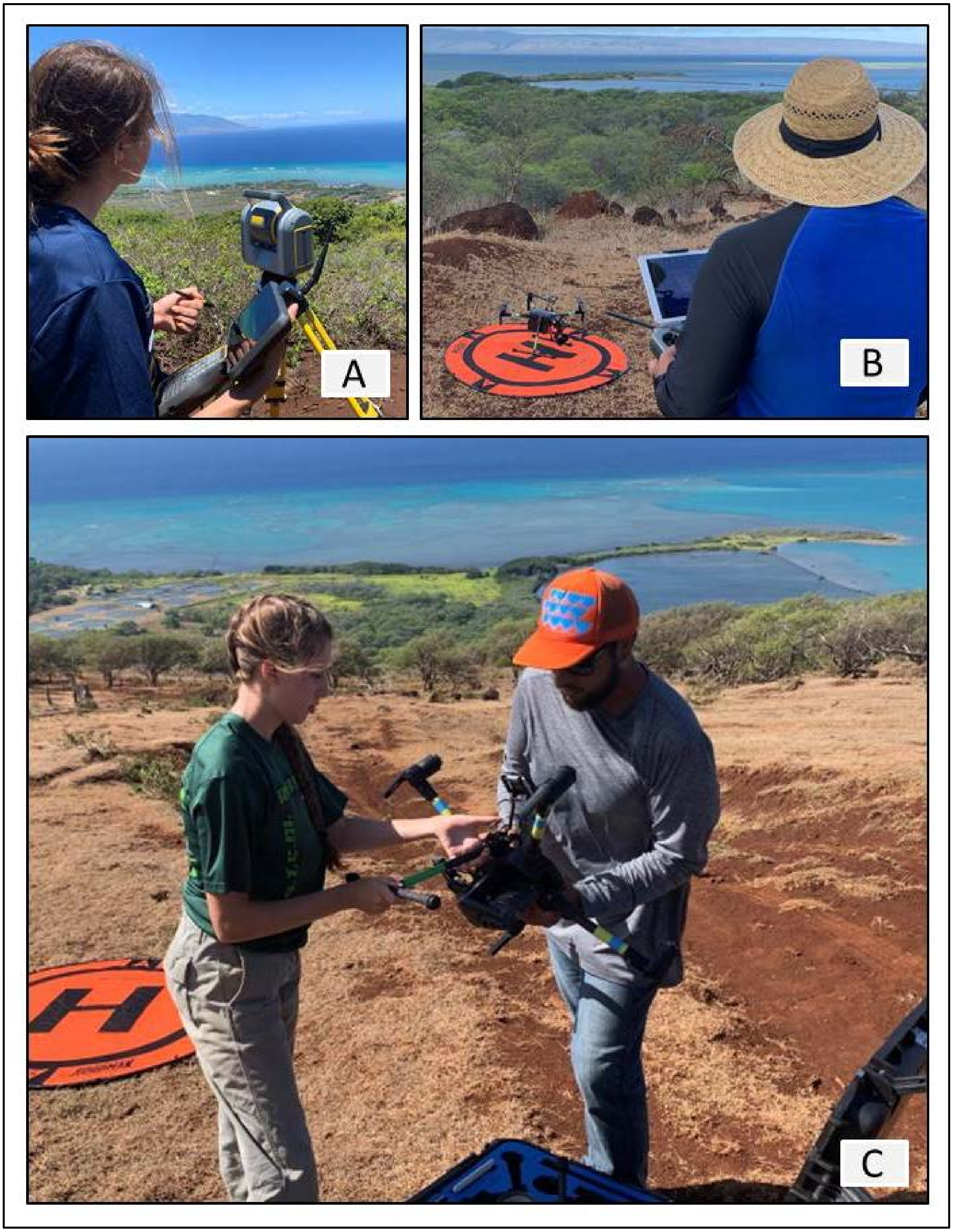

Figure 4. The interns were also instructed on proper procedures to assemble the Matrice 200 and how to operate it and the Trimble SX10. **A** Haase uses the Trimble SX10 data controller to position the SX10 for scans. **B** Melcher goes through a pre-flight checklist. **C** Andrade and Haase prepare the sUAS for flight.

Figure 5. Maps made easy software after completing a programmed flight along the bottom of the Keawanui, Moloka'i project site. Drone location (red triangle), and each photo's location (grey circles) and a live camera feed. Photo by Kimo Melcher.

