research overview: Coastal Complexity & Resilience

Seattle Aquarium | *Conservation Programs and Partnerships*

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1 Overview

Coastal species such as kelp, invertebrates, fishes, and marine mammals are increasingly threatened from climate-change related disturbances such as anomalous warm-water and marine-disease events. Unfortunately, our ability to understand the health and trends of these species is limited by the lack of widespread monitoring, as shallow, benthic ecosystems are logistically difficult to survey. *Unmanned systems such as Remotely Operated Vehicles (ROVs) and Artificial Intelligence (AI) methods of analysis have the potential to radically alter the amount of data we can collect, analyze, and use to guide fishery and conservation decision-making, but thus far these tools have yet to be systematically incorporated into a benthic monitoring program.*

In conjunction with Tribal, state, federal, and non-profit partners, Conservation Programs and Partnerships (CPP) at the Seattle Aquarium is initiating a new research project to fill this data collection and analysis need: Coastal Complexity and Resilience (CCR). The CCR project will expand upon ongoing CPP long-term monitoring of sea otters along the Outer Coast and rockfish in the western Strait of Juan de Fuca and throughout Puget Sound, while simultaneously utilizing novel ROV and AI methods to establish new subtidal sentinel sites throughout these regions. In parallel—and in keeping with Seattle Aquarium values of Honoring Place and Learning and Improving—we have engaged with coastal Tribes, schools, and communities in order to share our motivation, methods, and findings with those livest closest to these ecosystems. *Our ultimate objective: better understand the biological processes—such as the role of keystone sea otter predation—that provide resilience to Washington's coastal ecosystems.*

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2 Motivation

Climate change poses a significant threat to coastal ecosystems. This was recently demonstrated during the 2013-2015 anomalous warm-water event (i.e., "The Blob") and subsequent El Niño phase along the Pacific northeast: in northern California alone, more than 90% of bull kelp was lost along 350 km of coastline, sea urchin density increased 60-fold, the sunflower star became locally extinct, and red abalone declined via starvation by up to 96%, resulting in the closure of its productive fishery in California and Oregon (292 mt per year) [1, 2]. Curiously, despite widespread kelp loss to the north (British Columbia) and south (Oregon), canopy-forming kelp along Washington's Outer Coast appear to have largely recovered after a relatively minor decline associated with the 2013-2015 anomalous climate events (Helen Berry, DNR; Dr. Andrew Shelton, NMFS). Despite experiencing widespread sea star wasting, the rapid kelp rebound suggests the Outer Coast may exhibit a degree of resilience, i.e., the capacity to recover after a disturbance. The exact reason(s) why remain(s) unclear. At a regional scale (e.g., coastal Washington versus Oregon), it is possible the local sea otter (*Enhydra lutris kenyoni*) population contributed to this resilience [3, 4]—yet patches of urchin barrens still developed offshore of Tatoosh and the Western Strait following the 2013-2015 disturbances. Environmental drivers are important for structuring kelp dynamics along the Outer Coast [5]—yet the same broad environmental conditions lead to widespread kelp loss elsewhere. Given the likelihood of future climate-related disturbance events, understanding the health, trends, and functioning of coastal habitats and species—all required for effective conservation and management—requires additional information [6].

3 Methods

In collaboration and partnership with the Makah Tribe, National Marine Fisheries Service (NMFS), Olympic Coast National Marine Sanctuary (OCNMS), Puget Sound Restoration Fund (PSRF), Washington Dept. Fish and Wildlife (WDFW), and with support from the Sea Otter Foundation and Trust, North Pacific Coast Marine Resources Committee, and the Port of Seattle, the Seattle Aquarium is launching a new project to better understand the patterns of and processing affecting benthic community structure and ecological resilience in Puget Sound and along the Outer Coast. The CRR project will utilize: (*1*) cutting edge surveillance technology to gather imagery of shallow (5-40m) subtidal ecosystems including kelp forests and urchin barrens and (*2*) machine learning algorithms to process our imagery at scale, all while (*3*) engaging coastal communities and schools about the health of their ecosystems.

3.1 *Long-term ROV monitoring of subtidal sentinel sites*

Unmanned systems such as ROVs have the potential to radically expand the spatial extent across which we can gather information, but thus far their large size and expense has mostly restricted ROV usage to exploring deep locations unsuitable for divers [7]. However, technological advancement has produced models that are small, affordable, capture high-resolution imagery, and are deployable from small vessels [8]. At present, the Seattle Aquarium has obtained, tested, and customized a BlueROV2 from Blue Robotics, named Waksa·s, a Makah word for octopus. We will use Waksa·s to conduct transect-based surveys along fixed subtidal index sites, gathering photos and video of benthic species such as understory and canopy-forming kelp, invertebrates such as sea stars, sea urchins, and abalone, and fishes such as rockfish. These surveys will first expand upon existing Seattle Aquarium index sites, and then in collaboration with our Tribal partners, we will establish a new network of index sites along the western Strait and Outer Coast.

