Using a historical ecology approach to describe algal community change: Neushul revisited

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"In areas of high sediment and presumably low current velocities, an exceedingly disorderly growth of laminarians covers the bottom, looking like wide, dust-covered leather straps cast randomly about."

- M. Neushul, 1967

Abstract

Marine macroalgae provide important ecosystem services that warrant attention. Shifting baselines across decadal time scales make it difficult to detect and understand long-term changes in macroalgal communities. Historical data can provide the basis for these long-term comparisons, but is sparse for benthic systems. This study aims to use one rare comprehensive survey of benthic macroalgae in the San Juan Islands, Washington published by Michael Neushul in 1967 as a historical baseline for surveys of the benthic macroalgal community along the Brown Island shoreline. By repeating dive surveys along three of Neushul's original transects, using a DropCam to take still photos along ten transects, and conducting snorkel surveys along the shoreline edge of three transects, we make comparisons between the state of Brown Island algal communities in 1962/63' and July of 2021. We found that the presence of the canopy forming kelp *Nereocystis luetkeana*, which was observed in Neushul's original study, has reduced almost to nothing. Snorkel surveys along the shoreline and one dive survey showed the presence of the invasive brown seaweed *Sargassum muticum* that was not present in 1967. In general, subcanopy kelps and understory macroalgae are not a focus of recent studies of kelp distribution changes. This study provides a unique description of understory macroalgae communities with historical context. Further study of this area and a more thorough repetition of Nueshul's original transects can provide deeper insight into long-term trends and the current state of the Brown Island macroalgal community.

Introduction

Marine macroalgae, commonly known as seaweeds, provide key ecosystem services. They form structural near-shore habitat, act as a major input to the marine food web, and sequester carbon via primary production (Klinger 2015). In the Puget Sound seaweeds flourish in cold, clear, temperate waters and provide habitat to many organisms including kelp crabs and their predators, several species of locally threatened and endangered rockfish . Seaweeds are known to be the primary trophic resource in many near-shore habitats. They contribute significantly to marine primary production, removing dissolved carbon dioxide directly from the water as they grow. As an important ecosystem resource, it’s prudent to monitor macroalgal community structure and how this resource may be changing over time.

Transect surveys conducted with SCUBA diver observations and underwater photography are one current method used to measure algal community structure: recording plant associations, biodiversity, abundance, and distribution. Repeated transect surveys can be used to detect changes in these algal communities over time. Changes that occur over decadal time scales can be very different from the changes that we can observe under shorter time periods due to the seasonal and interannual variability of macroalgal communities. Shifting baselines through time alter our expectations of how communities might change in the future (Magurran et al. 2010; Dayton et al. 1998), making it important to contextualize transect surveys with a historical baseline.

Historical data can be a valuable tool for uncovering the structure and trajectory of communities (Carnell and Keough 2019; Lindenmayer et al. 2012). However, comprehensive historical surveys of the benthos are sparse. Complexities arise when considering that methods for data collection change through time. Modern tools allow us to collect ever larger quantities of data with more detail that may not be comparable with historic methods. This presents challenges when comparing historical ecological data to modern data.

In 1967, University of California Santa Barbara botanist Michael Neushul published a comprehensive benthic survey of marine macroalgae off Brown Island in the San Juan Islands entitled 'Studies of Subtidal Marine Vegetation in Western Washington'. This survey is a rare gem. It's a comprehensive historical baseline that uses modern transect survey techniques, making repeatability easy and accessible. SCUBA and underwater photography were cutting-edge marine research technologies in the early 1960's. Now, in 2021, they are standard and affordable. This makes it possible to repeat M. Neushul's survey methods and contextualize our benthic transect surveys with a historical baseline. M. Neushul sought to answer the question "What macroalgae are located in the nearshore habitat off Brown Island and what is their community structure?" This study conducted in 2021 seeks to build on the 1967 historical study to observe how the macroalgal community may have changed over the last 60 years and make a direct comparison between the state of algal communities in 1962/63' to July of 2021 in the San Juan Islands

The 1967 Neushul study identifies Laminaria as the dominant genus associated in the shallows, with Agarum dominating the mid-depths and red crustose and filamentous algae in the deeper portions of the surveyed transects (Neushul 1967). We anticipate that present-day surveys may observe similar patterns of significant losses of brown macroalgae within the order Laminariales, specifically of the species *Nereocystis luetkeana* (bull kelp), as have been observed both globally and within in the Salish Sea (Krumhansl et al. 2016, Berry et al. 2021). While changes in the abundance and distribution of these canopy forming kelps have been closely studied, the understory macroalgae are of particular interest to us in this survey because comparatively little is known about changes in their extent. Unlike bull kelp, understory macroalgal communities are not visible from the surface and historically, were not commonly observed. The study by M. Neushul provides a unique opportunity to compare current benthic understory macroalgal communities to a historical baseline.

Materials and Methods

This study has three main components: historical data extraction, field surveys, and analysis. Historical data extraction is further broken into two categories, explicit extraction and calculated extraction. Explicit extraction is the scraping of published values within the paper (e.g.: transect depths, lengths, cluster analysis values, etc.). Calculated extractions are those values that must be inferred or calculated separately from implicit data embedded within the paper (e.g.: GPS coordinates from maps, abundance calculations, etc.). Calculated extraction also includes those summaries or visualizations that we are able to create from extracted data not included in the original paper (e.g.: diversity metrics, summary statistics, new clustering models, etc.).

