Quality Assurance Project Plan 2025 Addendum

Remotely operated vehicles (ROVs) and scientific scuba divers: A methods comparison to optimize bull kelp conservation and restoration in Puget Sound

May 2025

SEATTLE AQUARIUM

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COVER PHOTO: ROV *Lutris* flying offshore of Elliott Bay Marina as part of the ROV-diver methods comparison, summer 2024. PHOTO BY: Zachary Randell, Seattle Aquarium.

Quality Assurance Project Plan 2025 Addendum

Remotely operated vehicles (ROVs) and scientific scuba divers: A methods comparison to optimize bull kelp conservation and restoration in Puget Sound.

By Zachary Randell, Megan Williams, Reid Thomson, and Shawn Larson

May 2025

Approved by:

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Zachary Randell, Senior Research Scientist, Seattle Aquarium	
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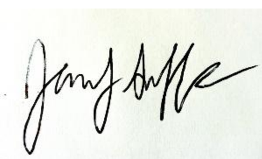
Nora Nickum, VP of Conservation Programs and Partnerships	6/16/2025
 Signature:	Date:
Jennifer Griffiths, HSIL Policy Lead signing in lieu of Damari Peralez-Long, Habitat Strategic Initiative Lead Subaward Manager, Washington State Department of Fish and Wildlife	
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2.0 Abstract

Bull kelp (*Nereocystis luetkeana*) provides robust ecological functioning to nearshore taxa such as fishes, invertebrates, sea birds, and marine mammals throughout coastal Washington. However, over the past several decades, bull kelp has experienced substantial declines in Puget Sound, and multiple government, tribal, non-profit, and academic entities are now focused upon bull kelp conservation and restoration. Traditionally, data regarding the abundance and distribution of kelp is gathered either via scientific scuba divers or, in the case of bull kelp which forms a surface canopy, aerial imagery from airplanes or satellites. Remotely operated vehicles (ROVs) have the potential to gather data across a larger seafloor extent than scuba divers can operate, though ROVs have yet to be systematically evaluated for kelp forest survey operations.

The purpose of this project is to evaluate how ROVs can complement ongoing and future bull kelp monitoring, conservation, and restoration. Our project consists of three pillars: (**1**) we have partnered with Reef Check to conduct a methods comparison between ROVs and scuba divers by flying the ROV above specific locations (transects) surveyed by divers. Our objective is to understand the pros and cons of both platforms. We have also partnered with Puget Sound Restoration Fund (PSRF) to (**2**) monitor their outplanted bull kelp with the ROV to evaluate how best the ROV can contribute to bull kelp restoration. Finally, we will leverage the data collected in this project and our work with the Port of Seattle to (**3**) expand upon an existing bull kelp habitat suitability model via incorporating our ROV-derived data to provide finer-scale predictions for locations suitability for bull kelp restoration. In summary, we envision this project will provide a comprehensive accounting for how best ROVs can complement ongoing and future bull kelp monitoring, conservation, and restoration throughout Puget Sound.

3.0 Background

3.1 Introduction and problem statement

As the predominant habitat-forming species in temperate coastal ecosystems, kelps (brown algae in the Order Laminariales) carry out critical ecological functions that provide food and shelter for other species (Dayton, 1985; Schiel & Foster, 2015), exhibit rapid growth that locally modifies water conditions (Krause-Jensen & Duarte, 2016; Wilmers et al., 2012), and provide ecosystem services essential to human well-being. Bull kelp is of particular interest as the dominant canopy forming species within Puget Sound (Calloway et al., 2020; Mumford, 2007), as its surface canopy provides extensive habitat and shelter for fish, including larval species such as rockfish that are transitioning out of the pelagic phase (Johnson, 2006; White et al., 2019). Numerous other understory kelp species also form three-dimensional habitat, though as their growth does not reach the sea surface and thus cannot be imaged from kayak or aerial platforms, much less is known about their abundance and distribution. In addition to ecological functioning, kelp forests in Washington have deep significance to indigenous and other local communities, and numerous efforts are sprouting up centered around kelp aquaculture.

Puget Sound has experienced marked bull kelp declines in recent decades, with an overall 65% loss of surface canopy since 1980, with some areas exhibiting a 96% decline (Berry et al., 2019, 2021). These declines have been most pronounced throughout south and central Puget Sound. The cause of these declines is not fully understood, though it is likely due to a combination of factors including climate-change related increases in water temperatures, as well as human related changes to sedimentation and nutrient regimes, especially related to coastal development (Khangaonkar et al., 2018). While herbivory, e.g., via sea urchin overgrazing (Filbee-Dexter & Scheibling, 2014) has been a driver of kelp loss in other temperate regions, it does not appear to be a proximate driver throughout Puget Sound.

In response to the observed declines of bull kelp canopy coverage throughout Puget Sound, state and federal agencies as well as tribal, non-profit, and academic entities marshalled to advance working groups, funding priorities, and state legislation. In 2020 the Northwest Straits Commission (NSC) and partners published the Puget Sound Kelp Conservation and Recovery Plan—the Kelp Plan, (Calloway et al., 2020)—linked here. With the Kelp Plan framework in place, January 2022 Washington Dept. of Natural Resources (DNR) developed their kelp canopy indicator (linked here) to prioritize funding for Puget Sound Partnership's Vital Signs Program (linked here). Additionally, the state has advanced numerous organizational efforts such as an accounting of all known kelp conservation and workgroup efforts (linked here), and the NSC has released kelp policy recommendations (linked here). These efforts also resulted in the signing of Senate Bill 5619 which set a goal to conserve and restore 10,000 acres of kelp and seagrass by 2040 (linked here).

Before these ambitious conservation and restoration objectives can be achieved, substantial knowledge gaps must be filled (Eger et al., 2020, 2022). For example, a recent 2023 re-convening of the Kelp Plan workgroup to assess progress thus far and identify priority next steps resulted in the publication of a Status Update (linked here). In it, the kelp community concluded that while bull kelp canopy distribution data collection is "on-track", knowledge about the abundance and distribution of other kelp species that associate with bull kelp such as understory algae (algae that do not reach the sea surface and thus cannot be documented by kayak or aerial methods) are "off track". Specifically, for Goal 3 Distribution and trends status, one of the primary "Next Steps" items identified was "Develop and Standardize understory monitoring protocols (e.g., ROV)". Likewise, under Goal 5: Restore kelp forests, kelp forest reintroduction at recruitment limited sites was found to be "Not Started", the lowest on the scale of progress, with "Next Steps" including using tools such as ROVs to identify barriers to recruitment.

Thus far, the primary method of surveying the benthos—the seafloor and the invertebrates, algae, and fishes living in and upon it—are via scientific scuba divers. Standardized survey protocols have been in place for decades across the pacific northeast. For example, Partnership for Interdisciplinary Studies of Coastal Oceans, PISCO, linked here, have been conducting benthic surveys for decades (Menge et al., 2019). Reef Check (linked here), a world wide organization of citizen science scuba divers has very similar benthic survey protocols (see **Appendix F. Reef Check benthic survey protocols**), and have recently expanded into Washington and established a network of subtidal survey sites (see their web map of sites here).

However, limitations exist regarding how much data divers can collect. Scuba diving requires swimming with life support equipment underwater (i.e., one must carry a tank of breathing gas on their back), thus divers are limited on how long they can stay down, how deep they can operate, and the amount of information that can be written on an underwater slate. That being said, divers provide unparalleled "search" potential—they can look under cracks and crevices with a flashlight, lift blades of algae to find cryptic taxa underneath, and can manipulate and interact with the environment in indispensable ways. We do not seek to replace divers—almost all of the Seattle Aquarium research team on this project are themselves scientific scuba divers—but rather we seek to flesh out and further refine a complementary benthic monitoring tool that can expand upon what divers do.

ROVs have great potential to augment scientific divers by surveying kelp forests across larger areas of seafloor than divers can operate, thereby increasing the amount of information on hand to guide conservation and restoration (Boavida et al., 2016; Buscher et al., 2020; Hamel et al., 2020). Thus far however, the large size and expense of ROVs have focused them to deeper areas where they are deployed off large, seafaring vessels. Kelp forest operations require a ROV than is small and sufficiently maneuverable to get in and out of canopy forming kelp forests without the ROV's tether (a line from the ROV to the surface vessel containing communication information) becoming entangled. Fortunately, over the past few years ROV technology has advanced considerably, and the latest ROV models on the consumer market are small, maneuverable, relatively inexpensive, and are suited for deployment within kelp forests.

