

# Evaluating Video Imagery as a Method for Monitoring Nearshore Ecosystem Change

Malea Marie Saul

University of Washington  
School of Oceanography  
1503 NE Boat St.  
Seattle, WA 98195

[msaul@uw.edu](mailto:msaul@uw.edu)

## **Abstract**

Documentation, communication, and explanation of the impacts of climate change on the sensitive nearshore ecosystem rely on tools that provide transparency about the technology and accessibility to the data. When used as a scientific tool, video documentation provides spatially uninterrupted documentation which can be repeated over a variety of temporal scales. From the photographic data, quantitative measure of the physical presence and structural evidence of change may be derived. In this study, we present a video acquisition approach designed specifically for nearshore coastal environments. The approach provides images from dual field of view angles and includes 360° mosaics that are obtained from easily deployed stationary and mobile platforms. The aim of this research and development project is to develop an approach for providing physical change information for use in GIS-based change models. Along with the video acquisition system, we present the protocol for its use and results from preliminary tests focused on measuring the accuracy and precision of the system. Additionally, the results of a case study of a nearshore habitat are presented. Application of a video acquisition system in nearshore research allows scientists to use video data to monitor and collect documentation of ecosystem change over temporal and spatial scales and provides a communication tool for educators and outreach professionals.

## **Introduction**

In the Puget Sound, and worldwide, climate change will have a vast effect on the nearshore environment. Projections of sea level rise, ocean acidification, increased sea surface temperatures, increased precipitation and frequency of storms will all play an important role in

the structure and health of the nearshore, affecting both the terrestrial and marine environments and the organisms present in each. One primary goal of climate research is to identify key ecosystem services that will be impacted by rapid changes of climate and related physical drivers of those services. Ecosystems' resilience and ability to sustain and adapt to the rate of change in the drivers of ecological function depend upon the spatial structure of features in the ecosystem. The relationship between spatial structure, ecological function, and climate change on both local and global scales underlies much of the current research in the fields of Landscape Ecology and climate impacts (Forman; Holling; Opdam and Wascher). While scientists are beginning to address the need for increased climate research and science education programs often focus on increasing public awareness of the potential impacts of climate change, the success of these efforts rely heavily on the tool used for documentation of change. This research and development project is focused on an approach for providing physical change information for use in Geographical Information Systems (GIS) based change models of the nearshore ecosystem acquired from the advances in video image acquisition. Specifically, this project investigates image acquisition potential from video related to environmental setting, camera perspective, and the suitability of common-off-the-shelf (COTS) high definition cameras.

### *Nearshore*

The Nearshore is an ecosystem defined by the dynamic interaction between the terrestrial riparian zone, the intertidal or littoral zone, and the submerged subtidal zone (Shipman). While each zone provides unique ecological services required for the processes which sustain a healthy ecosystem, the primary function of the nearshore is the unifying processes of water and sediment transport from the terrestrial environment to the marine environment.

The riparian zone refers to the land adjacent to the shoreline (Shipman). This zone experiences the most direct human impact as coastal development and urbanization alter the landscape for residential, industrial, and agricultural use. These land-uses impact water quality, soil stability, nutrient inputs, and habitat availability.

The intertidal zone, also referred to as the littoral zone, is the area that is between the high and low tide water levels (Shipman). It is affected the most by wave action, storms, and tidal dynamics. In many coastal urban settings this zone is hardened by seawalls and other shoreline armoring approaches in an attempt to limit erosion of beaches and bluffs which supply sediments through the nearshore.

The subtidal zone is the area below the low tide water line that is still close to shore and shallow (Shipman). This marine zone is often the habitat for key species that use the subtidal zone for spawning and migration. The structure of the subtidal zone constrains and controls many of the physical forces of waves and nearshore currents which are major agents of change to the nearshore.

Collectively, these zones are vulnerable to climate change in a variety of ways. Sea level rise is one of the most well-known modern climate change impacts that modify shorelines, however, the changing climate also influences rainfall and increases the frequency and intensity of storms (Simenstad, Ramirez and Burke). Addressing these issues has significance in ecological, environmental, and human health discussions. The dynamics of shorelines influence the state and condition of nearshore ecosystems as well as the health and quality of coastal waters. Thus, determining a method for data acquisition of change in the nearshore requires tools that can be used in each of the zones while at the same time share a common audience and user community.