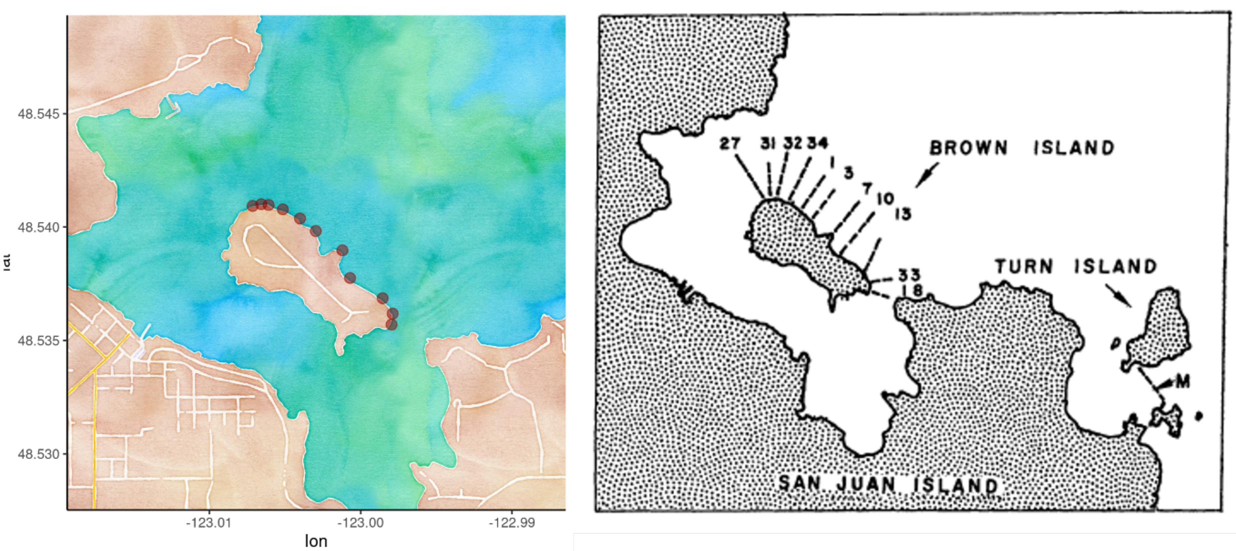

Figure 1: Left) Map of Friday Harbor and Brown Island with GPS coordinates of the beginnings of each original Neushul transect indicated in red, Right) Original map of transects published in Neushul 1967.

Historical Data Extraction

Neushul Table 1 data was extracted directly by copying out values into a spreadsheet. Transect cross-section data was extracted by mapping a grid over each figure in GIMP, and then keyed out by eye. Cross-section values extracted include: transect segment (ft), transect segment depth (m), substrate type, icon representation of cover (species/group), and cover associated with Neushul Table 1.

(species/group). Starting GPS points for SCUBA transects were extracted from Neushul Figure 1. using Google Earth, and transect heading and length were taken by overlaying map images with compass bearings in GIMP, and referencing individual transect lengths in Neushul Figures 6-9 (Table 1). Algae taxonomy information from the Neushul paper was extracted and cross-referenced with AlgaeBase to find the currently accepted genus and species names.

Table 1: GPS points for transect origins extracted from Neushul Figure 1. using Google Earth. Transect length and maximum depth were taken from Neushul transect cross-section figures.

Site #	Lon	Lat	Heading	Length (m)	Max Depth (m)
27	-123.0071	48.5409	330	138	14
31	-123.0065	48.5410	355	122	18
32	-123.0060	48.5409	15	83	20
34	-123.0051	48.5407	30	71	24
1	-123.0040	48.5403	35	61	24
3	-123.0029	48.5398	35	61	20
7	-123.0012	48.5389	40	74	24
10	-123.0007	48.5377	40	141	20
13	-122.9985	48.5368	25	132	26
33	-122.9978	48.5361	80	46	28
18	-122.9979	48.5357	110	52	24

Field Surveys

To identify more applicable methods to replicate data gathered in Neushul and to assess the time taken for each transect survey, a limited number of exploratory dives were made around Brown Island. Three representative transects were identified from the original paper: Transect 3, 27 and 33. Additionally, snorkel surveys were done using similar methods along a shallow bathymetric contour, crossing the shoreward origin of the original Brown Island transects.

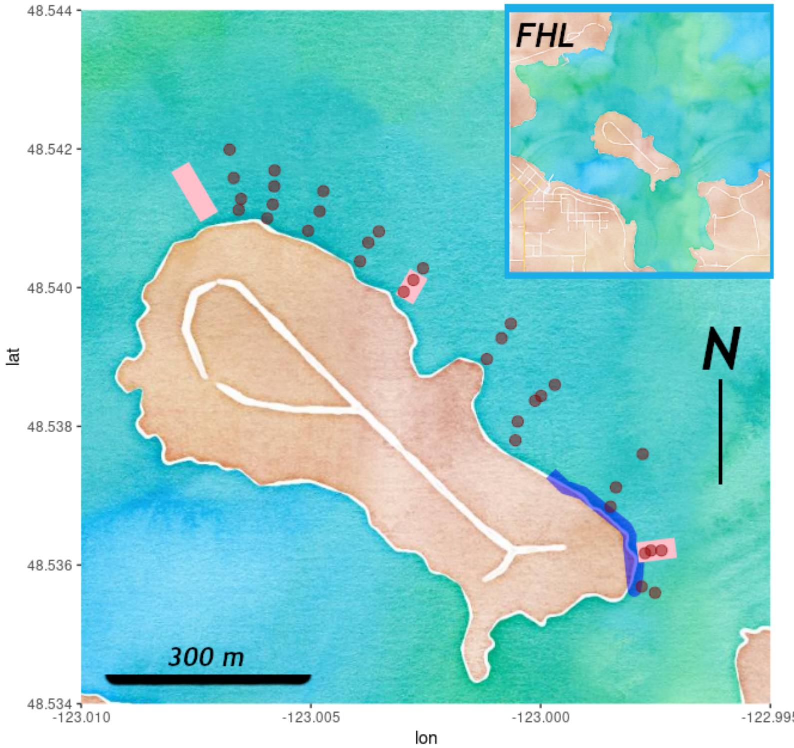

Figure 2. Map detail of Brown Island showing location of dive surveys (solid pink line), DropCam locations (red dots), and snorkel survey (purple highlight).

Field data collections were made with the following specific goals:

1. Dive surveys

    - *Lay transect tape* (from GPS starting point along heading to depth [buddy 1]; data collected on return)
    - *Uniform point count (UPC) data collection* (collected every 5 feet along transect: substrate type, all organisms directly above/below line on meter tape [buddy 1])
    - *Video data capture* (using GoPro underwater camera with SOLA dive light; centered on transect line moving shoreward [buddy 2])

We targeted 3 of the original dive surveys on transects 3, 27 and 33. Dive data was collected on 2021-07-08 and 2021-07-09 with Brown Island access via a Friday Harbor Lab small research boat.