In partnership with the Port of Seattle, in 2022 the Seattle Aquarium launched its Coastal Climate Resilience (CCR) research program centered around using customized versions of Blue Robotics' BlueROV2, a small and highly customizable ROV, to conduct standardized video surveys within bull kelp forests (see information about our work here on GitHub). We first developed novel methods of entering and exiting bull kelp forests without getting the tether inextricably entangled (see, e.g., here and here). We also customized camera and lighting placement to illuminate the seafloor underneath the ROV, optimizing data collection of substrate type, invertebrates, algae, and bottom-fishes. Additionally, a forward-facing camera collects video of bull kelp stipes as well as schooling fish in the lower portion of the water column. As an example, you can see a synchronized side-by-side of the two video streams here.

The large quantity of ROV photo and videos would be challenging for a human to manually annotate (extract data) in a reasonable timeframe. Therefore, we are in the process of creating image analysis pipelines using open-source (freely available), machine learning (ML) algorithms. ML has great potential to expedite the image analysis process and turn imagery into actionable data, though they still require large data sets of labeled (human annotated) data to "train" upon (Jacobs & Galluaudet, 2020). In 2023 our CCR team developed a program to train Seattle Aquarium volunteers to annotate ROV survey imagery using CoralNet (Williams et al., 2019), linked here, an open-source platform that uses convolutional neural networks (CNNs) to train an image classifier on user-uploaded images (Elawady, 2015; Villon et al., 2018). Our volunteer training program involves educating personnel on 66 categories of substrate, algae, and invertebrates. To date, we have 10 AI Teacher volunteers who have annotated over 1000 ROV survey images, generating 100,000 data points from our Urban Kelp ROV surveys with the Port of Seattle. Throughout 2024 we performed and overhaul of our ML methods, and as detailed in this document, we now use CoralNet-Toolbox (henceforth, Toolbox) to train ML models. Toolbox is proving to be far more effective than CoralNet, and our current model using HSIL imagery from summer 2024 is predicting percent-cover with an accuracy of 91.5%.

At its core, this project is centered around increasing the amount of information we have about the substrate, algae, invertebrates, and fishes within kelp forests, all to fill knowledge gaps identified by the state of Washington to help guide future bull kelp monitoring, conservation, and restoration. To do this, we will (**1**) conduct a ROV-scuba diver methods comparison with Reef Check to identify how data derived from both platforms differs in order to optimize each. We will also (**2**) team up with PSRF in order to evaluate how best ROVs may inform bull kelp restoration via surveys of treatment and control sites surveyed at the beginning and end of the growing season, as well as regular ROV monitoring of the outplanted kelp population. Finally, data from the first two portions of the project in addition to leveraged data from our Urban Kelp project with the Port of Seattle will guide (**3**) our expansion of an existing bull kelp habitat suitability model to increase the fine-scale resolution of the model's predictions of locations optimal for bull kelp restoration in Puget Sound.

3.2 Study area and surroundings

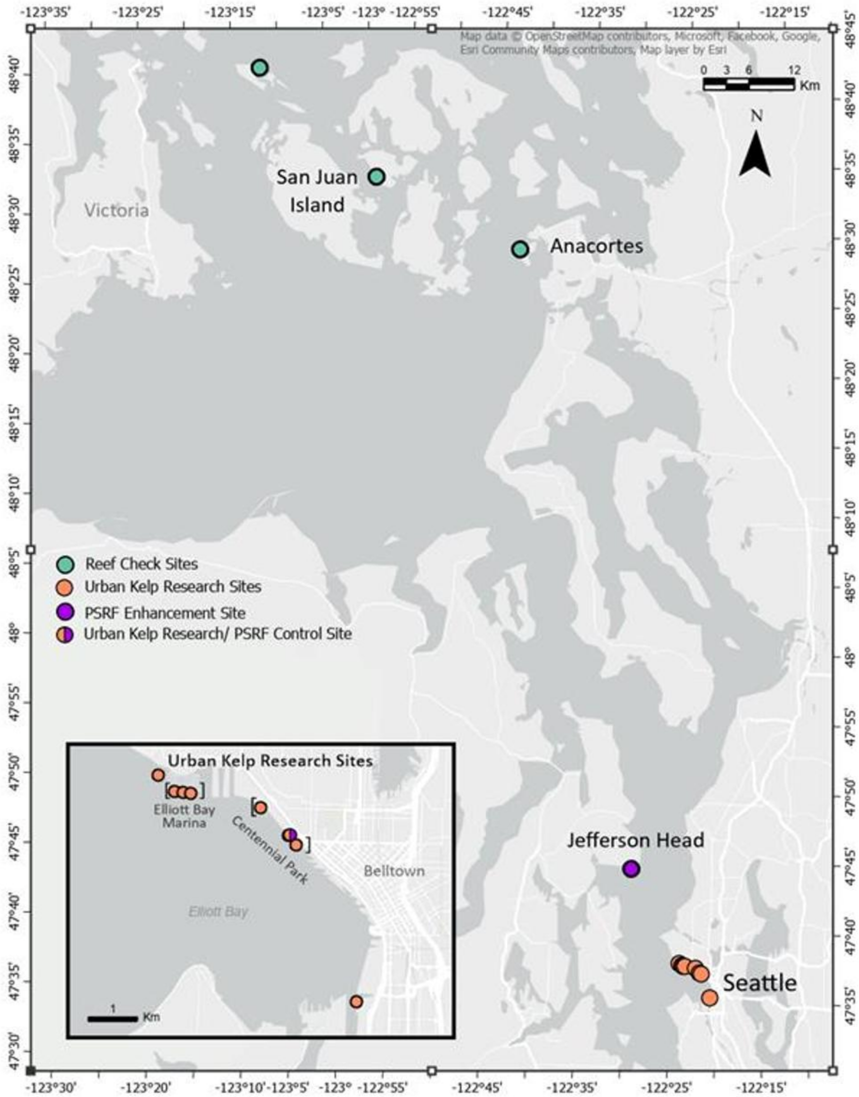

Figure 1. Map of study area with an inset of Elliott Bay and our Urban Kelp ROV sites

3.2.1 History of study area

Puget Sound, located in the Pacific Northwest region of the United States, is a complex and intricate estuarine system. As part of the Salish Sea, it extends from the Strait of Juan De Fuca through to Olympia, Washington. In terms of geological formation, the most significant event was the Vashon Glaciation, which occurred 15,000 years ago during the last Ice Age. As the glaciers retreated, they carved out the deep basins, channels, and sills that that now make up Puget Sound (Haugerud, 2021). In doing so, these glaciers left a variety of sediments such as glacial till. Marine sediments were introduced as sea levels rose, and these are typically finer grained. Other sediments in the nearshore include more recently delivered such as via rivers and landslides, and these are more often found in the deltas and the nearshore areas of Puget Sound.

3.2.2 Summary of previous studies and existing data

Our study area was designed to capture a broad set up these varying substrate characteristics as well as varying benthic community structure. In terms of recent data collection efforts, the most similar to our study are Washington Reef Check's scuba diver surveys which operate throughout the state; their program was initiated in 2021 and surveys fully got off the ground in 2022. Furthermore, in terms of bull kelp canopy coverage, the Northwest Straits Initiative maintains a robust kayak monitoring program (linked here). Additionally, DNR conducts aerial flyovers of kelp canopies, especially in the western Strait of Juan de Fuca and along the Olympic Coast (Pfister et al., 2018), as well as camera tows and other monitoring throughout Puget Sound (Berry et al., 2021). Furthermore, DNR successfully completed a summer 2024 survey using aerial drones to image all the bull kelp canopy throughout Elliott Bay, and they currently estimate those data will be available publicly summer 2025. We look forward to incorporating those data into our bull kelp habitat suitability model.

In terms of existing data we will leverage as part of this project, especially when expanding upon the bull kelp habitat suitability model, please see here and here for high level overviews of our Urban Kelp Research Project with the Port of Seattle. In 2022, we established a network of eight ROV survey sites in Elliott Bay (see **Figure 1**, inset). At each of the eight sites we conduct four ROV transects, ranging in length between 50-100m, depending upon the local configuration of the kelp bed and surrounding area. We surveyed these sites in the summers of 2022, 2023, and 2024, and the Port of Seattle has renewed our contract and we will continue these surveys in 2025. In particular, we expanded our surveys to include winter surveys in January 2025 when the annual vegetation is absent, enabling our ROV to extensively document the underlying substrate that is not typically visible in the summer, when it is covered by algae. These winter surveys in particular will be useful for our bull kelp habitat suitability model, as the ROV obtains fine-scale metrics of substrate categories such as sand, silt, cobble, shell-debris, pebbles, and hard substrate, all of which have varying associations with bull kelp's ability to grow and persist.

You can see an example of some of our Urban Kelp ROV data we will leverage for our habitat suitability model linked here. The substrate and benthic community data (columns "AE" through "BE") are the output from our manual annotations in CoralNet, and they have been appended to metadata including site information, photo ID, as well as GPS coordinates to facilitate spatial analyses (columns "A" through "AD"). Each row contains data from an individual geospatially referenced image.