3.2 *AI algorithms to process ROV-imagery at scale*

As it would not be feasible for a human to review the vast sum of photos and video we intend to collect, we have trained machine learning algorithms to extract community data from our imagery. Specifically, we are using CoralNet [9] to calculate metrics of percent-cover for aggregated taxa (e.g., sponges, understory algae, tunicates, as well as substrate type such as sand, cobble, shell debris, mud, hard substrate), and VIAME [10] to calculate abundances of individually conspicuous species (e.g., sea urchins, sea stars, abalone, fishes). By pairing large amounts of community data with existing habitat layers (e.g., from side-scan sonar derived benthic mapping), we will investigate the patterns, trends, and health of species across larger areas than SCUBA divers are logistically able to operate. And by regularly surveying these index sites as part of a long-term monitoring program, our research will directly investigate the patterns of and processes modifying the resilience of coastal ecosystems following disturbance events.

3.3 *Engage with coastal communities and youth*

Finally, in order to share our motivation, methods, and findings with coastal communities, we are expanded upon existing relationships and forging new ties along the Outer Coast. The Seattle Aquarium has a long relationship with the Makah, and we are working closely with Makah Fisheries Management (MFM) personnel in all aspects of this project. We have also established a dialogue with natural resource managers for the Hoh Tribe, Quileute Tribe, Quinault Indian Nation, and Samish Indian Nation. We are presently working with teachers at Neah Bay High School and the Quileute Tribal School to create and deliver lecture content about kelp forests, sea otters, climate change, and the ROV and AI tools we are using to evaluate coastal ecosystems. We are also working with the Seattle Aquarium's Community Education and Learning department to modify one of their existing Community Science (CS) activities, a multi-day introduction to data collection, hypothesis generation, data analysis, and research presentation. Our version of CS will utilize the ROV, AI, coding: students will participate in a ROV dive (e.g., in the Makah harbor for Neah Bay High School students), formulate a testable hypothesis based on the imagery, use VIAME to annotate the images, visualize and analyze the exported data with pre-configured scripts in *R*-studio, and finally, present their findings to their peers. Experiencing ROV-based research in their own backyard, so to speak, along with the introduction to coding—all with a backdrop of evaluating ecologically pressing questions—will provide meaningful STEM exposure to areas of coastal Washington that may not typically receive much outreach attention.

4 Additional information

Click here to see a presentation at the November 2021 Puget Sound Kelp Research and Monitoring Workgroup, given during the early stage of the CCR project. Furthermore, you can view lead Principal Investigator Randell being interviewed by Diane Tomecek, CEO and President of the Sea Otter Foundation and Trust (SOFT) regarding the CCR project. To view a recent synopsis of ROV testing and the proof-of-concept development of AI methods of analysis, download the report linked here. When opened in a pdf reader, this document links to videos from the ROV.

In an effort to make research open-source and available to all, Randell has his Ph.D. public dissertation defense on YouTube here, and his full dissertation can be found here. Finally, you can view more information on Randell's ResearchGate and GitHub page.

5 References

[1] L. Rogers-Bennett and C. A. Catton. “Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens”. In: *Scientific Reports* 9.1 (2019). DOI: 10.1038/s41598-019-51114-y.

[2] Sarah Gravem et al. “IUCN Red List: Sunflower Sea Star (Pycnopodia helianthoides)”. In: https://www.iucnredlist.org/species/178290276/178341498 (2020).

[3] Douglas B. Rasher et al. “Keystone predators govern the pathway and pace of climate impacts in a subarctic marine ecosystem”. In: *Science* 369.6509 (2020), pp. 1351–1355. DOI: 10.1126/SCIENCE.AAV7515.

[4] Andrew O. Shelton et al. “From the predictable to the unexpected: kelp forest and benthic invertebrate community dynamics following decades of sea otter expansion”. In: *Oecologia* 188.4 (Dec. 2018), pp. 1105–1119. DOI: 10.1007/s00442-018-4263-7.

[5] Catherine A. Pfister, Helen D. Berry, and Thomas Mumford. “The dynamics of Kelp Forests in the Northeast Pacific Ocean and the relationship with environmental drivers”. In: *Journal of Ecology* 106.4 (2018), pp. 1520–1533. DOI: 10.1111/1365-2745.12908.

[6] Brent B. Hughes et al. *Long-Term studies contribute disproportionately to ecology and policy.* 2017. DOI: 10.1093/biosci/biw185.

[7] Owen Hamel et al. “Methodology Review Report: 2020 Methodology Review of ROV Survey Designs and Methodologies”. In: (2020).

[8] Elena Buscher et al. “Applying a Low Cost, Mini Remotely Operated Vehicle (ROV) to Assess an Ecological Baseline of an Indigenous Seascape in Canada”. In: *Frontiers in Marine Science* 7.August (2020), pp. 1–12. DOI: 10.3389/fmars.2020.00669.

[9] Ivor D. Williams et al. “Leveraging automated image analysis tools to transform our capacity to assess status and trends on coral reefs”. In: *Frontiers in Marine Science* 6.APR (2019), pp. 1–14. DOI: 10.3389/fmars.2019.00222.

[10] Matthew Dawkins et al. “An open-source platform for underwater image & video analytics”. In: *Proceedings - 2017 IEEE Winter Conference on Applications of Computer Vision, WACV 2017* (2017), pp. 898–906. DOI: 10.1109/WACV.2017.105.