2. Snorkel surveys: at high and low tides, conducted parallel to shore at 1.5m depths.

   - *Lay transect tape parallel to shore* (perpendicular to dive transects at high and low tide [buddy 1])
   - *Uniform point count data collection* (collected every 10 meters along transect: substrate type, all organisms directly above/below line on meter tape [buddy 2])
   - *Video data capture* (using GoPro underwater camera with SOLA dive light; centered on transect line [buddy 3])
   - *Track path of snorkel* (using GPS in float [buddy 3])

   Snorkel surveys crossed the shallow ends of transects 18, 33 and 13 with tape laid out at 1.5m depth at a high (+5.1ft at 15:00 on 2021-07-06) and a low (-1.8ft at 11:58 on 2021-07-10) tide. Snorkel data was collected with Brown Island access via rowboat. Dropcam surveys were conducted along the lengths of all but one original transects: 1, 3, 7, 10, 13, 18, 31, 32, 33, and 34 at sites indicated on Figure 2. Snorkel survey methods are described in detail in Appendix B.

3. Dropcam surveys: with selected points along all transects

   - *Selected points along transects* (see Figure 2)
   - *Lowered Dropcam via metered line* (depth determined by meter markings on the line)
   - *Video data capture* (using GoPro underwater camera on PVC frame with SOLA dive light)

   Dropcam data was collected on 2021-07-01 and 2021-07-07 with Brown Island access via rowboat and a Friday Harbor Lab small research boat.

Analysis

Datasheets with dive and snorkel observations were transcribed into an R table for cluster analysis and for comparison with observations from Neushul's 1967 survey. We used M. Neushul's cross-section figures (Figures 6., 7., and 9., Neushul 1967) of dive transects 3, 27 and 33 to identify dominant taxa along each respective transect. We then treated the dominant taxa as a uniform point count to be able to compare the historical baseline survey to our survey. Transect video from dive surveys was analyzed for dominant species cover and associations at depth. Still photos of the dropcam video were analyzed using [CoralNet](). CoralNet is a free, open source site that uses deep neural networks to fully and semi automatically annotate images (Beijbom, 2015). CoralNet also serves as a data repository for benthic image analysis. We created our own Source (project folder of 34 images) and labelset (set of 27 labels, see Table 2) that we used to annotate the DropCam images. We manually labelled algae in the photos using the CoralNet in-browser image annotation tools. A simple random 25 point generator overlaid each image (Figure 7). Annotations were made by identifying the dominant algae at each crosshair. Each image was tagged with metadata fields associated with it: transect number, deployment number, location (latitude/longitude), depth, drop-time and date. Once all images in our Source were annotated, we then exported annotation details for all the images for further analysis conducted in R.

Results

Dive Transect Surveys

We used M. Neushul's cross-section figures (Figures 6., 7., and 9., Neushul 1967) of dive transects 3, 27 and 33 to identify dominant taxa along each respective transect (Figure 4). We then treated the dominant taxa as a uniform point count to compare Neushul's historical survey with our own uniform point count surveys of transects 3, 27 and 33 (Figure 3). Generally, the 1967 survey had more *Laminaria spp*., *C. costata*, and red bladed algae than the 2021 survey. We observed a similar presence of *N. fimbriatum* in

2021 as was observed by Neushul in 1967. Notably, M. Neushul observed *Z. marina* on transects 3, 27 and 33 which we did not see at all on the SCUBA transects conducted in 2021 (however we did see *Z. marina* in the dropcam video exclusively along transect 10). In the 2021 survey, we observed *S. muticum* which was not present in the 1967 survey. Finally, we observed more areas with 'no' algae. This could be either because there is indeed far less cover than when the original surveys were done, or because the 1967 survey simply listed algae as 'dominant', even if it had extremely sparse cover.