Additionally, you can see the current version of the bull kelp habitat suitability model here on the ArcGIS Online Experience, which is publicly visible.

3.2.3 Parameters of interest and potential sources

The parameters of interest for this project include:

- *ROV derived*: percent-coverage of benthic taxa and substrate type; n=50 percent-coverage data points per image from the downward-facing camera (x2 GoPro HERO12).
- *ROV derived*: abundances of invertebrates, certain conspicuous algae, and fishes from both the downward- and forward-facing cameras.
- *ROV derived*: spatial tracking of the ROV, i.e., 1Hz (1 per second) latitude and longitude coordinates of the ROV's position underwater to facilitate spatial analyses via ArduSub's Extended Kalman Filter (EKF).
- *ROV derived*: additional ROV sensor telemetry, from, e.g., our WaterLinked Doppler Velocity Log (DVL) used to measure the altitude of the ROV above the seafloor and enable autonomous mission planning.
- *Scuba diver derived*: abundances of invertebrates and algae as well as percent-coverage data using Reef Check scuba diver protocols.
- *Habitat suitability model derived*: map layers with finer-scale predictions of specific locations where bull kelp is forecasted to persist, given the inclusion of our ROV abundance and percent-coverage data.

4.0 Project Description

4.2 Project objectives

The objectives of this project are to:

- Conduct a methods comparison where ROVs and Reef Check divers gather data above the same 30m transects (survey locations) on the same day. These surveys will take place summer (late August/September) 2024 and 2025, as well as in the winter (January/February) 2025 and 2026. Surveys will take place at a minimum at two locations in Elliott Bay (Centennial Park and along the Elliott Bay Marina breakwater) and at two locations on the west end of San Juan Island, or at other locations in the San Juan island that are accessible given current weather conditions. A fifth site at Burrows Island was not originally included in the scope of work or Statement of Work for this project, though we intend to survey it anyways to fully practice our ROV-diver choreography with Samish Reef Check divers prior to the surveys along the west end of San Juan Island.
- Conduct ROV-based bull kelp restoration site surveys and regular monitoring with PSRF. The site surveys will take place in March and June of 2024 and 2025, and the routine bull kelp outplanting monitoring will take place every other week between March and June in 2024 and 2025.
- Update an existing bull kelp habitat suitability model's environmental layers and incorporate ROV derived percent-cover and abundance information. We will first update the existing data layers and incorporate new tools such as an analysis of bathymetry layers via the Benthic Terrain Modeling tool, we will simulate and incorporate ROV data to perform a sensitivity analysis, then we will incorporate real ROV data to obtain finer-scale predictions of optimal bull kelp habitat.

4.3 Information needed and sources

Below we first summarize the data we will collect in the field, followed by Table 1 which outlines the GIS layers to be utilized as part of Task 4.

ROV derived data will include sensor and telemetry files including .bin files and .TLOG files containing all geospatial information (e.g., the GPS coordinates where the ROV flew along the seafloor), as well as flight data such as ROV altitude above the seafloor, temperature, battery power remaining, etc. These data are obtained from the ROV laptop after each flight, and we download them and store them on the Seattle Aquarium DropBox.

ROV photo and video survey data will include 27.3 megapixel (MP) images shot on “time-lapse” mode on x2 GoPro HERO12 cameras, as well as 4K, 30 frames per second (fps) video, also shot on a GoPro HERO12. Our downward-facing cameras shoot photos, and our forward-facing cameras shoot video. The camera settings as well as a SOP for photo and video processing are described in **Appendix B. SOP for camera settings and imagery processing.**

We will extract percent-coverage information for substrate type and aggregate taxa such as brown, red, and green algae from the 27.3MP photos taken by the downward-facing camera using Toolbox (Pierce, et al., 2023) an open-source AI program. We will extract abundances of bull kelp stipes and certain schooling fishes from the forward-facing video that is to be analyzed in Video and Image Analytics for the Marine Environment—VIAME, (Dawkins et al., 2017)—linked here, and we will also use VIAME to analyze the downward-facing photos to extract abundances of individually conspicuous invertebrates (such as sea urchins, sea stars, and sea anemones), certain algae, and some demersal fish.

Scuba divers will gather invertebrate and algae “swath” data (counting abundances of individually conspicuous invertebrate and algae species) and Uniform Point Contact (UPC) to measure percent-coverage of substrate type as well as species not captured by abundance counts, such as, e.g., colonial sponges and fleshy red and green algae. These Reef Check protocols are detailed extensively in their recent QAPP signed October 12th, 2023, and the precise benthic protocols are also linked in **Appendix F. Reef Check benthic survey protocols**.

Table 1 below details the data layers that will be updated as part of our expansion of the existing bull kelp habitat suitability model.

Table 1. Data layers comprising the bull kelp habitat suitability model

Dataset	Source	Description
Washington State USGS CoNED MLLW Bathymetric DEM	Cowdrey, T. (2024). Washington State USGS CoNED MLLW Bathymetric DEM [Data Set]. Washington State Department of Natural Resources, Nearshore Habitat Program. [https://gis.dnr.wa.gov/image/rest/services/Aquatics/WA_bathymetry_CoNED_MLLW/ImageServer].	This bathymetric digital elevation model (DEM) provides depth values in meters up to elevations of +10 meters relative to mean lower low water (MLLW) at one-meter spatial resolution for the portion of the southern Salish Sea roughly constrained by the United States maritime border with Canada. For our purposes, this DEM is used to create metrics related to substrate composition including depth, study area (as it relates to depth) aspect, slope and rugosity.
Washington State ShoreZone Inventory – Shoreline type	Washington Department of Natural Resources, 2000 and Dethier, 2014	Line data characterizing shorelines based on Dethier Classification system composed of primary, secondary and tertiary substrate types capturing both physical and biological attributes of the coastal environment.

Washington State ShoreZone Inventory: Floating Kelp Extent 1994-2000	Washington Department of Natural Resources, 2000	Line layer showing the distribution of floating kelp from the larger Washington State ShoreZone Inventory.
ROV-derived data	Urban Kelp Research Project, Seattle Aquarium, 2022-20242023	Percent-coverage information for substrate type and aggregate taxa such as brown, red, and green algaeBull kelp stipes captured by the forward facing camera during surveys.

4.4 Tasks required

Task 4.1: **Field work to conduct a ROV-scuba diver methods comparison.**

- Randell, Williams, and Thomson will coordinate with the Seattle Aquarium Dive Program, Reef Check, and the Samish Indian Nation Reef Check divers to fly the ROV above Reef Check survey sites the same day that divers survey them.
- This methods comparison will take place at four sites in two distinct geographic locations: (1) Elliott Bay (specifically, offshore of Centennial Park and along the Elliott Bay Marina breakwater) and (2) the west side of San Juan Island (specifically, Deadman's Bay and Smallpox Bay). We will additionally perform a "shakedown" field trial with Reef Check and the Samish Dive Team at Burrows Lighthouse, just west of Anacortes, before proceeding to the main San Juan Island data collection trip. In winter 2024 (December 2024) we completed these surveys at the San Juan Island at two different sites: Shaw Island, and Satellite Island, due to the current weather conditions when we were up there (Figure 1).
- Seattle Aquarium staff will attend the Reef Check partner retreat to become certified in Reef Check's methodology (in early May), and upon completion of the training, will bring the methodology back to the Seattle Aquarium in order to certify additional dive personnel (in early June)
- The ROV-diver methods overlap will take place in summer 2024 (September), winter 2025 (February), summer 2025 (September), and winter 2026 (February).
- At minimum, x6 30m transects will be surveyed via Reef Check's divers as well as our ROV, matching precisely the Reef Check protocol (please see **Appendix F** for a link to the full Reef Check protocol).

Task 4.2: **ROV site surveys and outplanted bull kelp monitoring at Jefferson Head.**

- The work required includes training our HSIL Research Technician to operate the ROV (as this is our earliest field work), as well as to complete all telemetry file processing, AI image annotation, and video editing.
- We are coordinating closely with PSRF personnel. On our first PSRF ROV survey day, we will motor our vessel from Bell Harbor Marina, Seattle, to the Indianola pier, where we will pick up PSRF personnel, who will accompany us to their Jefferson head enhancement site.
- At the start of the field season (early March, 2024 and 2025), we will complete a ROV site survey (with x4 50m ROV transects) around the enhancement location. This ROV site survey will also take place at one of our Centennial Park sites which will represent a natural kelp bed "control site" (see **Figure 1**).
- Once these above site surveys have taken place, we will then monitor the bull kelp on the "off weeks", the weeks where PSRF divers are not surveying, as to increase the number of total sample points available. These surveys will involve a single ROV "pass" filming the outplanted bull kelp (as opposed to the more involved site surveys). This was removed as we found in the summer of 2024 that the ROV is very much not suited to conducting these surveys in the heat of the summer when the water is very green and particulate filled. Note that this finding does not apply to the before and after ROV surveys around Jefferson head, all of which we have successfully completed thus far.