## *Imagery*

Photogrammetry techniques have been used for spatial modeling since the mid-19th century, as they provide accurate data regarding the specific space at the time of capture. Constrained by the limitations of the quality of cameras throughout time, the development of spatial models and time series data from photographs has been restricted by the quality of extracted information along with access to and knowledge of camera technology. As cameras have become better, more cost-effective, and easier to use, they have become an increasingly useful tool in scientific studies that examine changes throughout time. From harsh weather to fast speed movements, the ability for accessible camera technology to offer fine-scale imagery in a variety of environmental conditions offers great promise to the future of environmental monitoring.

Technology that captures 360° imagery perspectives has also opened the door for a more complete environmental condition image stamp. At one point in time, the entire environment surrounding the camera can be captured, allowing for a complete, uninterrupted view of a landscape. The potential benefits to this advancement in imagery technology not only allow for the collection of environmental data, but also provide an immersive environment for data viewers to scroll and search through the system of the images themselves.

The integration of video documentation technology and collection methodology into general scientific research establishes a broad, standard resource of historical change, enabling scientists and the public to conduct further studies on the collected data now and in the future. The imagery data will not only measure the changes occurring in each environment and subset, but will also provide visual references for use in the communicating the results to the public.

Furthermore, advances in video documentation technology in recent history allow for greater accuracy and precision of geographically referenced images, as the resolution of images continues to increase dramatically while becoming more affordable and accessible for a wider use. Two rapidly advancing technologies associated with using video cameras as components are remotely operated aerial drones and underwater remotely operated vehicles (ROVs).

### *Drones*

Commercial drones are obtainable at a reasonable price and easy to use, offer built in GPS, barometer, time, date, and a full-HD camera. Through third party applications, the drone pilot can set a distinct track line for the drone to follow, allowing exact repetition of spatially based data collection on temporal scales. Analysis applications are also developing new software that allow easier use of drone data, both numerical and image-based. ESRI recently released a beta version of an extension to ArcGIS called Drone2Map, which imports the flight log data and automatically geo-references the collected imagery (ESRI). The advances in drone technology and analysis methods for drone data currently have momentum for use in geospatial data analysis, but may become limited as public concerns of privacy and private property increases.

Though the Federal Aviation Administration (FAA) has attempted to regulate drone usage by requiring registration of both commercial and non-commercial drones, releasing rules for drone usage, and requiring drone pilots licenses, their efforts have been met with public backlash on all fronts. However, the polar arguments of drone hobbyists and the concerned public led a federal court to rule against the FAA's rule to require owners of drones to register their craft on May 19<sup>th</sup>, 2017 (Koenig and Hananel). However, FAA Modernization and Reform Act Sec. 336 defines drones as Model Aircrafts, thus requiring recreational drone users to abide

by AC 91-57, Model Aircraft rules (Federal Aviation Association). These rules state that recreational drones must be flown strictly for recreational purposes, must be flown below 400ft and in the “line of sight” of the operator, can’t weigh more than 55 lbs, and can only fly in class G airspace, unless they obtain specific permission. The state of Washington does not currently have any laws about drones, but there are a number of bills being debated, which mainly focus on questions of privacy (State of Washington). The universities within Washington would quickly be subject to stricter drone usage rules, as use of drones in publicly-funded research and educational uses requires a Certificate of Waiver or Authorization (COA) (Lindsay, Burke and Wang). The University of Washington (UW) currently has a handful of COAs for drone research, but as security concerns increase, UW’s ability to obtain these permits and use drones for research decreases.

### **Design and Implementation**

The primary aim of this research and development project is to use advanced visual imaging technology to monitor physical change in nearshore ecosystems. The goal is to evaluate these new technologies as tools for acquiring quantitative data used to characterize the structure of the nearshore. Specifically, the project investigates visual image technologies that acquire imagery from a variety of visual perspectives, in different environmental settings and using common-off-the-shelf (COTS) cameras. In order to complete this research, the design and implementation of an instrument package and deployment platform for these acquisition under these settings were required. The construction of this instrument package necessitated specific attention to four primary design elements: environmental setting, perspective of view, specific camera, and the deployment platform.

*Design Elements:*

The nearshore ecosystem is the interface between marine and terrestrial processes. In order to effectively monitor the three zones of the nearshore, the design of an imaging instrument package for this system must include solutions for underwater, surface level, and aerial environmental settings. The underwater setting collects data from the aquatic environment below sea-level, the surface level setting collects data from the intertidal zone, and the aerial setting collects data from the terrestrial environment as well as a bird's-eye-view of the aquatic environment. Each of these environmental settings require different logistical parameters for successful data acquisition, but the synthesis of all three settings allows for a complete image acquisition solution for monitoring the riparian, intertidal, and terrestrial zones of the nearshore ecosystem.