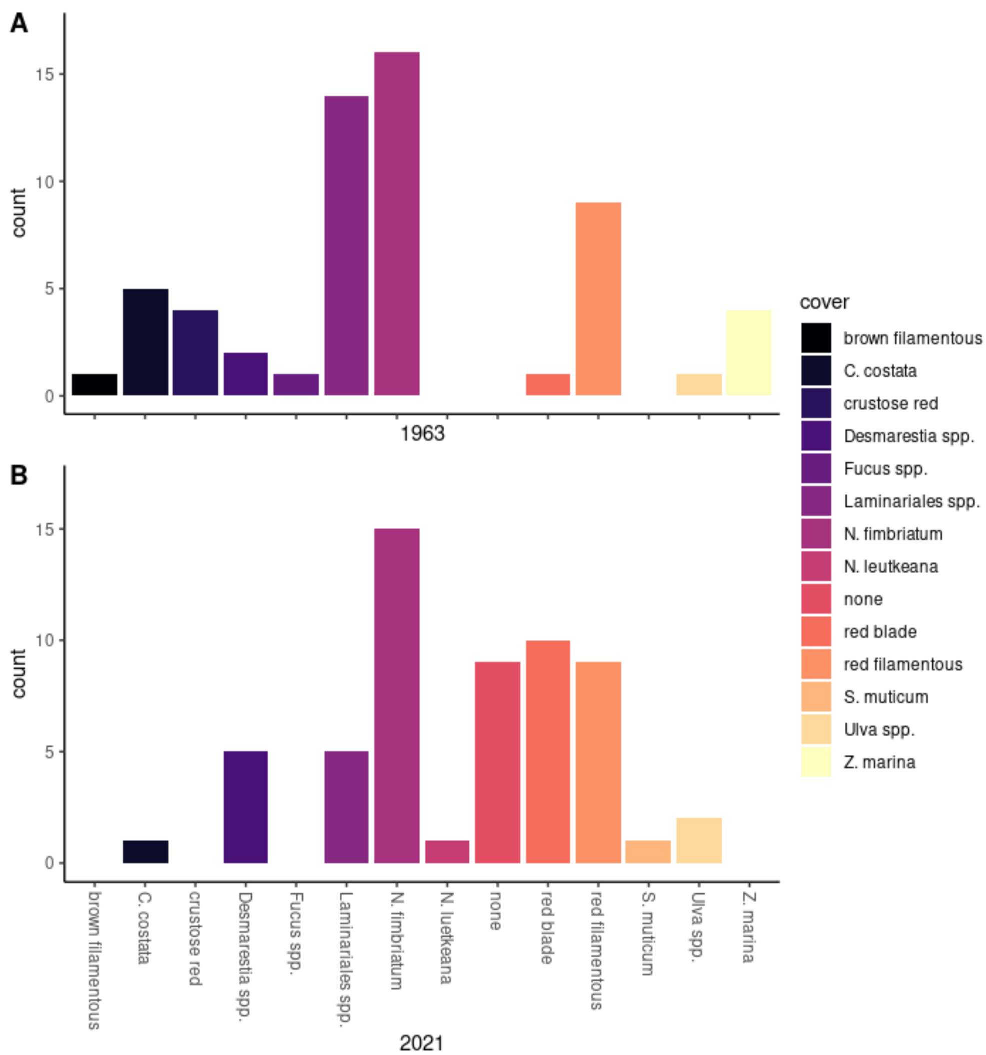

Figure 3. A broad comparison of SCUBA diver uniform point count (UPC) data (B) with the original Neushul data (A) along the repeated transects (3, 27, and 33). Across the x-axis are lumped categories created to directly compare the datasets, the y-axis is the number of times that category was counted.

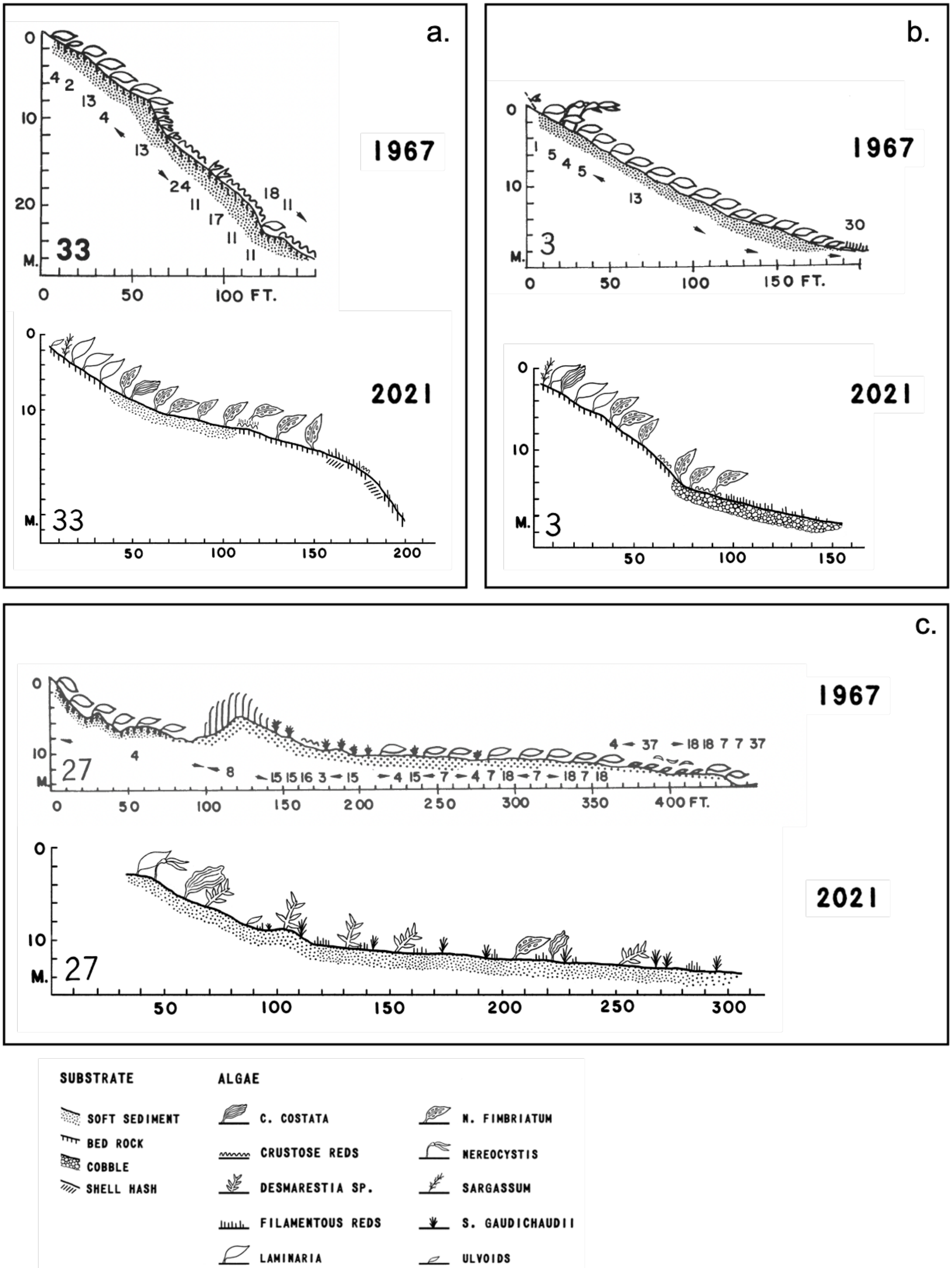

Figure 4. Illustrated cross sections of dominant algal taxa along transects 33 (a), 3(b), and 27 (c) showing a comparison between algae observed in original Neushul dive surveys and dive surveys repeated in this study. Adapted from Neushul 1967 Figures 6., 7., and 9.

Snorkel Surveys

The snorkel surveys were conducted parallel to the southeast coast of Brown Island in the shallows. The main goal of the snorkel surveys was to look more closely at the shallow zones of the mid intertidal to the upper subtidal off Brown Island. We conducted two snorkel surveys over two days, one at a +5.1ft high tide and one at a -1.8ft low tide. The snorkel survey transect was laid out at 1.5m depth, making our high tide survey right around the 0ft tide mark at the mean lower low water. The survey conducted at the high tide gave our snorkelers access to the middle intertidal zone. This zone was overwhelmingly dominated by *Fucus distichus*. In the deeper transect conducted at low tide, our snorkelers accessed the lower intertidal zone at around the -6.7ft tide mark. In the lower intertidal, we observed the invasive macroalgae *Sargassum muticum* as the dominant taxa on the transect line or in close association (within 1 m), in 24 of 48 segments spanning 240 m of shoreline. In the 1967 survey conducted by M. Neushul, there was none.