Task 5.1: **Process, edit, and color-correct ROV-derived photos and video**.

- As we shoot video using the "Native" white-balance setting, our imagery requires color-correction. We will use programs such as DaVinci Resolve Studio to edit videos and Adobe Lightroom to edit photos in order to process them for further analysis.
- All data will be uploaded to DropBox folders with downloadable links that we will make available to the HSIL team.

Task 5.2: **Use open-source AI programs such as Toolbox and VIAME.**

- We will use Toolbox to extract metrics of percent-coverage of aggregate taxa (e.g., substrate type, fleshy red algae, green algae, etc.) from our imagery.
- We will additionally use VIAME to generate metrics of abundance for individually conspicuous objects such as sea stars, sea urchins, bull kelp stipes, and fishes.
- All data from both Toolbox and VIAME will be extracted in the form of .csv files, and we will merge these data with our ROV's telemetry files as to provide a complete record of our benthic surveys.
- Both of these objectives will leverage our Seattle Aquarium volunteers, i.e., our "AI Teachers", who have gone through an extensive and standardized training process enabling them to help annotate our ROV imagery and train our AI algorithms.

Task 5.3: **Provide links to GIS database containing maps of our ROV survey locations.**

- We will process our telemetry files from the acoustic GPS system and the Doppler Velocity Log (DVL) to generate geospatial data for the locations where we flew the ROV.
- Starting in summer 2024 and onwards, we now use ArduSub's (our ROV flight control software) EKF to fuse the various data streams together on the ROV, generating a real-time position (lat/long coordinates) of where the ROV is. These data are recorded and are part of the ROV's telemetry log (the TLOG).

Task 6.1: **Share our GIS database containing all model components of our updated and expanded bull kelp habitat suitability model.**

- We will iteratively update the model with new inputs (see Table 7). These will focus upon new and updated environmental data layers (e.g., from the Salish Sea Model), as well as more detailed bathymetry and substrate data using the benthic terrain modeler tool.
- We will generate simulated data for our ROV to test the behavior and output from the habitat suitability model.
- Only once the model has been extensively updated and tested will we incorporate real ROV-derived data (metrics of percent-coverage and abundance).

5.0 Organization and Schedule

5.1 Key individuals and their responsibilities

Table 2 shows the responsibilities of those who will be involved in this project.

Table 2. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Dr. Zachary Randell Seattle Aquarium Phone: (408) 660-7842	Project Manager and Principal Investigator; Research Scientist	Writes the QAPP. Oversees project design and implementation. Coordinates field work with partner organizations. Participates in field and oversees imagery processing, AI training, and data analysis. Writes the draft report and final report.
Megan Williams Seattle Aquarium Phone: (206) 356-9850	Research Technician	Conducts field work, photo/video processing, AI analyses of photos/stills, and data analyses including spatial analyses.
Reid Thomson Seattle Aquarium Phone: (414) 748-1553	Research Technician	Conducts field work, photo/video processing, AI analyses of photos/stills, and data analyses including spatial analyses.
Dr. Shawn Larson Seattle Aquarium Phone: (206) 618-3762	Senior Conservation Research Manager	Dr. Randell's supervisor at the Seattle Aquarium. Provides internal review of the QAPP, approves the budget, and approves the final QAPP.
Joel Hollander Seattle Aquarium Phone: (206) 714-8968	Dive Program Manager	Oversees all Seattle Aquarium field work to ensure the safe conduct of scuba, ROV, and vessel operations.
Ken Nelson Department of Ecology Phone: (360) 522-2722	National Estuary Program Quality Coordinator	Reviews and approves the draft QAPP and the final QAPP.
Dr. Jodie Toft Puget Sound Restoration Fund Phone: (831) 251-5824	Deputy Director	We coordinate with Jodie and PSRF on several projects, and she will facilitate communication and collaboration as we conduct joint field operations as part of **Task 4.2**.
Jackie Selbitschka Reef Check Phone: (651) 492-8827	Washington Regional Manager	We coordinate with Jackie to ensure the Seattle Aquarium scientific divers are also certified Reef Check divers, and we have coordinated with Jackie to plan field operations associated with **Task 4.1**

5.2 Special training and certifications

The core personnel at the Seattle Aquarium who will be responsible for advancing this project on a daily basis are as follows:

- Dr. Zachary Randell: Primary Boat Operator (PBO) for the Seattle Aquarium vessel. Scientific Diver at the Seattle Aquarium. Trained ROV operator. Experience conducting subtidal and surface operations in temperate waters since 2010. Ph.D. in Integrative Biology with a Minor in Statistics from Oregon State University (defended 2021; his public dissertation defense can be found here on YouTube), with research focused on kelp forest monitoring, analysis, and dynamical modeling (dissertation linked here).

- Megan Williams: PBO for the Seattle Aquarium vessel. Scientific Diver at the Seattle Aquarium. Trained ROV operator. Trained in video/photo processing and machine learning methods of image analysis. In-progress three quarter Geographic Information Systems (GIS) credential course (linked here) at the University of Washington. Master of Science degree in Marine Biology from James Cook University, 2022. Her graduate research was centered around the effects of "sea-weeding" (removing sargassum from coral reefs) on non-coral benthic communities.
- Reid Thomson: Trained ROV operator. Trained in video/photo processing and machine learning methods of image analysis. Graduated Boston University in 2024 with a B.A. in Marine Science.

5.4 Proposed project schedule

Tables 3—5 list key activities, due dates, and lead staff, and a budget breakdown for this project.

Table 3. Schedule for completing field and laboratory work

Task	Due date	Lead staff
4.1 – ROV/scuba methods comparison with Reef Check.	**October 2024, April 2025, October 2025, and April 2026**	**Randell, Williams, Thomson**
4.2 – ROV surveys of bull kelp restoration with PSRF.	**August 2024, August 2025**	**Randell, Williams, Thomson**
5.1 – Process video imagery.	**Continually via quarterly reports starting July 10 2024 through October 2026**	**Williams, Thomson**
5.2 – AI analyses of ROV imagery.	**Continually via quarterly reports starting July 10 2024 through October 2026**	**Randell, Williams, Thomson**
5.3 – links to maps of ROV survey locations.	**January 2025, January 2026**	**Williams**
6.1 – link to GIS database containing habitat suitability model.	**January 2025, January 2026**	**Williams**

Table 4. Schedule for final report

Task	Due date	Lead staff
Draft to supervisor	**June 2026**	**Randell**
Draft to client/peer reviewer	**July 2026**	**Randell**
Draft to external reviewers	**July 2026**	**Randell**
Final draft to Strategic Initiative	**September 2026**	**Randell**
Final report due on web	**September 2026**	**Randell**

5.5 Budget and funding

PI Randell and Research Technician Williams are both covered by the Seattle Aquarium's General Operations budget, though a small portion of Randell's time is covered on this grant to supervise the completion of the project. Research Technician Thomson's entire salary and benefits are covered by this HSIL project, and completing the ROV field work, photo/video processing, AI analyses, data analysis, and GIS analyses are his primary responsibilities. Total personnel salary costs are $189,150.02 for the project, including $66,202.51 for fringe benefits (**Table 5**). The Seattle Aquarium applies a 10% indirect rate on personnel and fringe costs, totaling $22,300.00.

We also budgeted $22,300.00 for field work and travel. This largely will go towards fuel and moorage costs for the Seattle Aquarium vessel in order to complete **Tasks 4.1** and **4.2.** The Seattle Aquarium makes priority use of its vessel for this research. These travel funds also include support to send Seattle Aquarium personnel to the Salish Sea Ecosystem Conference (SSEC) as the HSIL Virtual Subrecipient Summit.

In terms of equipment, the Seattle Aquarium has funded (matched) over $35,000 worth of ROV and related equipment to initiate the CCR program. We have also budgeted approximately $38,000 worth of equipment funds into this HSIL project to upgrade our ROVs, purchase additional sensors, and purchase equipment necessary to power the ROV from the Seattle Aquarium's vessel. We also included $13,408 in supplies, largely consisting of relatively small spare and replacement ROV components or camera parts.