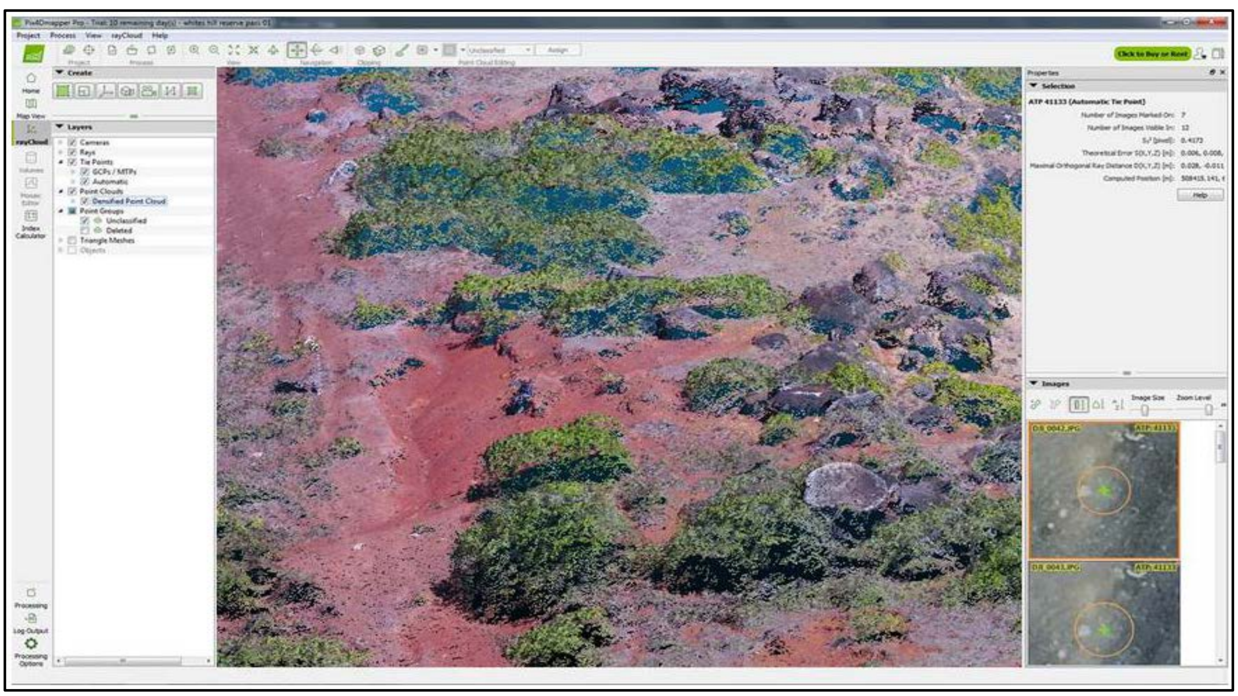

Figure 6. Pix4Dmapper locates common points between overlapping photos to create a 3D surface that can be georeferenced to its corrected for scale and global position with the inclusion of GCPs.

Goals and Objectives

The overall objective of this project is to provide insights and recommendations to guide the land use and management strategies (e.g., forest restoration, anti-erosion structure installation, etc.) in two Hawaiian dryland landscapes currently subject to severe erosion. These watersheds, like the rest of Hawaiʻi and the greater Pacific region, face an increasingly challenging and uncertain climate future that will require innovative and multi-disciplinary solutions.

Objective 1 -Generate high-resolution digital elevation models and orthomosaics for land managers to establish baselines for future restoration and research efforts.

Objective 2 -Build relationships with land managing partners and integrate these findings into their land use decisions. This will be done by providing current high resolution geospatial data to help managers better understand microtopographic features that foster plant growth, provide resilience to drought, as well as identify areas highly sensitive to compaction and runoff.

Objective 3 -Produce a land cover classification map and locate areas of active erosion

Existing imagery of the two study areas is too spatially coarse to clearly delineate areas of active erosion and identify vegetation communities at a level useful for land managers (Figure 7). Higher-resolution imagery and digital elevation models can provide definitive evidence to locate features of interest and provide a baseline for measuring change over time. These datasets can guide and inform land managers' decisions.

Objective 4 - Identify potential locations within a watershed that are best suited for outplanting efforts and that will best take advantage of erosion mitigation structures such as check dams, wattles, contour dams, etc (i.e., when placed will hold the most sediment).

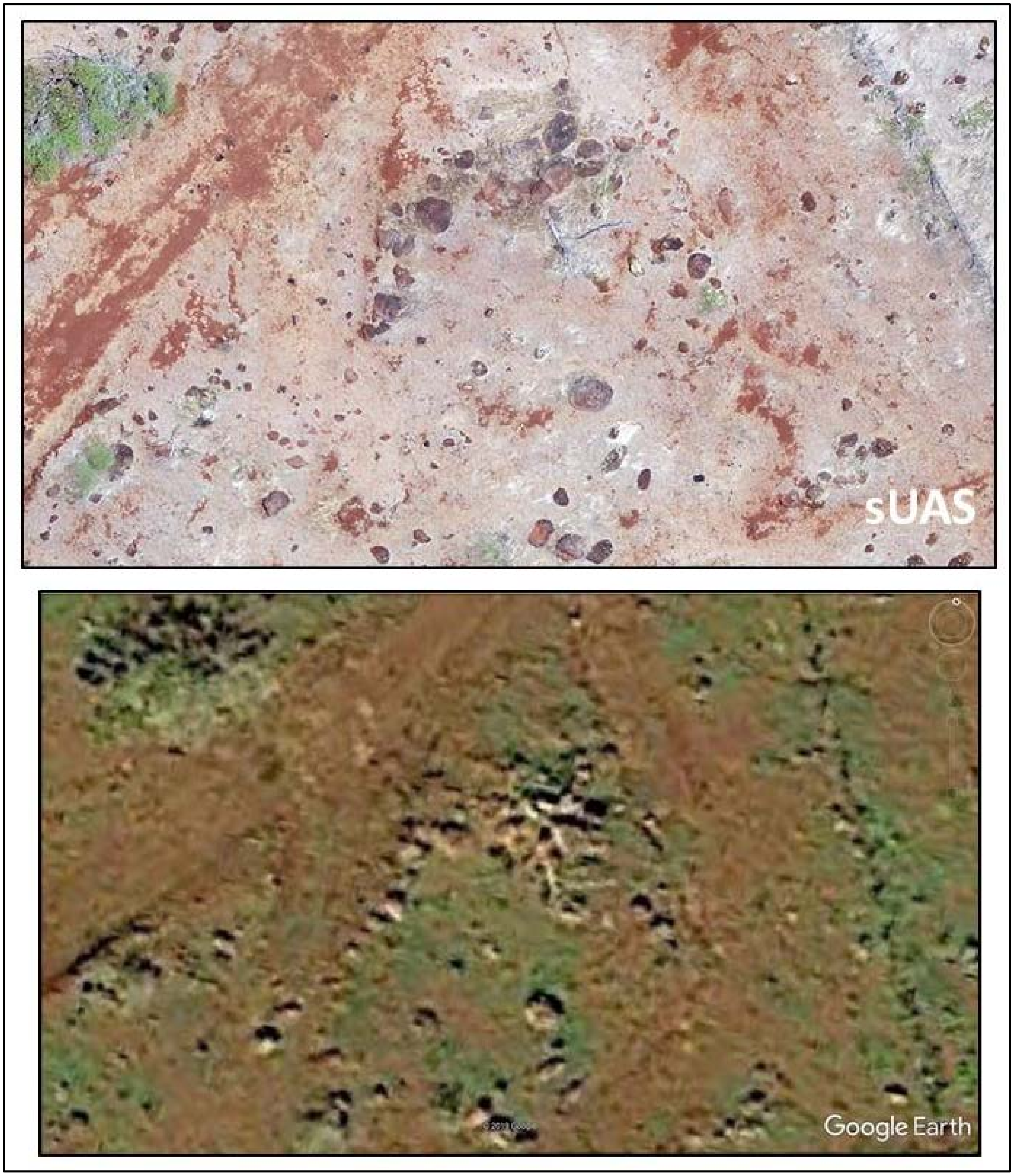

Figure 7. Comparison of 2-cm resolution sUAS imagery (top) with more readily available (but more coarse) satellite imagery (bottom). High-resolution imagery can be used to confidently measure changes in land cover and plant communities over time.