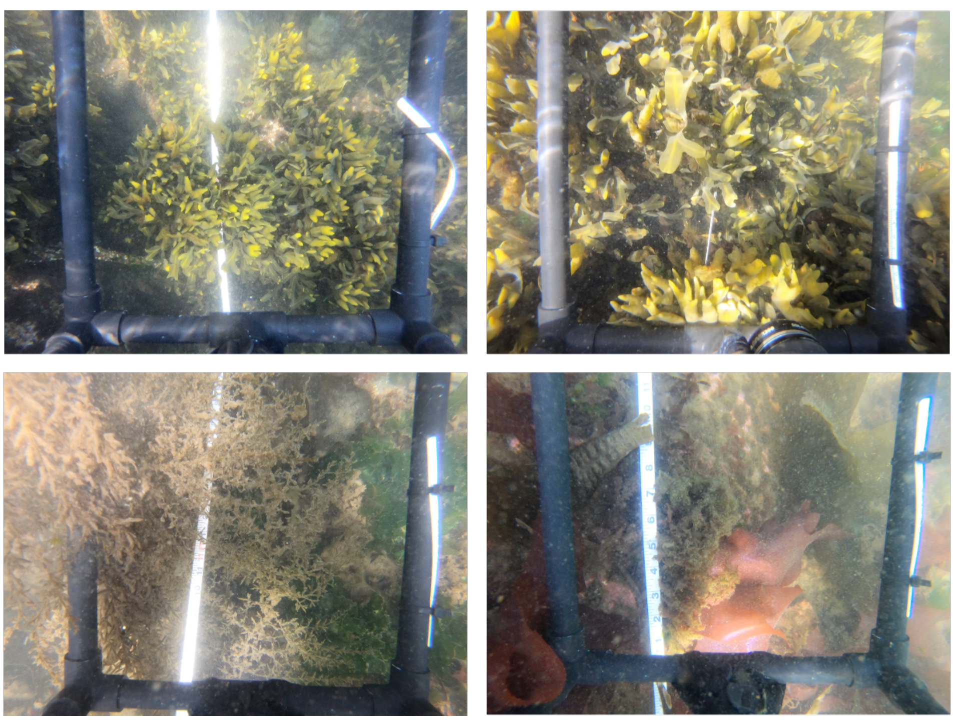

Figure 5. Stills from snorkel survey transect video, comparing the middle intertidal zone (above) and the lower intertidal zone (below). The middle intertidal zone was dominated by Fucus distichus, while the lower intertidal zone showed a large abundance of Sargassum muticum which was not recorded as present during the original Neushul surveys.

DropCam Surveys

Analysis of DropCam survey still photos in CoralNet revealed several patterns of algae distribution along surveyed transects. Brown algae were most frequently represented in DropCam still photos, followed by green and red (Figure 7a). Zonation patterns related to depth were observed consistently across transects, with green algae presence falling off sharply as depth increased, followed by a more gradual decrease of brown algae as depth increased and persistence of red algae into the deepest DropCam locations (Figure 7b). With the data we collected, it's difficult to determine a clear pattern of transect level relationships (Figure 7c). No clear grouping between or among transects is apparent. Across all surveyed transects, "Algae" were the most frequently represented functional group (Figure 7d), with *Neoagarum fimbriatum* most frequently represented as the dominant cover species (Figure 7e).

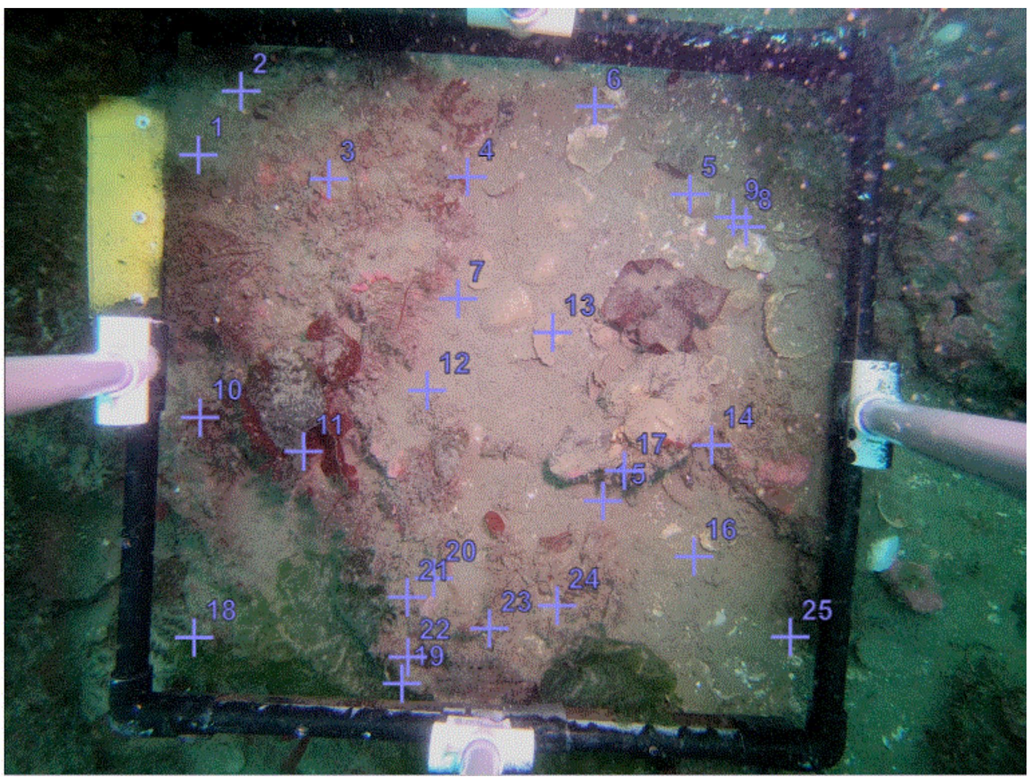

Figure 6. DropCam still photo from deployment 2 on transect 33, annotated on CoralNet with 25 randomly generated points. See Table # for description of labelset codes. Point 1: MGSU, Point 2: MGSU, Point 3: RAFI, Point 4: MGSU, Point 5: HASH, Point 6: HASH, Point 7: MGSU, Point 8: HASH, Point 9: HASH, Point 10: UBSPoint 11: CHCA, Point 12: MGSU, Point 13: HASH, Point 14: RAFI, Point 15: MGSU, Point 16: MGSU, Point 17: RAFI, Point 18: ULVA, Point 19: ULVA, Point 20: MGSU, Point 21: RAFI, Point 22: RAFI, Point 23: RAFI, Point 24: RAFI, Point 25: MGSU.