Table 5. Budget breakdown by category

Budget category	Total funds allocated
Personnel	**$189,150.02**
Fringe benefits	**$66,202.51**
Travel	**$22,300.00**
Equipment	**$38,000.00**
Supplies	**$13,408.00**
Indirect at 10% on personnel and fringe	**$25,535.25**
Total Grant Amount	**$354,605.00**

6.0 Quality Objectives

6.2 Measurement quality objectives

Our ROV surveys within kelp forests are relatively new—we have developed the protocols ourselves since PI Randell starting working at the Seattle Aquarium in March of 2022. However, our ROV surveys are fundamentally derived from scientific scuba diving benthic survey procedures, such as PISCO's methods as well as Reef Check's methods (see **Appendix F. Reef Check benthic survey protocols**). Therefore, our primary Measurement Quality Objective is to conduct ROV surveys in a manner that expands upon the rigor, statistical independence, and repeatability of standardized benthic scuba based surveys to capture abundances of mobile and conspicuous invertebrates and algae, and percent-coverage data regarding substrate type and aggregate (not individually discernable) taxa.

Central to the standardization of benthic scuba diver surveys is the ability to link abundances and percent-coverage estimates to precise areas of seafloor—this allows one to generate density estimates. For divers, this involves laying down a meter tape (often a 30m tape) and counting conspicuous and individually identifiable invertebrates, algae, and fish species. Likewise, divers also conduct Uniform Point Contact (UPC) surveys to record the percent-category of aggregate taxa as well as seafloor type along each meter mark down the tape.

As an expansion of these benthic diver surveys, our ROV methodology also captures abundances and percent-coverage information. However, instead of laying down a meter tape to track the area of seafloor surveyed, we precisely track the spatial position (i.e., latitude/longitude coordinates) of the ROV along the seafloor. And a step further, because we know the altitude of the ROV above the seafloor (via a Doppler Velocity Log), and because we know the angle of the camera lens that is facing downwards, via a simple trigonometric function in *R* we can calculate the area captured by the downward-facing camera at any moment in time (see, e.g., here). We can combine these area and geospatial tracking data streams to analyze a variety of ROV surveys parameters, as exampled by **Figure 2**, which display our real-world survey parameters for our summer 2022 ROV surveys with the Port of Seattle.

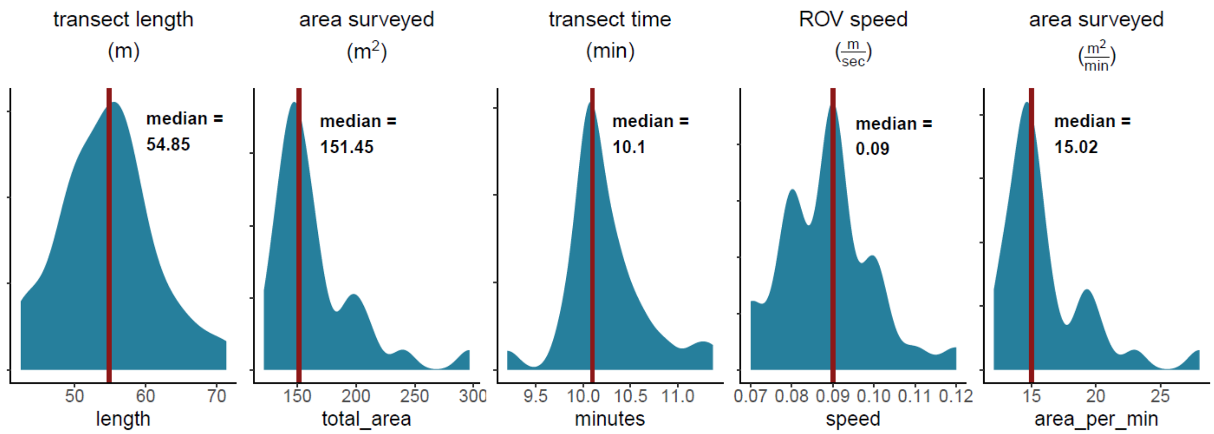

Figure 2. ROV survey parameters

Frequency histograms of ROV survey parameters from n=32 ROV transects (surveys) completed winter 2025 for the Port of Seattle. The red line denotes the mean value of each parameter. Survey parameters include transect length in meters, seafloor area filmed in units of meters squared, survey time in minutes, ROV speed in meters per second, , and rate (or ROV survey effort) in units of meters squared filmed by the downward-facing camera per minutes.

This is all to say, precise spatial tracking is an essential component of our ROV surveys, thus it is a key Measurement quality objective. Please see **Appendix A: SOP for ROV Navigation and survey flights** for details about how we achieve this objective. We have x2 separate systems that provide geospatial information, providing redundancy. The first is WaterLinked Underwater GPS (UGPS) system, and the second is WaterLinked's Doppler Velocity Log DVL-A50. In particular, the latter sensor provides highly precise spatial tracking across the seafloor via x4 acoustic beams. The "performance" model of the DVL-A50 (which we have) has a long-term accuracy of 0.1%.

Additionally, regarding our AI analyses, they will take extended periods of time to train before they can generate output that does not need to be "reviewed" by a human (where the human either "verifies" or "corrects" the algorithm's predictions). Our target is for our algorithms to perform at 90% accuracy. For some categories of taxa that are commonly observed, we are near this goal—our CoralNet algorithm can detect sugar kelp with 89% accuracy—but we have over 10,000 data points of sugar kelp. Most other categories in CoralNet do not yet have as many data points and thus are not at that high of an accuracy, and until they are, we will maintain our "human review" of all project data.

6.2.2 Targets for comparability, representativeness, and completeness

6.2.2.1 Comparability

As detailed above in **6.2 Measurement quality objectives**, maintaining comparability of our ROV methodology with similar scuba diver surveys is a core goal our work. The ROV methods used in this project will expand upon the protocols developed for the Urban Kelp Research Project with the Port of Seattle (and please see **Appendices A—E** for a complete list our Standardized Operating Procedures (SOPs) associated with our ROV surveys).

To ensure comparability across our surveys, as part of the Urban Kelp study we complete x4 replicate transects at each of the x8 ROV survey sites in Elliott Bay. The x8 sites are displayed in **Figure 1**, and **Figure 3** below shows a map of x4 ROV transects at each of the x3 ROV sites in Centennial Park. These x4 transects are akin to the classic 30m scuba diver transects that are part of PISCO and Reef Check protocols, enabling comparison to the numerous Reef Check diver sites throughout coastal Washington.

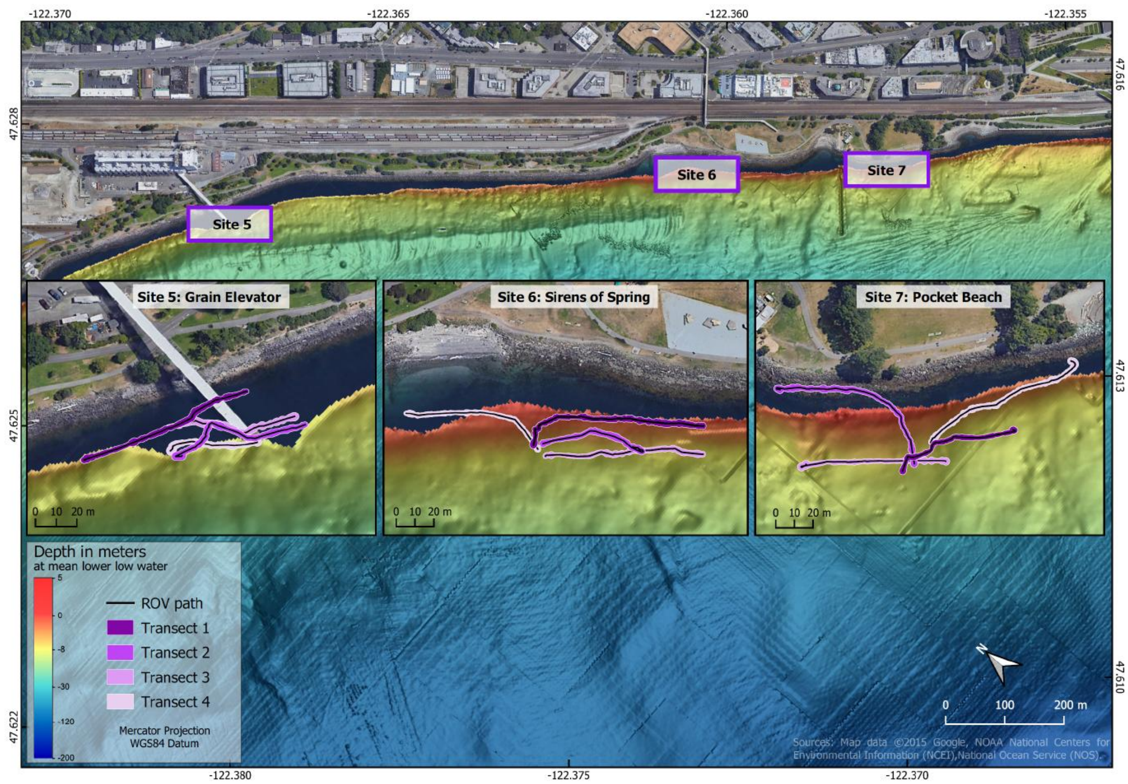

Figure 3. Site and transect maps from our Urban Kelp research

The x3 replicate sites along Seattle waterfront at Centennial Park—Grain Elevator, Sirens of Spring, and Pocket Beach—enabling statistical comparison and differentiation of these sites with the x3 replicate sites along the Elliott Bay Marina breakwater as part of the Urban Kelp Research

Project with the Port of Seattle (not displayed here). The transects depicted here were from our summer 2022 ROV surveys.