Collaborative Elements

Land Managers

This project involves two communities with separate needs on Molokaʻi and Hawaiʻi islands. The work on Molokaʻi began with a visit to the study site in Keawanui , where my advisors and Melcher met with the Molokaʻi K.S. Staff and Edmund "O'boy" Pedro the land manager (Figure 8). The Molokaʻi parcel is also home to a number of archaeology sites, and the erosion of soils may lead to degradation of these sites and the highway that runs along the downslope edge of the site. The PI-CASC funds allowed us to hire Kaiʻanui Andaya.as a PIPES intern and Evelyn Haase as a Molokaʻi High School Intern, and they provided much needed support for the Molokaʻi collections. The application process for the Molokaʻi intern was a process that began with the first of three visits to Emilio Macalalad's environmental science classes at Molokaʻi High School. The first presentation to Mr. Macalalad's environmental science class was our opportunity to recruit our Molokaʻi intern and share our ideas for the work that would be done. After joining Melcher and Andaya in the field for data collections at the Keawanui site, Evelyn presented what she learned to Mr. Macalalad's classes during our second visit. Finally, Melcher returned to Molokaʻi when all of the image processing was completed to share the maps and models and to give a full overview of the project and the work that had been done. Our goal for the presentations at Molokaʻi High School were to talk with students about erosion, an issue relevant to Molokaʻi residents, and then to share the work being done around the islands and on Molokaʻi to remediate the impacts of erosion.

Figure 8. Melcher with advisors and Molokaʻi Kamehameha School staff visiting the Keawanui site. (March 2019)

On Hawai‘i island, Melcher first met members of the Kailapa Community Association (KCA) while presenting the Spatial Data Analysis and Visualization (SDAV) lab’s analysis of the work completed in the adjacent Pelekane watershed with crew members of the Kohala Watershed Partnership Cody Dwight, Philip Keli‘iho‘omalu "Kukui" Garcia and others. While presenting to the KCA, Melcher met Diane Kaneali’i and Jordan Hollister of the Kailapa Community Association and Andrew Choy of the Department of Hawaiian Home Lands. As recipients of the Resilient Hawaiian Community award, the KCA was reaching out to experts in various fields for help in the rehabilitation of the area. After talking about the area’s needs and how the SDAV lab could contribute, it was decided that they would map the area that Michael Graves and Katherine Peck had been searching for archaeology sites. Michael and Katherine introduced them to the site and Andaya and Melcher were able to locate all of the GCPs that would be used in the study. There is still unfinished work that needs to happen to complete the work in Kailapa. Coordinates for the GCPs need to be taken and aerial imagery of the site needs to be gathered. The imagery will then need to be further processed into deliverables while Melcher continues to work with the community on steps forward.

Training

Using funds from the PI-CASC grant we were able to train a high school and college student in the data collection methods used in this project. During a trip to Moloka‘i in February of 2019, Melcher met with representatives from numerous schools to present an employment training opportunity for an interested Moloka‘i student. Evelyn Haase, a high school senior and student of Mr. Macalalad, was selected. PIPES intern Kai‘anui Andaya accompanied Melcher to Molokai for fieldwork. Haase joined them between June 3rd and 14th and helped by preparing the sUAS for flight and assisting with lidar data collections. Haase and Andrade were instructed on the proper steps of assembly and operation of the Trimble R10, Trimble SX10, and Matrice 200. When the 11 days on Molokai were over, both Haase and Andrade were well trained and fully capable of setting up all the equipment listed as well as using the handheld controllers to operate them. Prior to this trip GCPs had been placed and their coordinates gathered, so it was only later in the summer that Andrade was given the opportunity to see GCPO installation and surveying done first hand. Shortly after completing their internship positions, Haase and Andrade shared the skills they learned and the experiences they had in a presentation to their peers (Figure 17).

Manager deliverables

The deliverables currently available from this project are survey-grade differential GPS coordinates of ground control points, raw aerial imagery, point cloud datasets derived from sUAS flights and ground-based Lidar laser scans, and two of the main deliverables for the Molokaʻi project (high-resolution orthomosaics and digital elevation models). These first two major deliverables will be further developed into habitat suitability and hydrology models that will be an informative resource for the land managers helping to guide restoration decisions at our two sites. Imagery collection and data processing for the Kailapa site is scheduled for Spring 2020.

Creating maps and data layers that are correct to scale and georeferenced is a process which requires the establishment of GCPs. Part of our deliverables are a set of GCP coordinates for each site, along with photos, maps, and descriptions of where the GCPs can be found (Figure 9 and 10). This dataset will benefit any future mapping efforts by saving them the time and expense of establishing their own ground control.