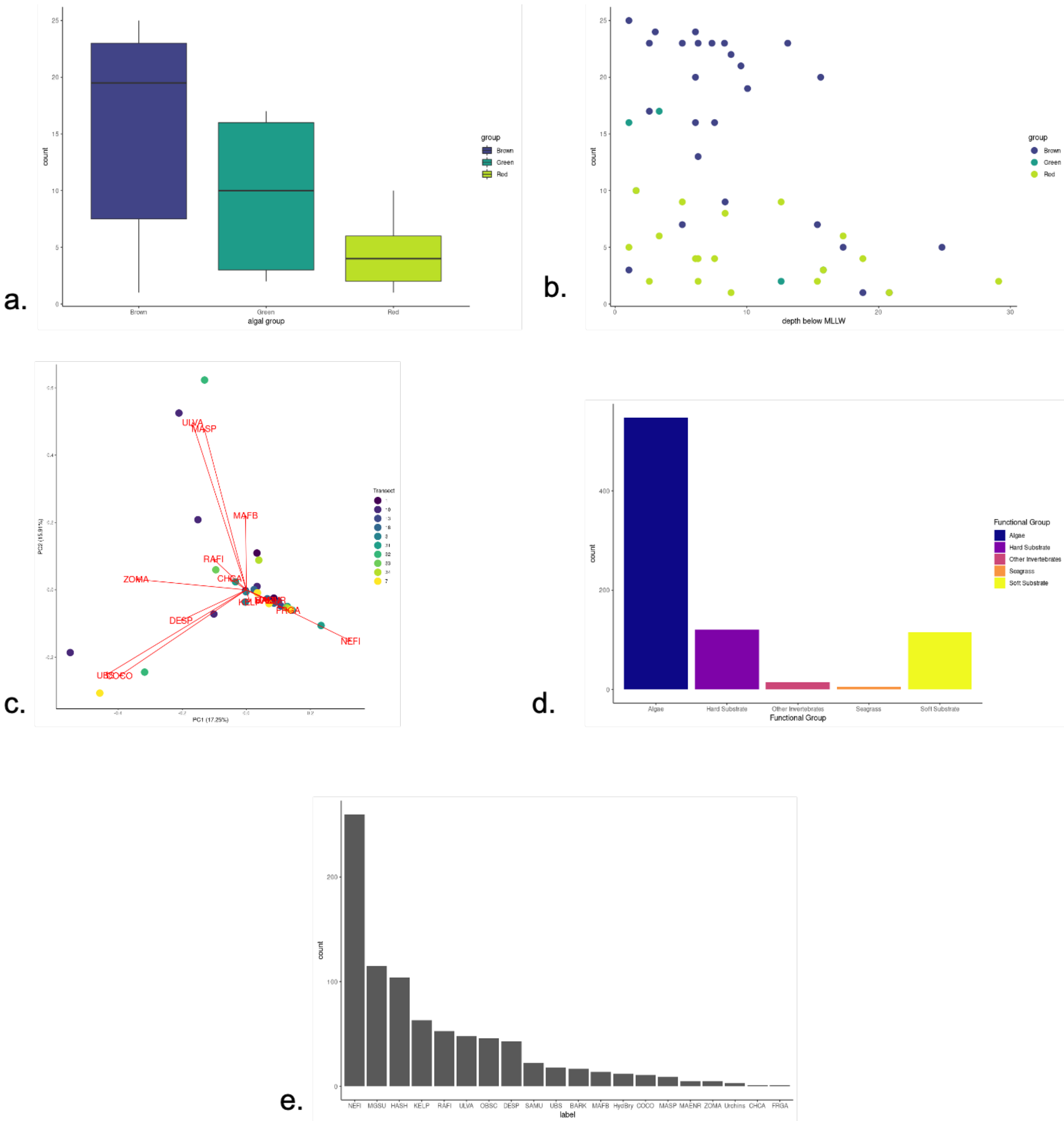

Figure 7. a) Boxplot frequency of brown, red, and green algae in each DropCam still photo, b), A scatterplot showing zonation patterns in CoralNet point counts. Green algae drops off quickly as depth increases, brown algae declines with increasing depth, and red algae persist to the deepest DropCam sites. c) A visualization of multivariate algae data taken from the DropCam still photos and CoralNet. Only algae data is included, bare space and invertebrates visible in the frame were excluded. The axes represent the total amount of variation explained by differences between communities observed in each photo. Each point represents one of the CoralNet photos, color-coded by transect number. Closer points are more similar in terms of composition, distant points are less similar. The vectors (in red) indicated the species driving differences among the photos and the directions that those species "pull" photos in which they are present., d) Barplot representing the total number of times each functional group label (see Table 2) was applied to a DropCam photo in CoralNet, e) Barplot representing the total number of times each algae species label (see Table 2) was applied to a DropCam photo in CoralNet, in descending order of frequency.

Table 2. CoralNet label set of 27 labels. Each label name is given a short code and a functional group.

Name	Short Code	Functional Group
Hydroid/Bryozoan	HydBry	Other Invertebrates
Kelp (unidentifed Laminariales)	KELP	Algae
Echinoderms: sea urchin	Urchins	Other Invertebrates
Substrate: Unconsolidated (soft)	MGSU	Soft Substrate
Substrate: Unconsolidated : pebble/gravel	SUPG	Soft Substrate
Bare Rock	BARK	Hard Substrate
Shell/ Shell Hash	HASH	Hard Substrate
Obscured	OBSC	Other
Alaria marginata	ALMA	Algae
Callophyllis spp.	CALL	Algae
Chondracanthus sp.	CHCA	Algae
Costaria costata	COCO	Algae
Constantinea rosa-marina	CORM	Algae
Desmarestia sp.	DESP	Algae
Fryeella gardneri	FRGA	Algae
Fucus distichus	FUDI	Algae
Macroalgae: Articulated calcareous: red	MAACR	Algae
Macroalgae: Encrusting: red	MAENR	Algae
Macroalgae: Filamentous / filiform : brown	MAFB	Algae
Mazzaella splendens	MASP	Algae
Neoagarum fimbriatum	NEFI	Algae
Nereocystis luetkeana	NELU	Algae
Red algae, filamentous	RAFI	Algae
Sargassum muticum	SAMU	Algae
Unidentified red blade (substratum)	UBS	Algae
Ulva	ULVA	Algae
Zostera marina	ZOMA	Seagrass