Furthermore, in terms of comparability, six of the eight Urban Kelp ROV survey sites are further grouped into “super sites” (**Figure 1** inset), specifically the x3 Centennial Park (**Figure 3**) and x3 Elliott Bay Marina breakwater sites. These groupings were established to provide replication at the site level, thereby enabling statistical differentiation of the two broader locations: Centennial Park versus the Elliott Bay Marina breakwater. Thus, our ROV methodology—while relatively new—is fundamentally based on tried and tested subtidal field methods such as standardized survey areas, as well as and replication at the proper spatial scale given the desired spatial scale of inference.

Finally, regarding comparability, note in **Figure 3** that the transects have a slight “wiggle” to them—this is a reflection of our seafloor area measurements—and the slight oscillation in area surveyed is a reflection of the small changes in ROV depth as we manually maneuvered the ROV and attempted to maintain a consistent 1m altitude above the seafloor. Since then, we now use *surftrak* (linked here)—open-source software developed by Clyde McQueen, a Seattle Aquarium Special Projects Volunteer (SPV), that enables our ROV to autonomously adjust its depth across varying terrain to maintain our desired 1m altitude above the seafloor. The successful development and testing of *surftrak* on ROV *Lutris*, one of our x2 ROVs, was a major milestone that is but one of several custom software efforts underway to ensure that our ROV imagery is as consistent and comparable as possible. By keeping the ROV at a consistent 1m depth above the seafloor, we minimize variation in lighting and keep the scale of our imagery consistent.

7.0 Study Design

7.1 Study boundaries

The ROV surveys and ROV-diver method comparisons conducted for this project will encompass three sites within Elliott Bay, two sites on San Juan Island, and one site near Anacortes, Washington. **Figure 1** in **3.2 Study area and surroundings** details of overarching spatial extent of our study, and **Figure 3** in **6.2.2.1 Comparability** presents a finer spatial scale of ROV transects by displaying our ROV surveys along Centennial Park for the Port of Seattle from the summer 2022 field season.

Regarding our expansion of the bull kelp habitat suitability model, please see **7.3.1 Analytical framework** for a complete description of our approach and the layers.

7.5 Possible challenges and contingencies

7.5.1 Logistical problems

Conducting subtidal operations is inherently challenging. Field days often have to be postponed due to inclement conditions such as wind (especially when conducting our winter ROV surveys in Puget Sound). Furthermore, visibility can be heavily impacted by summer algal blooms, though we target our ROV surveys during specific times of the year when the water is relatively clear (most anytime *other* than May, June, July, and early August). We also target flooding tides or slack high tides, as these are associated with the clearest water. However, even when the marine and topside conditions are favorable, there is inherent risk associated with subtidal operations, especially when operating electronics such as ROVs in salt water.

To mitigate this risk, we have x2 ROVs from Blue Robotics—ROV *Nereo* and ROV *Lutris*. They are configured identically, such that if one goes down for whatever reason, we have a backup that can be seamlessly rotated into the field. Furthermore, part of the appeal of the Blue Robotics ROV system is that any given component can be easily replaced. If, e.g., the electronics enclosure floods (which we have not experienced before), we can simply obtain a new ROV electronics enclosure for $1,400 (linked here). This modular approach provides an added degree of redundancy for our operations. Finally, in order to further mitigate risk, we regularly conduct "pressure tests" of the ROV's enclosed and sealed spaces. These pressure tests (via a vacuum pump) are a key early warning of any issues with the ROV's o-rings, and conducting this test proactively enables us to correct any problems.

11.0 Data Management Procedures

11.3 Electronic transfer requirements

All electronic information (such as photo/video imagery and derived benthic data) will be stored on a secure DropBox account maintained by the Seattle Aquarium. Randell, Williams, and Thomson all have licenses to this account and thus have read/write/delete privileges. Any of the content on DropBox can be shared, viewed, and downloaded via links like this, and anyone can download the content at such links. However, the content at the link cannot be edited by anyone except the three Seattle Aquarium staff listed above.

13.0 Data Verification

13.1 Field data verification, requirements, and responsibilities

Research Technician Williams has developed a training and standardization program for our AI analyses of ROV survey imagery (**Figure 7**). Specifically, she developed a training pipeline where our Seattle Aquarium “AI Teacher” volunteers are taught to identify the 32 percent-cover categories of substrate, algae, invertebrates we identify from the downward-facing camera in Toolbox. This involves classroom sessions as well as at-home work with a species identification guide. Williams has recorded some of these training sessions so that they can be viewed repeatedly, if required.

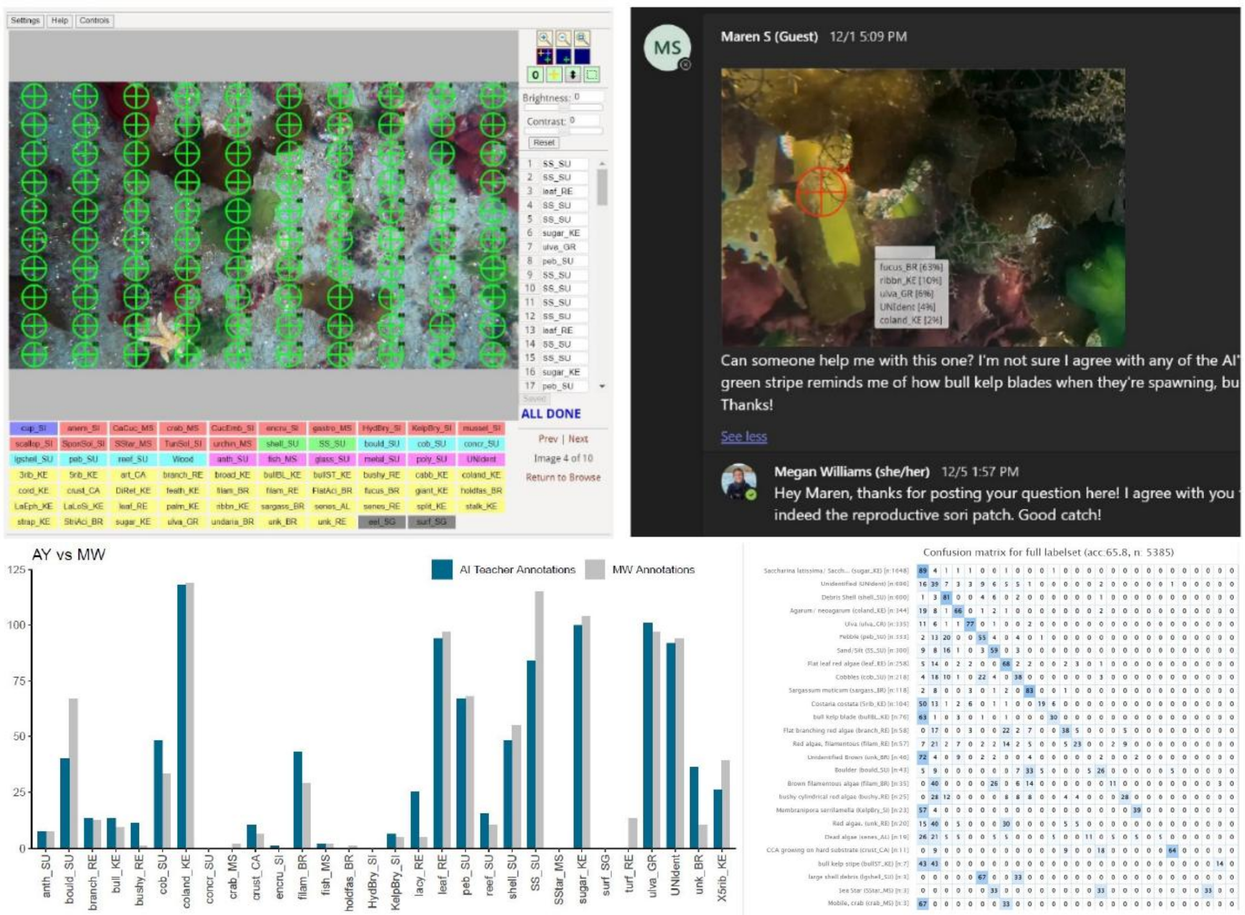

Figure 4. AI Teacher training process

Row 1. (Left) a training image with 100 points uniformly distributed that all AI Teachers annotate. (Right) our Microsoft Teams channel enabling questions to be answered. Row 2. (Left): an AI Teacher’s training annotations (in blue) versus our ground truth annotations (in gray), allowing rapid identification of error. (Right) our CoralNet algorithm's confusion matrix. The diagonal denotes the probability of the algorithm accurately identifying specific percent-cover categories.