This study utilized three points of view (POV) during image acquisition. The POV, or perspective of the camera during acquisition, determines the resulting image's spatial relationship relative to the viewpoint of the camera. The design of the instrument package and deployment platform allowed for the capture of images from three perspectives - orthographic (facing straight down), oblique (angled) and 360° (panoramic) perspectives. The specific function of each perspective was not the primary purpose of this study, so a different perspective was assigned to each of the environmental settings in order to provide insight on the functionality and use of the different perspectives

As camera technology advances almost exponentially, reliable, easy-to-use, common-off-the-shelf high definition cameras have become more accessible. Many commercial grade cameras, such as the GoPro, allows users to control the photo and video collection on the camera itself or remotely from a smartphone with their live video streaming function. Other advances in

camera technology have opened up options for wide panoramic or 360° image formats for end users. For this study, three lower cost, commercial cameras were chosen based on the perspectives they provided, ease of use, and video capture capability (Table 1).

*Platform:*

Integrating the design elements of an advanced image acquisition instrument package required the design and implementation of deployment platforms which can function in different environmental settings, using different cameras, to acquire images from different perspectives. Two platforms were used in this study: a Phantom 3 Professional drone, which is a commercial-grade aerial vehicle, and the Experimental Imaging Platform (EIP), which was designed and built specifically for this study.

The Phantom 3 Professional drone was recommended by Dr. Christopher Lum, Assistant Professor of Aeronautics and Astronautics at UW and head of UW's Autonomous Flight Systems Laboratory, because of the technical benefits, ease-of-use, and high definition imaging the commercial model offered to this project. The user-oriented design of the commercial drone allowed consultation, technical support, and a built in full-HD video camera. While the Phantom 3 drone's self-equipped camera is capable of providing both oblique and orthographic perspectives depending on the pan and tilt of the lens, the drone platform was used for acquiring orthographic perspective imagery, as the imagery would resemble more traditional geo-spatial monitoring methods (Matese, Toscano and Di Gennaro). Additionally, the flight log from each recorded flight provided real-time GPS of the drone, time, date, and barometer measurements. Because the drone was commercially built with the camera built in, no alterations were made to the platform itself.

While there are a number of remotely operated vehicles (ROVs) available for use in nearshore waters, few provide oblique surface mount camera options. Therefore, the Experimental Imaging Platform (EIP) was developed specifically for this study and was designed to acquire 360° underwater video and oblique surface level video (Figure 1). The EIP was designed to collect both sets of video footage simultaneously while being remotely operated in a straight-line transect along the shoreline. This platform design sought a stable and easily controllable camera mount for the underwater and surface level environmental settings cameras. Additionally, the EIP was intentionally designed to use only materials that can be easily obtained from any local hardware store.

The final implementation of design options for the EIP consisted of a polyvinyl chloride (PVC) plate commonly used for irrigation cases, with a GoPro Hero5 Black mounted to face to one side, and center mount for a pole on which to mount the ThetaS 360° camera in an underwater housing. Three drive thrusters from the SeaMATE PUFFERFISH ROV program were mounted on the 3/4" PVC frame fitted to the main surface plate. The thrusters were tethered to a control box on-shore (MATE). The distance that the platform can be positioned from shore is therefore limited by tether length while orientation to the shore is limited by the skill of the driver. Floatation via polyethylene foam was added underneath the main surface plate to reach a buoyancy that insured the oblique camera was located at the surface of the water. Initial testing of the waterproof housing for the ThetaS camera showed the orientation of the collected imagery were opposite of desired, so a PVC pole was secured in the middle of the irrigation cap with a mount for the underwater camera on the lower end to stabilize the underwater camera in the correct orientation. The pole can be moved vertically throughout the platform and secured so the lens of the ThetaS camera can be located at either 0.5 meters or 1

meter below the water surface. A clamp for securing the housing and mounting of the ThetaS camera to the EIP was designed and 3D printed at the Ocean Technology Center at the University of Washington (Figure 1). The GoPro Hero5 Black was secured with a 3d printed mount on the surface portion of the vessel with the ability to manually flip the direction of the camera depending on the heading of EIP movement (Delandtmic).

The main design limitation of the EIP platform is power consumption. Both cameras, while continuously recording video, have an average battery life of 25 minutes each. Alternative power source to the platform were tested but in each case the weight and waterproofing consideration of onboard batteries or extended tethers exceeded the cost, size, and ease of deployment feasible within the limitations of this project.

*Final configuration:*

The final configuration of the instrument package for acquiring the nearshore imagery data within the three environmental settings consisted of two platforms equipped with a total of three cameras representing three different perspectives. One platform, commercially made, is a Phantom 3 Professional drone equipped with a full-HD pan-tilt gimbal camera for orthographic video data collection. The second platform, developed specifically for this project, is the Experimental Imaging Platform equipped with a GoPro Hero5 Black with an oblique perspective mounted to face the shore as the platform moves, as well as a ThetaS camera with a 360° perspective of the underwater environment.