Discussion

Our short study highlighted three main takeaways after comparing benthic surveys conducted in July of 2021 to benthic surveys conducted from June 1962 - August 1963. First, we support our hypothesis that there is an observable reduced presence of the canopy-forming kelp *N. luetkeana* at Brown Island, San

Juan Islands, Washington. Second, this study provides a rare historical baseline comparison of the understory macroalgal community at Brown Island; thanks to the advanced use of SCUBA by M. Neushul in the early 1960's. In our understory macroalgae comparison, we found abundant presence of the invasive macroalgae *S. muticum* in the lower intertidal to subtidal zone. Lastly, we provide a succinct comparison of benthic survey methodologies and their tradeoffs.

Our first takeaway is a qualitative observation of reduced canopy forming kelp *Nereocystis leutkeana* on the northern shoreline of Brown Island, WA. In the surveys conducted by M. Neushul, *N. leutkeana* was observed in shallow portions on transects 3, 31, 32, and 34. Transects 31, 32 and 34 are located near each other on the northern shoreline of Brown Island. An interesting facet of repeating and comparing data with historical surveys is interpreting the historical data. While the illustrated cross-section of transect 3 by M. Neushul shows the presence of *N. leutkeana*, it was not described as being the dominant taxa in the dive transect segments. Therefore, changes in *N. leutkeana* are not showcased in the quantitative comparison shown in Figure 3. However, from personal communication, we know of verbal accounts of observations of an *N. leutkeana* bed (floats being visible at the surface) in this location (personal communication, Tom Mumford). In addition, a 1912 U.S. Dept. of Agriculture "Kelp Map" of Puget Sound-Washington shows a "Medium Heavy" kelp bed located along the northern shoreline of Brown Island and a "Very Heavy" kelp bed cover along the southern shoreline of Brown Island (Geo B. Rigg, 1912). Based on the Washington Department of Natural Resources map in 1912, and M. Neushul's survey in 1962/1963, we can support our hypothesis that there is a trend of *N. leutkeana* loss at Brown Island, Washington. Kelps like *N. leutkeana* have garnered attention as canopy forming foundation species that occupy 43% of the world's marine ecoregions (Krumhansel 2016). Globally, kelp populations have declined in coverage as measured by satellite and aerial photography in at least 38% of their ranges (Krumhansel 2016). In a study entitled 'Long-term changes in kelp forests in an inner basin of the Salish Sea' the geographic range of bull kelp, *N. luetkeana*, was assessed over 145 years of observations (Berry et al. 2021). Compared to a historical baseline observation in 1878, bull kelp extent decreased by 68% in the South Puget Sound and up to 96% in individual sub-basins (Berry et al. 2021). Global and local patterns of kelp losses are emerging in the literature, with high local variability (Krumhansel et al. 2016, Berry et al. 2021).

Understory macroalgal assemblages can be variable across multiple scales (Smale et al. 2020). Sub-canopy macroalgae support a wide variety of associated invertebrates that can be highly host-specific (Schaal et al. 2016). This suggests that loss of particular algal species in a community may have a large effect on overall community diversity and complexity across multiple trophic levels. However, few studies have been conducted to survey the understory macroalgae community, their distribution extent, and the ecosystem services they provide. Our study is unique in that we are able to provide a comparison of understory macroalgae communities with historical context. In this study, we observed the invasive macroalgae *S. muticum* in our 2021 survey where M. Neushul had previously observed none (Figure 5). In a literature review published in 2019, it was suggested that turf-forming seaweeds, especially invasive seaweeds like *S. muticum*, generally increased in abundance after marine heatwave events while native canopy-forming kelps and fucoids typically declined in abundance (Straub et al, 2019). Predictions of marine heatwave events with higher intensity, longer duration and increased frequencies means we may expect to see replacements of large long-lived habitat forming seaweeds with smaller, understory macroalgae (Straub et al, 2019). In our study, the understory macroalgae *Neoagarum fimbriatum* was observed as the dominant cover in both the 1962/63 survey and in the 2021 survey (Figure 3). The persistence of *N. fimbriatum* as a dominant cover in the understory macroalgal community suggests resilience to factors that may be contributing to canopy-forming kelp losses, like the marine heatwave that swept the greater Puget Sound in spring and summer of 2014 (Bond, 2015, Berry et al., 2021, Straub et al. 2019).

Surveys of understory macroalgae necessitate either a dredge, snorkeling, SCUBA diving and/or a form of underwater photography. We used three types of benthic survey methodologies: snorkeling, SCUBA diving, and underwater photography via a DropCam setup. Snorkeling allowed us to access the lower intertidal and upper subtidal band of the shoreline. This zone is difficult to cover with a boat or with SCUBA because of wave action. Time constraints kept the snorkel survey to the east and northeastern shorelines of Brown Island. There were challenges with boat wakes (especially the large wake produced from the passenger ferry *Victoria Clipper*) and reduced visibility from the sediment churned up by wave action and boat wake. The SCUBA diving method was thorough and provided a seamless view of the benthic algal community along the transect. It also provided the best direct comparison to the original transects conducted via SCUBA in the historical survey. Drawbacks were associated costs and time constraints that necessitated choosing only 3 transects to cover. The DropCam survey was best at covering the most area in the shortest time frame. It was the most time-efficient method, however surveying with just a DropCam video sacrifices the ability to move and brush understory macroalgae out of the way to get a complete view and personal experience of the “3D” macroalgal community structure.

Acknowledgements

Seaweeds have been a traditional food and source of materials since Time Immemorial for PNW First Nations and Tribes. Friday Harbor Laboratories occupies the traditional lands of the Coast Salish, Lummi, S'Klallam, Samish, and Tulalip tribes. We acknowledge and give thanks to all those who have cared for, managed, and been sustained not only by seaweeds but all the rich gifts of the Salish Sea, guided by generations of traditional ecological knowledge keepers. Funding was provided by two Hannah T. Croasdale Fellowships from the Phycological Society of America, the Friday Harbor Laboratories Beatrice Crosby Booth Scholarship, Friday Harbor Laboratories Adopt-a-Student Program sponsor Dr. Susan Mahoney, and Dr. Jacqueline Padilla-Gamiño. We extend a large thank you to Kindall Murie, Gabriela Wood, Miranda Roethler, Sicheng Wang, Izzy Graham, and Kristy Kull for valuable help in collecting dive and snorkel field survey data, and Pema Kitaeff for snorkel training and planning.