Furthermore, once our AI Teacher volunteers are literate in the 32 percent-cover categories, as well as the CoralNet program they will interface with, they then go through a standardization process. Specifically, each AI Teacher "annotates" (labels a data point with the specific category underlying the data point) 10 images, each containing 50 data points, 500 data points total (see, e.g., **Figure 7** row 1, left). These data points are uniformly distributed across the image (in contrast to the random distribution of our "real" data points), enabling all AI Teachers to train on the same subset of data points. Once the training set is complete, Williams analyses the data and compares the AI Teacher annotations to her own via a *R* script, allowing her to view which categories were missed by the AI Teacher, or mislabeled (**Figure 7**, row 2, left). This enables us to identify any systematic errors or misunderstandings about the percent-cover categories.

Once this training procedure is complete, the AI Teacher graduates to labeling "real" ROV data from the field. However, again, Williams monitors the annotated data by reviewing all data points across every 10^{th} image to identify any trends in mislabeled data. If more than 10% of data are found to be mislabeled, we correct the image labels and have a conversation with the AI Teacher to help them understand correct labeling / identification.

Furthermore, note that we maintain a Microsoft Teams channel dedicated to our ROV methods development and AI training (**Figure 6** row 1, right). All of our Seattle Aquarium staff, volunteers, and Special Projects Volunteers are on this Teams channel, and this provides a communication platform through which AI Teachers can contact us with specific questions and obtain rapid feedback.

Note that our CoralNet AI algorithm has been trained on over 1000 images, with over 100,000 data points generated across eight Urban Kelp ROV sites thus far. The AI algorithm is making predictions, thus our AI Teachers are now manually reviewing the algorithm's predictions by marking each point as "verified", if labeled correctly, or by providing the correct label if the algorithm's guess was incorrect. As noted previously, certain common labels are being predicted with relatively high percent accuracies (e.g., sugar kelp is being identified correctly 89% of the time, **Figure 6**, row 2, right).

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15.0 References

Scientific literature cited:

Pierce, J., Clinton, E. (2023). CoralNet-Toolbox, GitHub repository, https://github.com/Jordan-Pierce/CoralNet-Toolbox

16.0 Appendices

Appendix A. SOP for ROV navigation and survey flights

Central to our ROV surveys is the ability to consistently and precisely record the geospatial positioning of the vehicle at all times. Across the latter half of 2022 and throughout 2023 we have implemented a SOP using three key sensors and open-source software to provide highly precise ROV positioning information, including a redundancy in case the primary acoustic systems exhibits error. The SOP, along with relevant links, can be found below. Please see here for a complete list of ROV, sensor, and topside parts and components associated with our work.

- Once the vessel is anchored securely above a ROV survey location, we first set up WaterLinked's Underwater GPS system. We use the U1 wireless acoustic transmitter affixed in a vertical position on the BlueROV2.
- Deploy the acoustic antenna. Plug the antenna cable into the G2 box, and power the G2 box. The depth of the receivers is set at increments of 0.5m, with x2 receivers at 1.5m depth and x2 receivers at a depth of 3m being advisable.
- The GNSS Satellite Compass should be mounted on the vessel with the front facing the bow. Plug the Power over Ethernet (PoE) into the GNSS Compass, and plug the other end into an Ethernet switch. The GNSS Compass, G2 box, and ROV laptop all need to be on the same network (192.168.2.1), and this can be achieved by plugging them all into a powered Ethernet switch.
- Measure the distances between the GNSS Compass to each of the D1 receivers mounted on the acoustic antenna, and enter those distances (including D1 receiver depth in the water column) into the UGPS GUI.
- Once powered, confirm the GNSS Compass is receiving a signal. In BlueOS (a program we use to fly the ROV), pull up wl_ugps_external_extension—a custom, open-source piece of software that will feed GPS positioning and compass heading information from the GNSS Compass to the UGPS G2 box (thereby enabling far more precise GPS and compass information than the G2 box is able to obtain by itself). Once the extension is running in BlueOS and all four indicators are green, the vehicle is ready to fly and coordinates will be automatically recorded in QGroundControl's .csv telemetry log.
- In order to fly a mission, load a preprogrammed Mission Plan in QGroundControl. These Mission Plans can take variety of forms, but in short, they provide the specific tracklines across which we want to fly the ROV and gather imagery. The Mission Plans are to be configured ahead of time via latitude/longitude coordinates provided either manually in QGroundControl or via a .csv.
- Power the ROV, time-sync the cameras (see **Appendix B. SOP for camera settings and imagery processing**), power the externally mounted lights, and deploy the ROV over the side of the vessel. Fly the ROV to either the Mission Plan's individual transect survey (in the summer) or a grid pattern (in the winter). Proceed with the survey, i.e., fly the vehicle

such that the ROV “icon” in QGroundControl (denoting the precise GPS location of the vehicle) is atop the tracklines. Activate *surftrak* as to autonomously keep the ROV 1m above the substrate. Fly the vehicle at no more than 0.3m/s. Once the survey is completed, retrieve the vehicle and download the .csv telemetry file from QGroundControl containing the GPS coordinates from the mission, as well as the GPS coordinates generated by the DVL.

- In the event there is some sort of issue with the navigational system, we can always fall back to using information from the WaterLinked [Doppler Velocity Log] (DVL) to plot our surveys. This redundancy ensures our surveys always have precise spatial tracking.

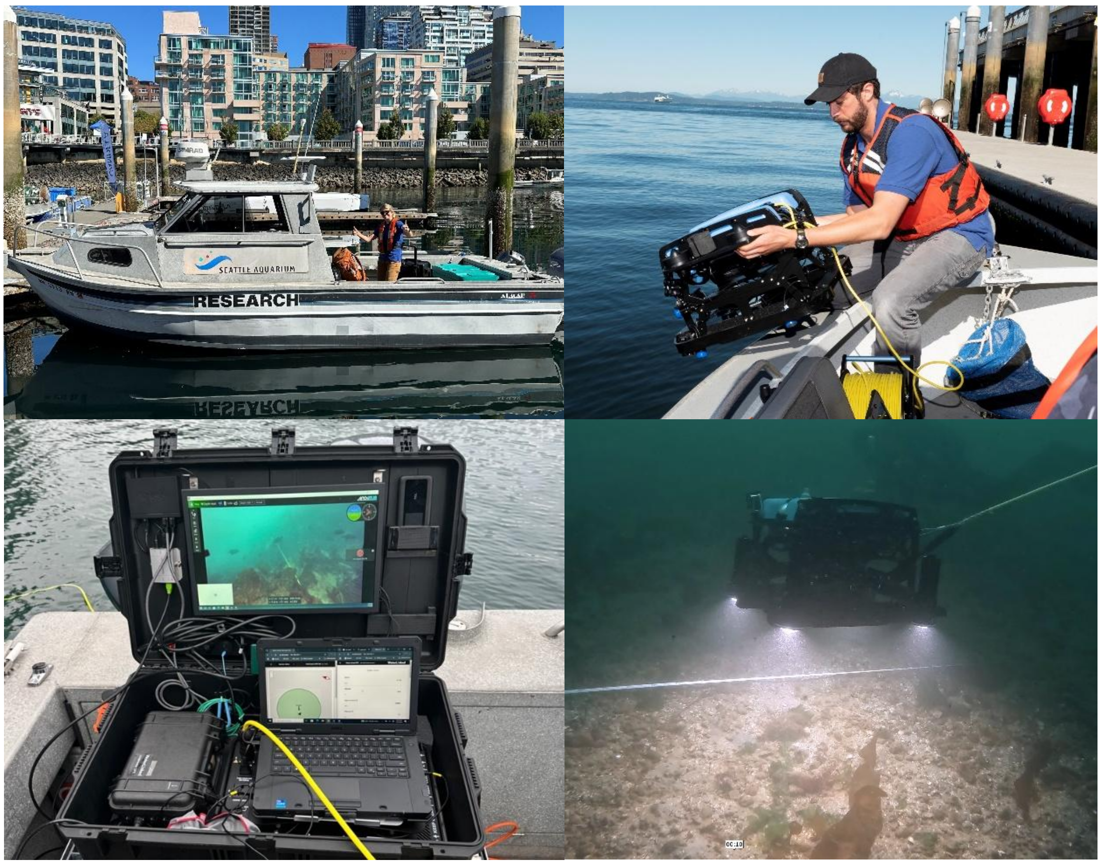

Figure A1. Seattle Aquarium vessel and field deployment of the ROV. Row 1. (left) the Seattle Aquarium vessel, a 24’ Aluminum Almar; Randell and Williams are trained vessel operators. (right) Randell deploying ROV *Nereo* off the side of a vessel. Row 2. (left) the Command Console used to track and fly the ROV. (right) ROV Nereo illuminating and filming the seafloor beneath Pier 59 along the Seattle waterfront.