## **Testing Methods**

The primary purpose of testing was to assess the performance of the video acquisition approach in a nearshore setting that had a discrete waterline, patches of vegetation, large woody debris (LWD), and evidence of human-built infrastructure. Video data was collected via an aerial drone and the Experimental Imaging Platform (EIP) on April 15, 2017 between 2:30pm and 3:30pm on the east side of Portage Bay in Seattle, WA. Ten flight passes along a designated flight path were conducted with the drone and one transect was recorded along the shoreline with the EIP.

### *Drone Testing Methods:*

The usage of imagery from the Phantom 3 Professional drone was tested for GPS accuracy and image quality. The video of each flight path was recorded along with GPS of the drone, barometer, time, date, and specific camera settings. For testing, ten ground control point flags were placed 3-meters apart in a straight-line transect along the shoreline. Geographic position was determined for each control point with a Garmin Etrex 10 handheld GPS unit. Three drone flight passes along the transect were conducted at altitudes of 3 meters, 6 meters, 10 meters, and 20 meters above ground level (AGL). All aerial drone flights were performed in the nadir alignment to the ground control flight line with the camera orientation in an orthographic perspective. Flight log data was updated every second. Following video acquisition, the recorded GPS and additional flight information was transferred from the flight log into a Microsoft Excel spreadsheet along with the handheld readings of the GPS of the ground control flags. The GPS data was then imported into ArcGIS to determine the accuracy of the imagery collected from the drone compared to the handheld device.

### *EIP Equipment Testing:*

The surface vessel testing consisted of individual equipment tests as well as an entire system test. The thrusters were tested before installation and performed as expected. The underwater casing clamp designed initially to reinforce the waterproof housing of the ThetaS camera was tested by Christian Sarason and found to be watertight to a depth of 120 meters, however, initial tests with the camera inside the housing showed that the orientation of the imagery was the opposite of desired. The housing clamp design was then adjusted to provide more stability and control of the orientation of the camera lens. The entire EIP was tested for buoyancy in a test tank and flotation was adjusted with polyethylene foam to obtain the desired orientation of the surface level camera. The EIP was tested again at the field site and polyethylene foam was added to the tether of the thrusters to allow greater ease in vehicle movement.

### *Data Analysis Methods:*

Video data from the drone and EIP were transferred from the cameras and stored on an external hard drive. Using the Video to JPEG Converter application made by FreeStudio, individual frames of each drone flight video were extracted at 1 second- and 10 second-intervals from the underwater and surface level videos. The image number of the photos extracted from the drone footage corresponds to the GPS data by second and thus image number was synchronized to the GPS time log. Using Windows Media Player, the drone videos were viewed and tagged at the beginning and end of each transect. The drone videos of each transect were cut to include only image acquisition of the ground control transect. Using Adobe Premiere Pro CC 2017, the EIP videos from the surface and underwater settings were synchronized in time with a

distinct audio mark found in both sets of footage. Both videos were then cut to begin when the vehicle was initially submerged in water and the surface level camera was in the initial view towards the shoreline. The videos end when the cameras were taken out of the water. Images were then extracted at 10 second intervals from both videos using the FreeStudio application and saved.

The geographic positions from the GPS data log of each of the aerial drone flights were imported into ESRI ArcMap version 10.4 with the corresponding image frame number. The position of the drone at the time of image acquisition and each ground control flag were then represented as points within the GIS analysis software. The geographic position of the ground control points and the straight-line transect, or reference path, as determined by the GPS data from the handheld unit was also imported into the GIS analysis software. In order to determine the level of error in the georegistration of each image, the difference in distance between reference line and the position of each aerial drone image at each ground control point and the was determined. The similarity in the values of uncertainty for all flight altitudes required that only images from one height (20 meters) need be used in future analysis.

Using the 20 meter drone flight image, land cover patches were then digitized as polygons and classified by object type. The perimeter length, area, and count were identified for Large Woody Debris (LWD), gravel patches, grass, human-built infrastructure, and small shrubs.

Individual frames from the EIP images were combined into a photo mosaic, examined and objects of interest were identified and enumerated. Surface level images were examined using Windows Photo Viewer. In the surface level photos, LWD, gravel, grass, human-built infrastructure, and small shrubs were counted and recorded in a Microsoft Excel Spreadsheet. The Ricoh Theta Desktop Application was used for inspecting the underwater 360° photos, but

the distortion of the images impeded the ability for adequate quantitative measurements to be made. Thus, descriptions were given to each image for qualitative analysis.