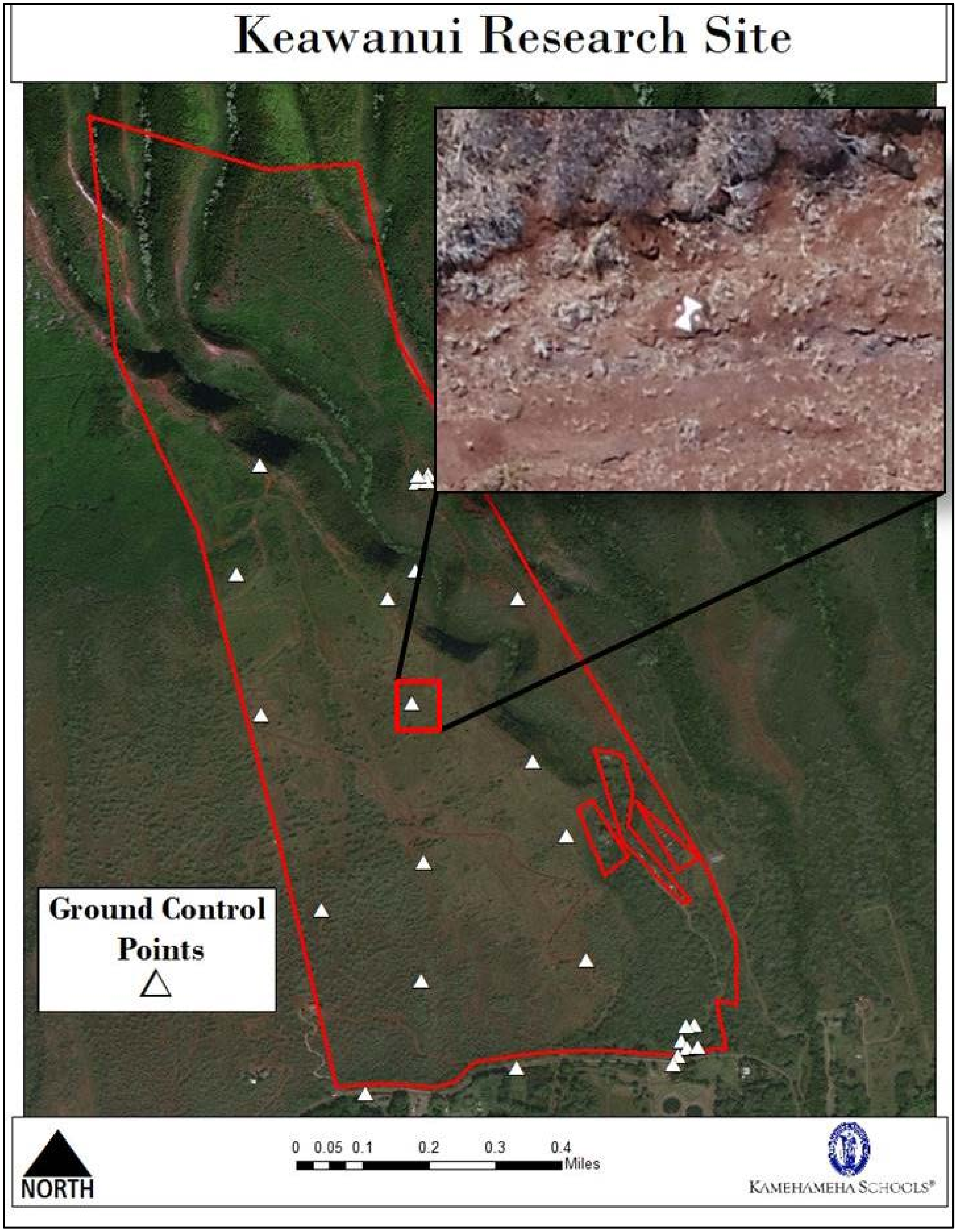

Figure 9. Ground control points were evenly distributed around the Keawanui site taking advantage of fixed features in the landscape. The inset picture shows a GCP as seen in the aerial imagery.

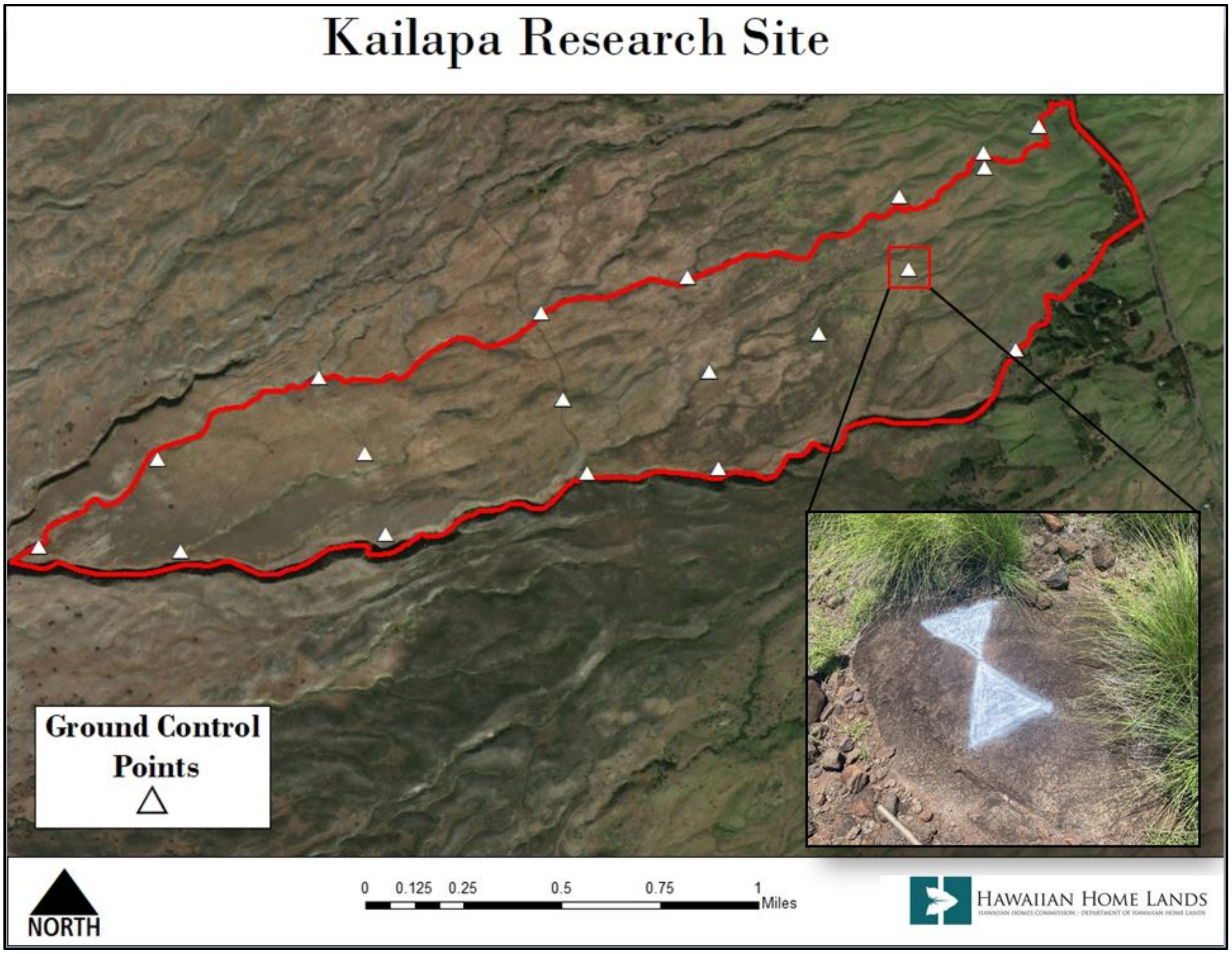

Figure 10. When properly georeferenced, the maps and models produced for this project will have minimal inaccuracies. This map shows the location of the GCPs in the Kailapa site with an inset image showing a close up of one.