Appendix B. SOP camera settings and imagery processing

We use the following settings on our GoPro HERO 12 video cameras, as well as the following steps to edit the resulting imagery:

- GoPro video settings: 4K resolution 30fps frame rate, Wide lens, ISO = 100-1600, Native White Balance, Flat Color, High Sharpness, 0.0 EV Comp.
- Produce video clips for each transect in Davinci Resolve 18 by combining and trimming videos to isolate the beginning and ending of each transect. We delete the interim "travel" period (flying the ROV to and from the survey location) once the transect has been extracted.
- Adjust the color balance of the video to achieve a natural white balance in Davinci Resolve 18. Use pre-configured white balance settings to generate realistic colors from the Native White balance setting (akin to shooting Raw photos). You can see the difference between the "Native" video we shoot vs the processed videos here.
- Extract the sharpest image at intervals of 8 seconds using a Python code (linked here)
- Proceed with analysis of still images (see **Appendix C. SOP to train CoralNet-Toolbox and extract data**).

We use the following setting on our GoPro HERO 12 to shoot time lapse photos of the seafloor, as we have found the photos are of higher quality than stills extracted from video:

- Timelapse photo, Wide, 3 fps, RAW, native white balance, ISO 100-200, sharpness low, color flat, shutter speed 1/300. Customize the settings using GoPro labs firmware website (specific setting customized here).
- Time sync command via QR code introduced to the cameras stereo pair just before the survey begins.
- Transfer the data from the SD card to the DropBox folder corresponding to the date of the survey.
- Import photos to Adobe Lightroom software for images editing.
- Process the photos by adjusting overall exposure, highlights, shadows; apply dehaze effect, enhance texture and clarity; color correct by adjusting a tone curve.

Appendix C. SOP to train a classification model in CoralNet-Toolbox

The following steps are required to create a training dataset, train a classification model using Ultralytics YOLO in Toolbox, and apply the model to make predictions.

1. Toolbox installation and setup
    - Instructions for installing and running Toolbox can be found in the documentation linked here.

2. Prepare training and testing images
    - Ensure images are color corrected and a quality desired for analysis.
    - Split images into training and testing folder. Our technique is:
        - Training folder: Move 2 out of every 3 images here.
        - Testing folder: Move 1 out of every 3 images here.

3. Load labelset
    - Open Toolbox and import your classification labelset
        - Go to Labelset → Import
        - Our JSON labelset can be found here. You can also preview the labelset in Excel here.

4. Import and annotate training images
    - Import training images into Toolbox
        - File → Import → Rasters → Images
    - Create images patches (classification annotations)
        1. Select a label in the lower label window.
        2. Choose the image patch tool (rectangle icon) from the toolbar on the left.
        3. In the annotation window (center window), left click the appropriate location in the image to add a patch for that label.
        4. Repeat for each label across your training images.

5. Export classification dataset
    - After annotating, export the dataset:
        - File → Export → Dataset → Classify
    - Toolbox will generate a dataset directory containing train, validation, and test folders with labeled image patches.

6. Train classification model
    - Start training a YOLO classification model
        - Ultralytics → Train Model → Classify
    - In the training window:
        - Dataset: Click Browse and select the exported dataset folder.
        - Model Selection: Choose the Ultralytics YOLO model that fits your needs (e.g., YOLOv8 or YOLOv11). A guide comparing model options is available here.
        - Parameters:
            - Set the location where you want your trained model to be saved.

        - You can use default training parameters or customize them. More information about the parameters can be found here.
    - Click OK to begin training. You can monitor training progress in the terminal.

7. Load and deploy model
    - After training completes:
        - Go to Ultralytics → Deploy Model → Classify
        - Under Actions, click Browse Model and select your trained weights file (best.pt).
        - Click load model

8. Test the model on new images
    - Remove training images:
        - In the image window, click "Select All", right-click and select delete all images to remove.
    - Import test images:
        - File → Import → Rasters → Images and choose the testing folder.
    - Create random image patches:
        - Click Sample at the top
        - Set your desired sampling configuration (e.g., number of patches).
        - Set Select Label to Review
        - Check "Apply to all images" and click Accept

9. Run predictions
    - To predict label for the new image patches:
        - For a single image: press Ctrl + 1
        - For all images:
            - Ultralytics → Batch Inference → Classify
            - Check "Apply to all images" and "Predict review annotation"

10. Review and correct predictions
    - Predicted labels appears for each review image patch.
    - Confidence levels are shown in the Confidence window.
    - To fix incorrect predictions:
        - Select the image patch so that it is shown in the Confidence window
        - Select the correct label in the label window

11. Export and improve dataset
    - To analyze results
        - Export annotation file as a .csv file: File → Export → CSV

- To improve your model
    - Create a new dataset with the corrected predictions
    - Merge this with the original dataset:
        - Ultralytics → Merge Datasets → Classify
        - Set a name and location for the merged dataset
        - Class Add Dataset and select the datasets you want to combine

12. Improve existing model
    - The merges dataset can now be used to train a new model following Step 6.
    - Instead of selecting a new YOLO model, you can use your existing model:
        - Under Model Selection switch to Use Existing Model
        - Browse to the model weights (best.pt)

Appendix E. SOP for PSRF ROV monitoring

ROVs have yet to be used to monitor bull kelp restoration, nor have Seattle Aquarium personnel participated before in this bull kelp restoration, so the first few instances of our participation in these activities will be experimental such that we intentionally work to identify how best to use our ROV to supplement the diver surveys that monitor these outplanted locations. That being said, certain field protocols are already established, especially regarding the before-and-after full site surveys along the "restored" (or enhanced) vs control locations:

- Prior to the deployment of the bull kelp seed, Seattle Aquarium personnel will motor to the Jefferson Head enhancement site and deploy anchor as close as possible to the site.
- We will deploy our ROV (no divers) along with all navigational equipment (our acoustic GPS system, GNSS Satellite Compass) as to provide precise tracking. Using information from PSRF, we will have programed the center of the enhancement site into our navigational system such that we can see that waypoint and navigate accordingly.
- We will run the ROV systematically such that we survey "back and forth", specifically in a reciprocal transect manner (with 1m spacing between reciprocal transects), as to obtain benthic-facing imagery that slightly overlaps between adjacent transects. This will allow us to image the same "spot" multiple times between adjacent transects, thereby enabling the construction of 3D models. These overlapping transects will encompass at minimum a 500 square meter grid, providing a comprehensive accounting of the seafloor and fine-scale substrate considerations. This back-and-forth sampling will proceed with a grid

overlayed on our screens on the vessel, such that we simply fly the ROV along a pre-determined path.

- These full site surveys will take place at the enhancement sites (at Jefferson Head) as well as a simple, "control" site at Centennial Park where bull kelp is known to control. The purpose of this is to compare and contrast the restored location to a control location as to disentangle any possible differences in local factors such as, e.g., substrate type.
- Furthermore, these full site surveys will take place in March, prior to deployment of the bull kelp seed, and in June, at the conclusion of the PSRF monitoring, as to provide a before and after comparison.

In addition to the beginning and end of the bull kelp monitoring season surveys, we will supplement PSRF's diver based surveys of the outplanted bull kelp by surveying during the "off weeks". That is to say, PSRF's divers survey every other week, thus we will supplement these surveys by surveying via the ROV when the divers are not present. This will provide greater temporal resolution regarding the growing patterns of the outplanted bull kelp. Note - we found this to not work particularly well. Specifically, in the summer when the algae blooms are in full bloom, we simply do not have enough water visibility to navigate the ROV safely.

Appendix G. Glossaries, Acronyms, and Abbreviations

Glossary of General Terms

Extended Kalman Filter (EKF): a Bayesian statistical framework that integrates multiple sensor streams (e.g., from our acoustic GPS tracking system, Doppler Velocity Log, and compass) into a single point estimate for where in the world the ROV is. ArduSub (the ROV flight control software we use) automatically performs these calculations.

Acronyms and Abbreviations

EKF	Extended Kalman Filter