## **Testing Results**

The test results for the underwater housing and clamp design for the ThetaS camera tested to be watertight to a depth of 120 meters, indicating the equipment, when installed correctly, can remain waterproof while traversing the nearshore.

The EIP was successful in collecting imagery, however, was not stable enough to provide a steady and consistent orientation of the imagery. More thrusting power is necessary for a straight and direct transect line, as the wake present in the testing environment significantly affected the orientation of the platform.

Both the GoPro and the ThetaS collected 22 minutes of video in three .MP4 files. The videos from the GoPro and ThetaS were combined respectively and edited down into separate four minute videos of the single transect. Of the four minutes of video imagery collected for the surface and underwater settings, 24 photos were extracted. Only two of the 24 extracted from the surface camera were oriented directly perpendicular to the shore. In order to provide a more accurate transect, two additional images were then manually extracted from the recorded surface camera video from locations between the two original images. These four images were combined into a photo mosaic and used to count the LWD, human-built infrastructure, shrubs, gravel, and grass patches (Table 2). Twenty-four photos of the underwater setting were also extracted at the same time stamps as the surface setting from the ThetaS video recordings and given descriptions based on the broad surrounding environment (Table 3). The wide-angle perspective of view from the GoPro camera and the 360° perspective of the ThetaS camera distorted the edges of the

imagery, resulting in a significant error and thus limitations for calculating the exact area of objects. Consequently, only counts were determined for final results in the surface and underwater environmental settings.

Image extraction from the drone video resulted in a set of 33 images from the flight pass at 3 meters AGL, 36 images from 6 meters AGL, and 14 images from 10 meters AGL, each with corresponding longitude and latitude. Figure 2 shows the geolocation test performed with the longitude, latitude, image frame number, and AGL of the drone images. Table 3 provides a list of offset values of the georegistered aerial drone images to the reference path created from the GPS of the flags. The drone's image quality test found that the geographic position recorded by the onboard GPS at 3m, 6m, and 10mmeters height had an average error of 2.67, 3.47, and 3.05 meters respectively (Table 4). The position recorded at the ground control flags from a straight line transect was found to have a mean error of 0.7282 meters , with a maximum error of 2.276 meters and minimum of 0.113 meters (Table 4, Figure 2).

Using the 20 meter AGL drone image, classified land cover was counted and the area and perimeter length were calculated. In the study area, 17 polygons of LWD were digitized along with 8 shrubs, 16 counts of human-built infrastructure, 4 patches of gravel, and 1 patch of grass (Table 5). The mean area of LWD was determined to be 11.572 square meters (m<sup>2</sup>), with shrubs averaging at 7.676 m<sup>2</sup>, gravel patches at 30.763 m<sup>2</sup>, infrastructure at 2.314 m<sup>2</sup>, and grass at 401.997 m<sup>2</sup>, the perimeter averages being 7.521 meters (m), 5.588m, 21.928m, 2.721m, and 128.064 m respectively. Area and length value distributions are presented in Figure 4.

## **Discussion**

The success of this study is reflected in the design of the acquisition system itself. Both the drone and the EIP successfully collected imagery within the three environmental settings, providing a visual insight into the structure and functions present in the nearshore ecosystem. However, the deployment platforms each had limitations.

The drone effectively collected imagery that allowed for quantitative analysis, however, the inaccuracy of the drone GPS data log limited precise georegistering of the images. The drone data log, throughout the three AGL tests, reported four consistent locations, indicating no decrease in precision with altitude (Figure 2). The error may be a result of the motion of the drone or the recording resolution, as the drone's GPS was recorded to 0.001 decimal degrees, or 1.463 meters. Despite the error, georeferencing was completed using the image from 20 m AGL and the reference line and analysis of the imagery was done. However, the high error disqualifies any attempt at fine-scale analysis, which indicates that using a commercial drone as a platform will not obtain results that can accurately monitor the nearshore ecosystem at the scale needed.

The imagery from the EIP was limited by the effectiveness of the COTS cameras to collect quantitatively useful images. The distortion of the wide angle lens of the GoPro and the panoramic lenses of the ThetaS made the images unquantifiable, as no calibration of the distortion took place, and thus correcting the warp of the photos was impossible with the accessible tools for this project. Even though no quantification of structure could take place, qualitative analysis of the produced imagery does aid in the process of monitoring the nearshore, as the images serve as a time stamp of the environmental settings and can be used for comparison in the future if repeated.