High resolution aerial imagery was gathered using the Zenmuse X5S Gimbal Camera. Imagery taken with a sUAS is geotagged with the altitude and coordinates of the sUAS for where each image was taken (Figure 11). Additionally, the metadata for each photo includes the camera specifications, direction of travel, and a timestamp. Using this high resolution imagery and the metadata that accompanies it, land managers can make comparisons by looking at photos taken in future collections for changes in plant communities, land cover, or other relationships of interest.

A point cloud is a 3D representation of an object or surface derived from photos using structure from motion or laser sensors such as with the Trimble SX10. Using Pix4Dmapper, Trimble Business Center and/or CloudCompare, land managers will be able to take a virtual tour of their sites, an experience that can be shared with distant colleagues and other interested parties (Figures 6, 12, and 13). Subsequently when future efforts produce additional georeferenced point clouds, environmental changes can be viewed in a 3D environment.

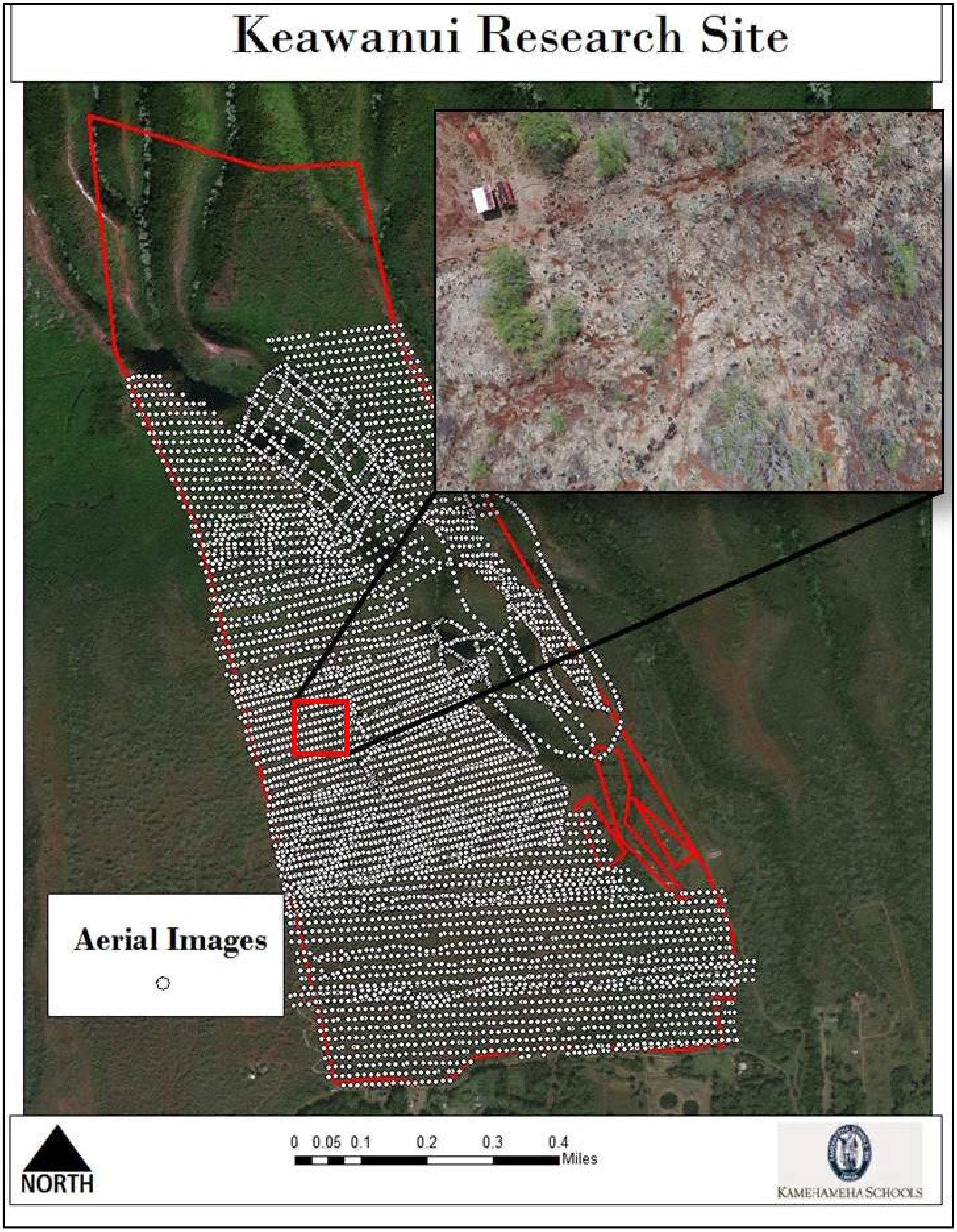

Figure 11. The Maps Made Easy software package uses information about the camera and your desired flight path to create a mission plan that includes the location where each picture will be taken. Included is an inset image showing the typical footprint of each photo.

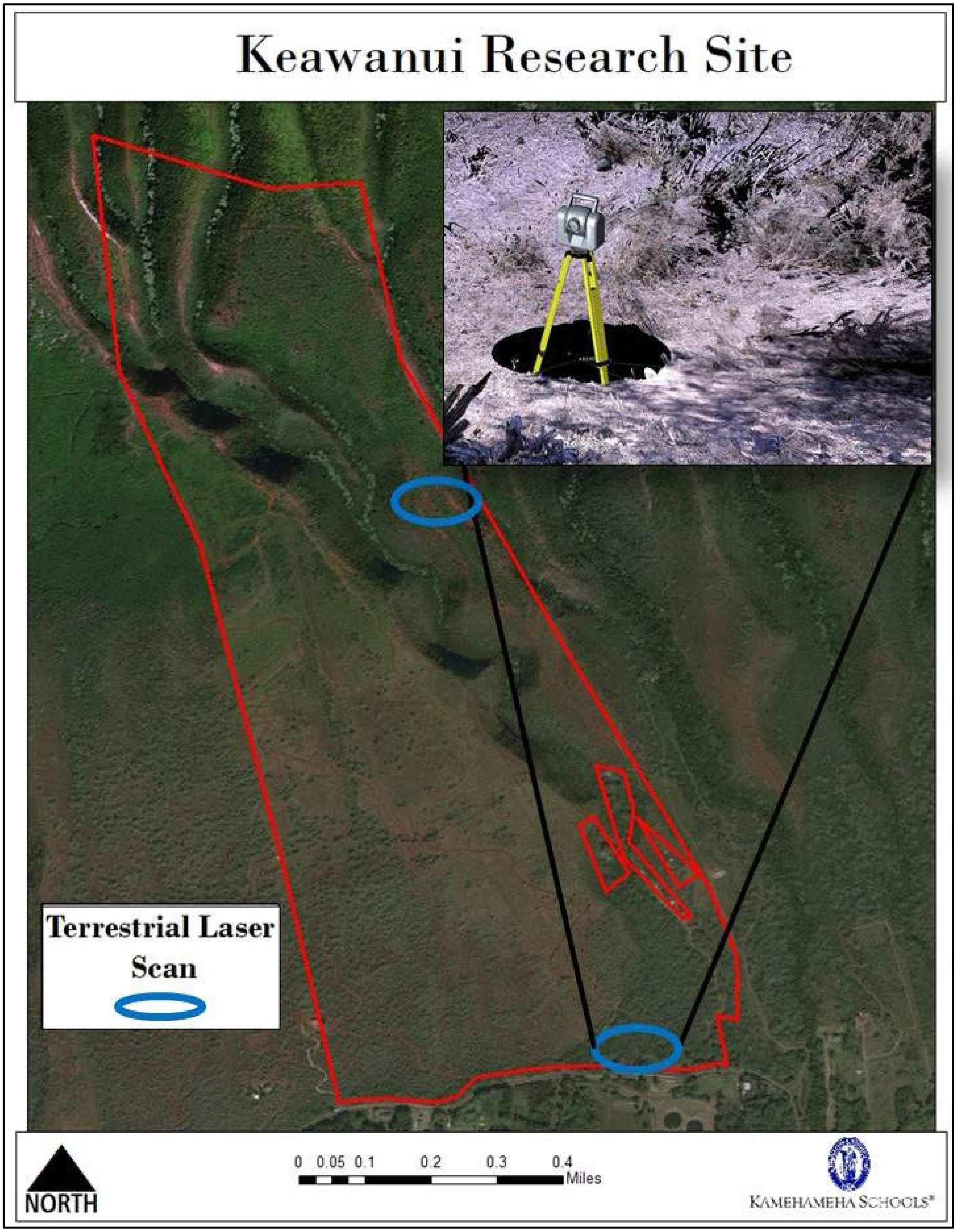

Figure 12. The Trimble SX10 was used to scan two important eroding locations on Molokai. The inset photo shows an example of the results from a single Lidar scan.

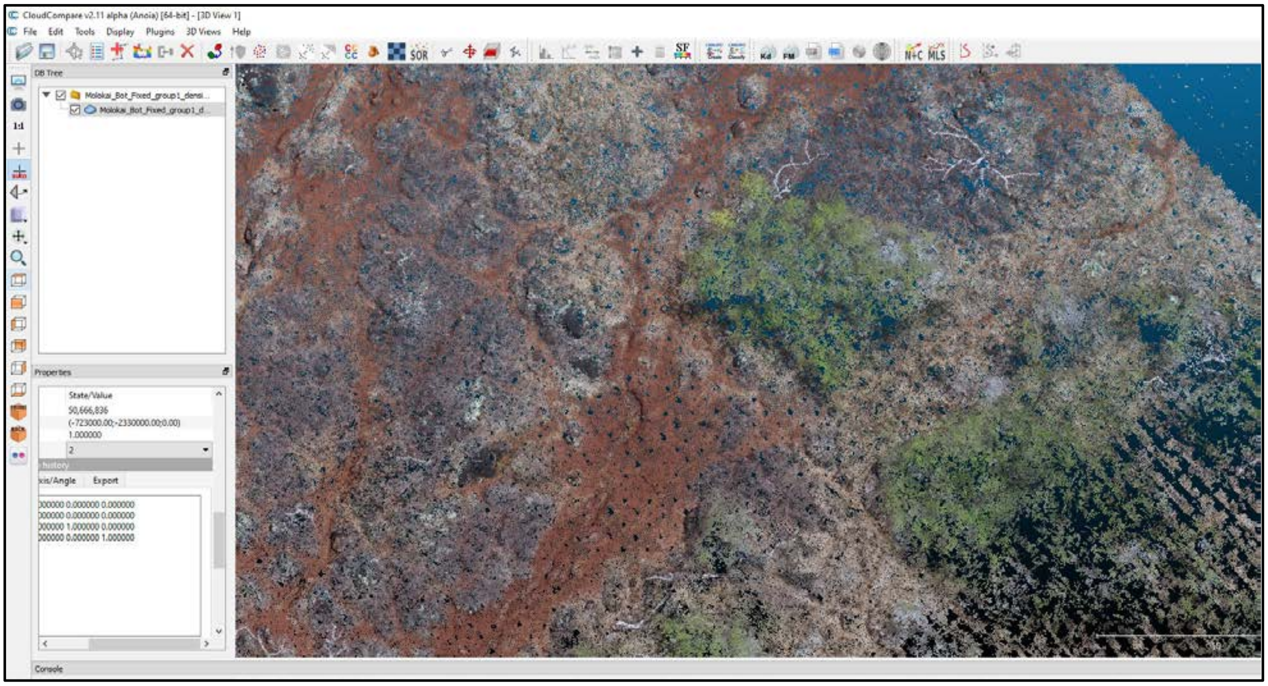

Figure 13. CloudCompare is a free software package that allows for the user to visually display and manipulate 3D point clouds. In this editing environment a point cloud can be cut and shaped and differences between various models compared.