The specific limitations for accurate, quantitative results from both platforms indicates the difficulty of using low cost vessels in imagery data collection procedures, as both the EIP and the drone were ultimately not stable enough for the desired data to be collected. The drone movement affected the accuracy of the GPS data and the EIP mobility was not good enough for traversing a straight transect path. Furthermore, the results show significant limitations of using COTS cameras for data collection as the distortion of these low cost cameras is significant.

At this point in time, using COTS cameras in methods for quantifying nearshore ecosystem change is limited. However, with the rapid advancement of imagery, drone, and surface vessel technology, obtaining accurate data is not far off. Imagery data, though preferred with quantitative attributes, can also be immensely useful on a qualitative scale as a documentation of ecosystem change when compared to similar images at different times. The set of images produced as a collection of one space throughout time provides a communication tool for educators and outreach professionals to use to aid in the visualization of nearshore change. Communicating environmental issues like how climate change will affect the nearshore can be greatly aided by this imagery, as having visualizations allows for a direct look and easier understanding of the changes occurring.

In conclusion, although promising for future development, current low cost, easily accessible technology does not provide adequate stability or accuracy for imagery to be quantifiable on the fine-scale resolution necessary for monitoring nearshore ecosystem change, but can still serve as a tool for visualizing environmental change.

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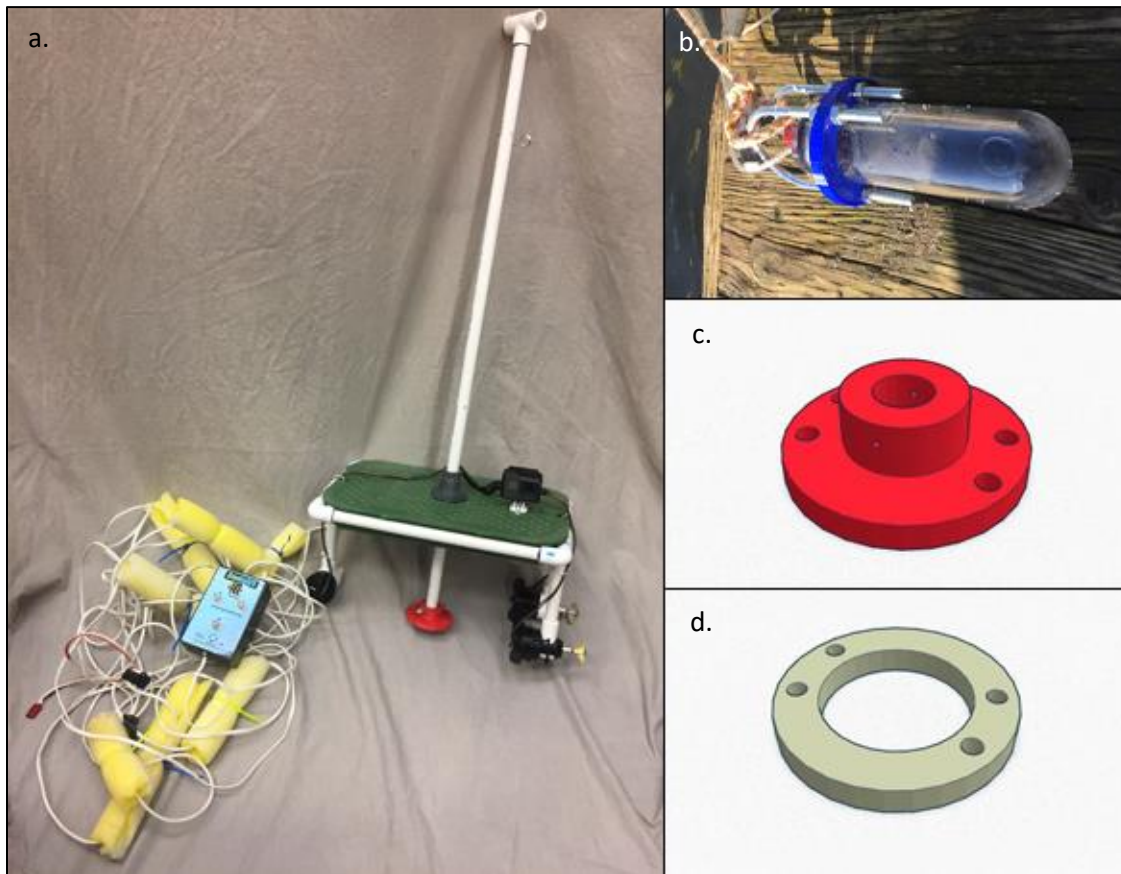
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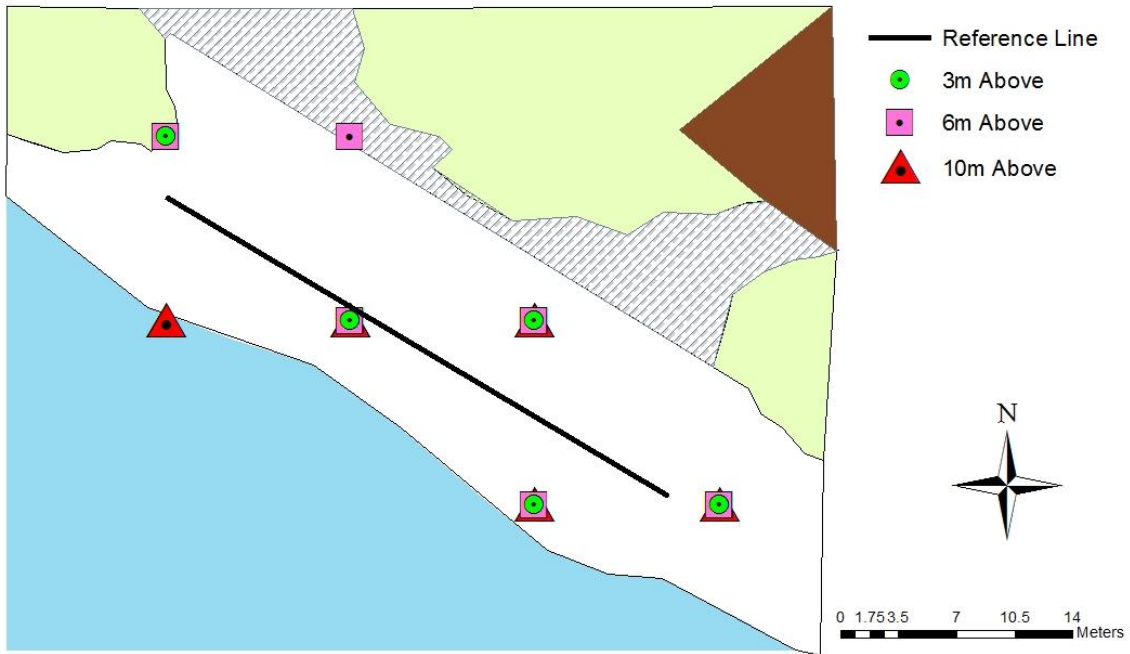
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## Appendix