The deliverables from this project are of higher spatial resolution than those freely distributed online, giving researchers and land managers the ability to ask questions which they could not have previously. The orthomosaics and DEMs (Figure 14, Figure 15),can be used to track the movement of water, soils, and vegetation over time, as well as in many other applications.

These datasets will be distributed in two phases, with deliverables for Molokai being shared with Kamehameha Schools and the Hawaii island data going to the Department of Hawaiian Home Lands and the Kailapa Community Association. The first phase will consist of the GPS coordinates, raw aerial imagery, point clouds, and digital elevation models and orthomosaics gathered over the course of the project. The second phase of deliverables consists of the habitat suitability and hydrology models that will be the major dataset used in Melcher’s MS thesis and will require additional processing time. These additional products should be ready for distribution by the end of spring 2020.

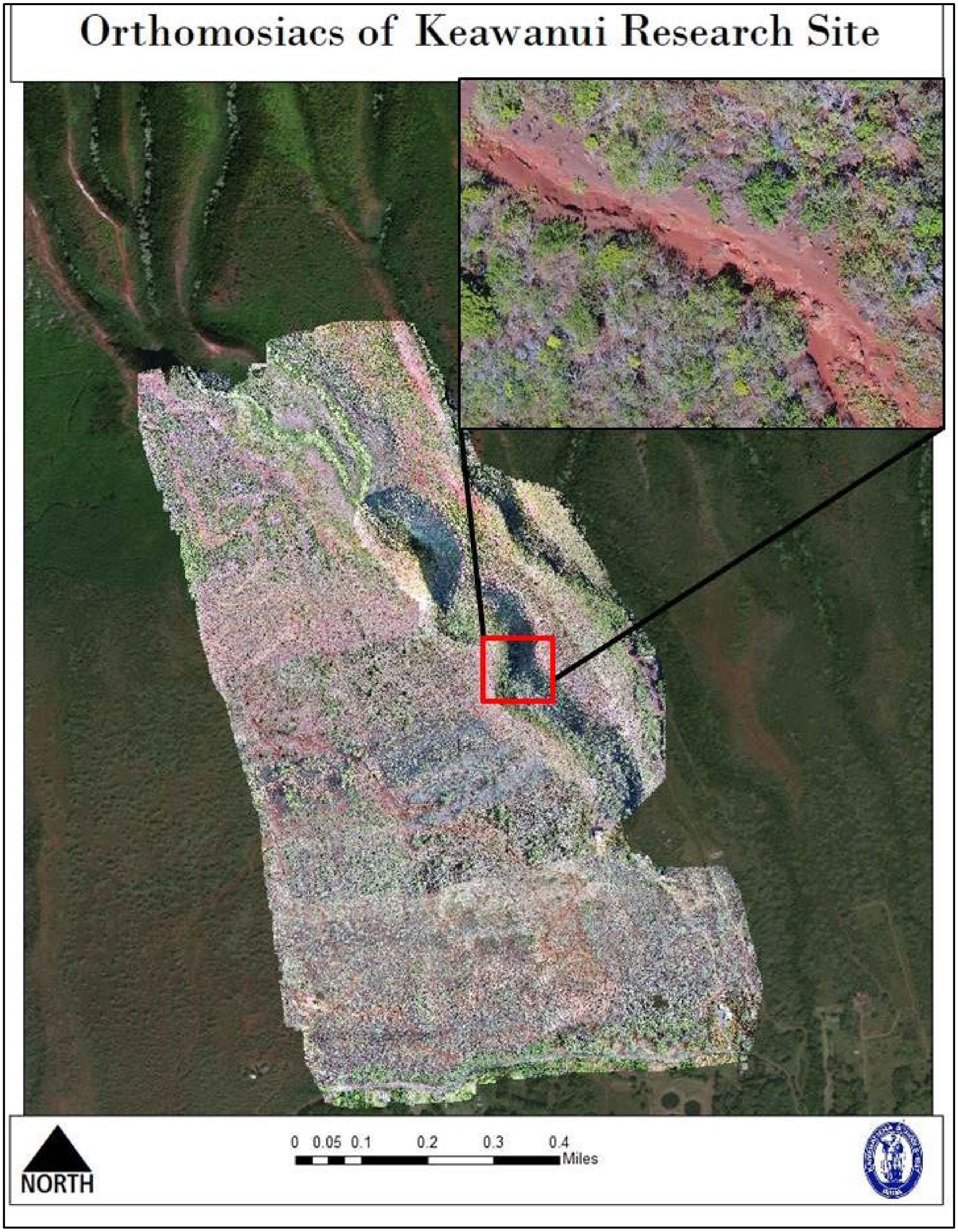

Figure 14. Pix4Dmapper stitches many photos together, such as the one that has been inset, to produce orthomosaics that cover vast expanses of land and have many applications.

Figure 15. Hillshade model derived from a DEM showing landscape feature details.

Overall Project Conclusions

The timeline for this project extends beyond the allotted time of the grant, so aspects of this project still need to be completed. Data collections on Molokaʻi took priority due to the travel and housing required by that site. The placement of GCPs and collection of their coordinates on Molokaʻi went as planned, but high winds caused issues when collecting aerial imagery. One day while in flight the onboard guidance system malfunctioned and the sUAS was lost. As a result of this experience, the SDAV lab now places additional third party tracking units onto every sUAS before each flight. Ground-based lidar was gathered on Molokaʻi with the Trimble SX10 at two different sites in Keawanui in areas that are visibly eroding. The first site we scanned was located where the waters from Keawanui gulch intersect with the Kamehameha V Highway. Sediment collects and fills the culvert until eventually the water is unable to pass through and the roadway becomes flooded. The second site we scanned on Molokai is along a ridge near the apex of the watershed and has suffered severe erosion. The scanning of these sites required the placement of closely placed GCPs that were then used to geographically position each individual SX10 scan and the point clouds it produces using the Trimble Business Center software package (Figure 12). The data collections on Molokaʻi have been completed and the imagery has been used to create DEMs and orthomosaics (Table 1). These are available now for distribution but further work is needed to create the models that will be used in Melcher's thesis research.

The data collections on Molokai were completed first in an effort to make best use of the available funds. Because Keawanui was prioritized the data collections at Kailapa are still incomplete. The work of finding and marking the ground control points in Kailapa has been done, but GPS coordinates for these need to be taken and aerial imagery needs to be collected (Table 1). Just as with Molokaʻi, once this GCP information and aerial photos are gathered they will be brought into Pix4D where they can be processed into DEMs and orthomosaics that will be shared with collaborators. The next steps for this project will be to analyze the DEMs and orthomosaics for both sites and to produce the desired models as described above.

Having completed a large portion of the data collection for the project there isn't much that I would change beyond finding a way to minimize the amount of travel. Travelling can sometimes be a stressful experience when transporting expensive equipment, and if perhaps we had stayed on Molokai for the full duration of the data collection this discomfort could have been avoided. But travelling so encumbered teaches its own lessons. Over the course of the project Melcher was put in charge of his first two subordinates, a new experience that in itself teaches many lessons.

Table 1. Progress on the PI-CASC and MS Thesis deliverables.

	Keawanui	Kailapa
GCP Placement	PI-CASC	TBC
GPS Coordinates	PI-CASC	TBC
Raw Imagery	PI-CASC	TBC
Lidar Scans	PI-CASC	TBC
Orthomosaics	PI-CASC	TBC
Digital Elevation Models	PI-CASC	TBC
Habitat Suitability Models	M.S.	M.S.
Hydrology Models	M.S.	M.S.

PI-CASC = Data for the PI-CASC Grant

M.S. = Data for Melcher's MS Thesis

TBC = To Be Completed for the PI-CASC Grant

Presentations

J. Melcher, Seeking Solutions for Erosion in Hawai‘i. Kamehameha Schools Moloka‘i Office, Kaunakakai, HI, (February 2019)

J. Melcher, How can we slow erosion? Moloka‘i High School, Ho’olehua, HI, (May 2019)

J. Melcher, E. Haase. Documenting Erosion on the South East Slopes of Moloka‘i, Moloka‘i High School, Ho’olehua, HI, (August 2019) (Figure 17)

K. Andaya, The Application of Geospatial Surveying Methods in the Ahupua‘a of Keawanui & Kailapa. 2019 PIPES Student Symposium, Hilo, HI (August 2019) (Figure 17)

J. Melcher, What can we do about erosion? Moloka‘i High School, Ho’olehua, HI, (November 2019)

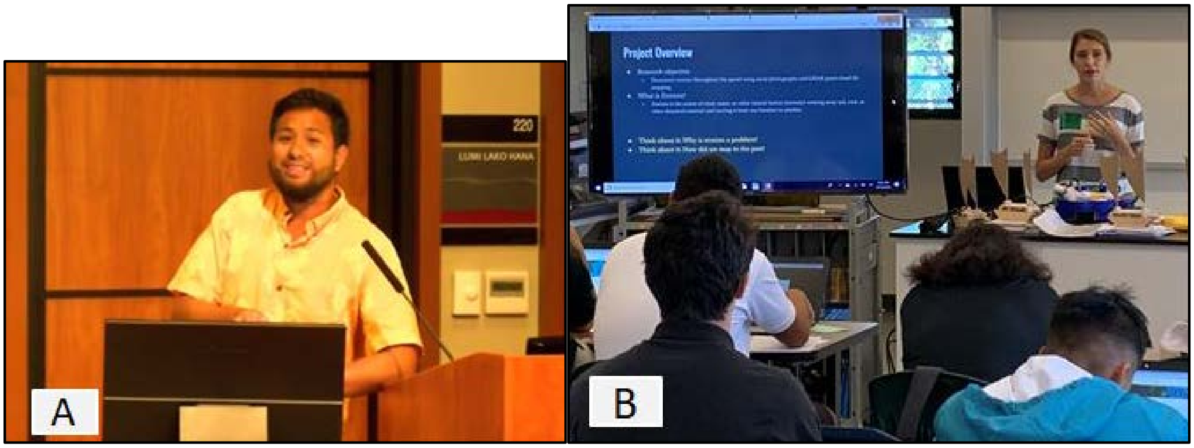

Figure 17. Both interns involved in the project had the opportunity to present their experiences. **A** Kaiʻanui Andrade presents at the 2019 PIPES Symposium (August 2019) (Photo provided by PIPES). **B** Evelyn Haase presents to her classmates at Molokaʻi High School. (August 2019) (Photo by Kimo Melcher)

Final list of collaborators

Ryan Perroy, Associate Professor, UH Hilo Geography and Environmental Studies
Rebecca Ostertag, Professor, UH Hilo Biology
Natalie Kurashima, Integrated Resources Manager, Kamehameha Schools
Jené Michaud, Professor, UH Hilo Geology
Jonathan Price, Professor, UH Hilo Geography and Environmental Studies
Kaiʻanui Andaya, Student, UH Hilo

<u>Kailapa, Hawaiʻi</u>

Cody Dwight, Kohala Watershed Partnership
Philip Keliʻihoʻomalu "Kukui" Garcia, Kohala Watershed Partnership
Diane “Maka’ala” Kaneali’i and Roger “Maha” Kaneali’i Jr, Kailapa Community Association
Jordan Hollister, Kailapa Community Association
Andrew Choy, Department of Hawaiian Home Lands
Michael Graves, Professor, University of New Mexico
Katherine Peck, Student, University of New Mexico

<u>Keawanui, Molokaʻi</u>

Sharon and Louis Perroy
Charlie-Tommy, Student, UH Hilo
Edmund “O’boy” Pedro, Molokaʻi Land Manager
Evelyn Haase, Student, Molokaʻi High School
Maka Cobb-Adams, Kamehameha Schools
Venus Rosete-Medeiros, Kamehameha Schools
Keith Chang, Kamehameha Schools
Jonathan Stenger, Kamehameha Schools
Kelley Dudoit, Staff, Molokaʻi Community College

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