**Figure 1.** a) EIP with camera not attached b) ThetaS camera in waterproof housing with clamp c) top of clamp design with ability to be clamped with U-bolts to the bottom of the clamp and attached with a pin to the adjustable pole of the EIP d) bottom of clamp design, placement around waterproof housing.

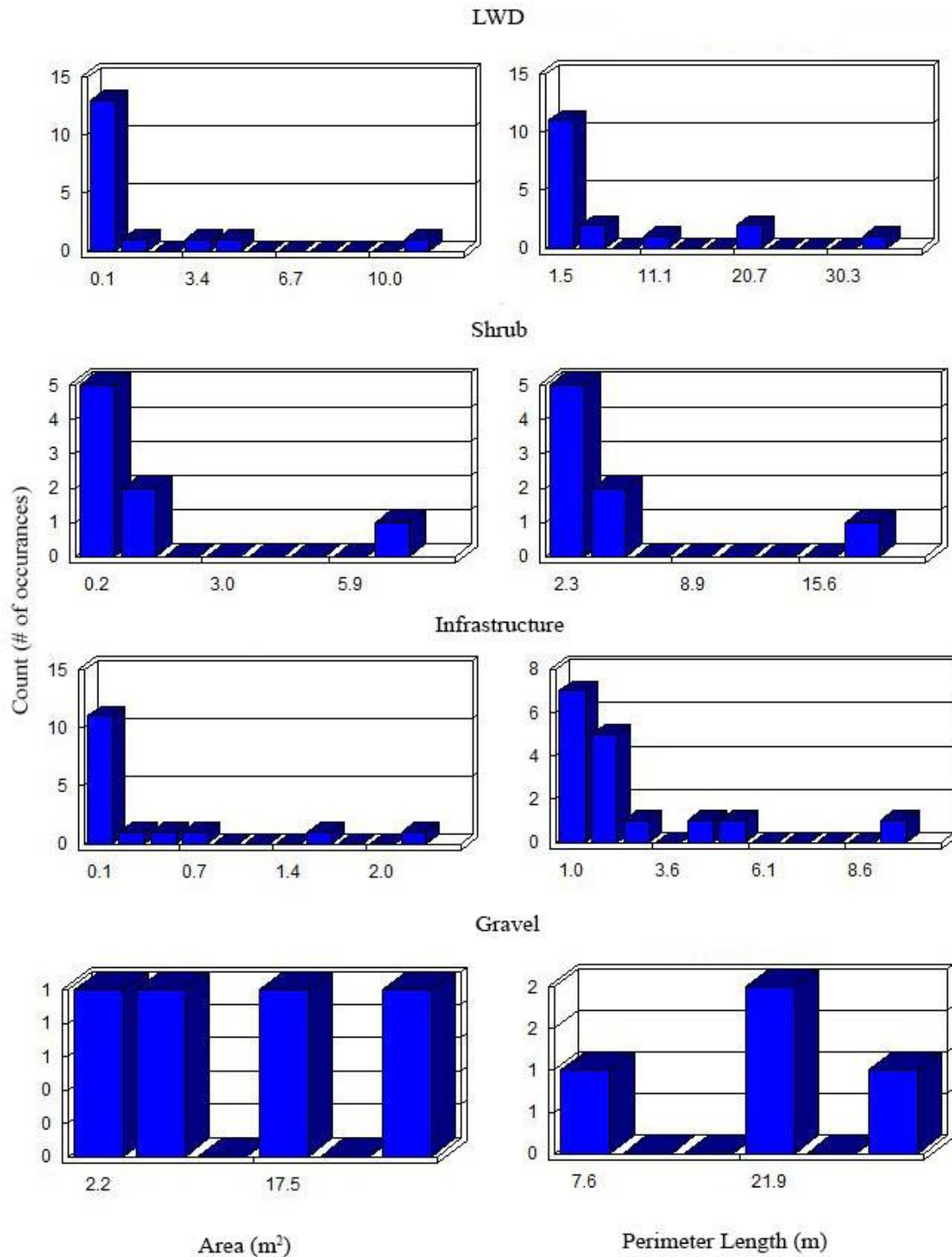
### Geolocation Test



**Figure 2.** Geolocation test of drone GPS at 3, 6, and 10 meters above ground level.



**Figure 3.** Photo mosaic created from four surface environmental setting images.



**Figure 4.** Distribution graphs of the counts of large woody debris, shrubs, infrastructure, and gravel representing ranges of areas and perimeter lengths of the polygons created from the georeferencing and digitization processes.

## Tables

Camera	Perspective (POV)	Effective Pixels (MP)	Frame Rate (fps)	Resolution (pixels)	Extras
Ricoh ThetaS	360°	12	30	Full HD 1920x1080	Live view via smartphone app
GoPro Hero5 Black	Widescreen	12	30	4K 3840x2160	Waterproof to 10 m, action camera
Phantom 3 Professional	94°	12	30	4K 3840x2160	3-axis gimbal stabilizer, pan/tilt ability

**Table 1.** Camera specifications of the three COTS cameras used.

Type	Count (#)
LWD	2
Shrub	10
Gravel Patch	2
Infrastructure	3
Grass Patch	2

**Table 2.** Counts of classified land covers from photo mosaic (Figure 3) created from surface environmental setting images.

Object ID	Description
1-4	Rocky – clean cobbles & pebbles
5-7	Rocky with biology present – majority cobbles & pebbles, algae
8- 24	Majority algae, 10-15 cobbles noticeable under algae

**Table 3.** Qualitative descriptions of the images extracted from the underwater environmental setting.

Above Ground Level (m)	Average Error (m)	Min. Error (m)	Max. Error (m)
Handheld GPS of Flags to Reference Line			
0	0.728	0.113	2.276
Drone GPS to Reference Line			
3	2.668	0.411	4.559
6	3.466	0.411	7.459
10	3.052	0.420	5.856

**Table 4.** Error of handheld and drone GPS. Handheld and drone GPS error calculated from recorded GPS to calculated reference line.

Type	Count (#)	Max. Area (m <sup>2</sup> )	Min. Area (m <sup>2</sup> )	Mean Area (m <sup>2</sup> )	Total Area (m <sup>2</sup> )	Max. Length (m)	Min Length (m)	Mean Length (m)
LWD	17	11.572	0.069	1.511	25.692	34.782	1.470	7.521
Shrub	8	7.676	0.217	1.711	13.692	19.774	2.279	5.588
Gravel	4	30.763	2.185	16.047	64.187	34.254	7.593	21.928
Infrastructure	16	2.314	0.057	0.476	7.615	9.672	1.011	2.721
Grass	1	401.997	401.997	401.997	401.997	128.064	128.064	128.064

**Table 5.** Aerial environmental setting imagery digitization statistics.