Data

Raw data, photos, and full analysis and visualization scripts for this project can be found at:

https://github.com/whippo/Neushul & https://coralnet.ucsd.edu/source/2667/

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Appendix A . Algal Species Observed

Phylum	Order	Family	*Genus species*	Neushul	MB2021
Chlorophyta	Ulvales	Ulvaceae	*Ulva spp.*	X	X
	Bryopsidales	Bryopsidaceae	*Bryopsis spp.*	X	
Ochrophyta	Desmarestiales	Desmarestiaceae	*Desmarestia herbacea*		X
			Desmarestia spp.	X	X
	Laminariales	Agaraceae	*Agarum clathratum*	X	
			Costaria costata	X	X
			Neoagarum fibriatum		X
		Alariaceae	*Alaria marginata*	X	
		Laminariaceae	*Cymathere triplicata*	X	
			Laminariales spp.	X	X
			Nereocystis luetkeana	X	X
	Fucales	Fucaceae	*Fucus distichus*		X
			Fucus sp.	X	
		Sargassaceae	*Sargassum muticum*		X
Rhodophyta	Bangiales	Bangiaceae	*Porphyra spp.*	X	
			Pyropia sp.		X
	Bonnemaisoniales	Bonnemaisoniaceae	*Bonnemaisonia californica*		X
			Bonnemaisonia nootkana	X	
	Ceramiales	Delesseriaceae	*Cryptopleura spp.*		X
			Myriogramme spp.	X	
			Nienburgia borealis	X	
			Polyneura latissima	X	
			Rhodoptilum plumosum	X	
		Rhodomeiaceae	*Osmundia spectabilis*	X	
		Wrangeliaceae	*Griffithsia pacifica*	X	
			Pleonosporium spp.	X	
	Gigartinales	Dumontiaceae	*Constantinea rosa-marina*		X
			Constantinea subulifera	X	X
			Weeksia coccinea		X
		Endocladiaceae	*Gloiopeltis furcata*	X	
		Furcellariaceae	*Opuntiella californica*	X	X
		Gigartinaceae	*Chondracanthus exasperatus*		X
			Gigartina spp.	X	
			Iridaea spp.	X	
			Mazzaella splendens		X
		Kallymeniaceae	*Callophyllis heanophylla*		X
			Callophyllis spp.	X	X
			Salishia firma	X	
		Phyllophoraceae	*Stenogramma interruptum*	X	
		Solieriaceae	*Agardhiella coulteri*	X	
			Sarcodiotheca gaudichaudii	X	X
	Halymeniales	Halymeniaceae	*Halymenia spp.*	X	
			Prionitis sternbergii		X
	Rhodymeniales	Fryeellaceae	*Fryeella gardneri*	X	X
		Faucheaceae	*Gloiocladia spp.*	X	
			Leptofauchea spp.	X	
		Rhodomeniaceae	*Botryocladia pseudodichotoma*	X	
			Sparlingia pertussa	X	X
Tracheophyta	Alismatales	Zosteraceae	*Zostera marina*	X	X

Appendix B . Snorkel Survey Methods

Goal: Collect shallow, near-shore algal community data for comparison with historic surveys.

Data Collected:

1. Diversity and distribution of macroalgae and substrate
   a. Video of substrate and associated organisms
2. Diversity, quantity, and associations of macroalgae and substrate
   a. Uniform point count survey (UPC)
3. GPS location of surveys
4. Depth of substrate

Materials:

1. Transect tape (3 x 200m, or equivalent)
2. Meter stick
3. Time piece
4. Clipboard with UPC datasheet (waterproof paper) and pencil
5. 'Diver down' float
6. GPS unit in waterproof container
7. GoPro camera and light rig
8. Snorkel gear (fins, masks, exposure gear, etc.)

Methods:

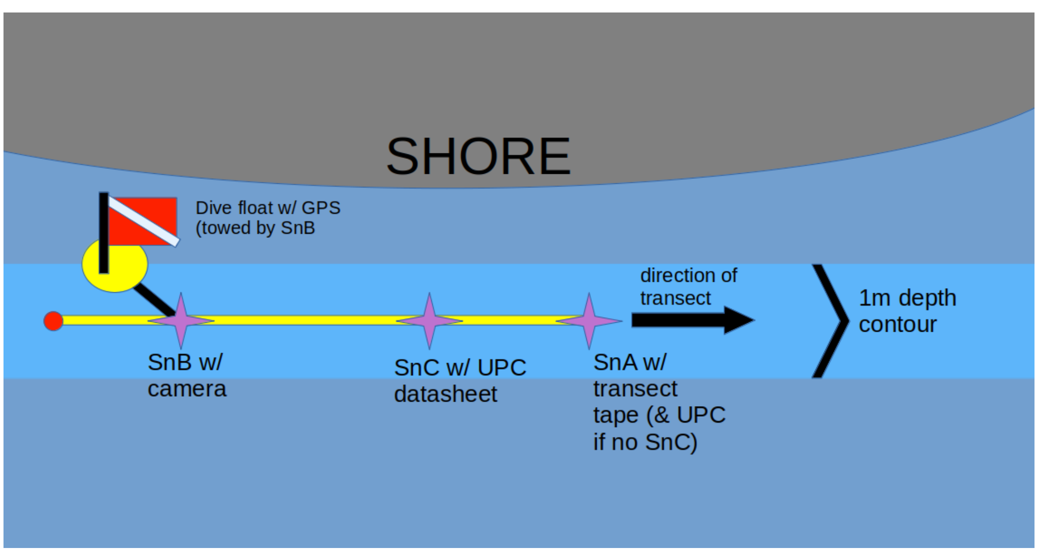
This survey can be done with 2 or 3 snorkelers in the water, and an additional surface support person on the shore or in a boat. It is best to do the survey within an hour of the slack tide to maintain relatively constant water depth and avoid currents.

Setup

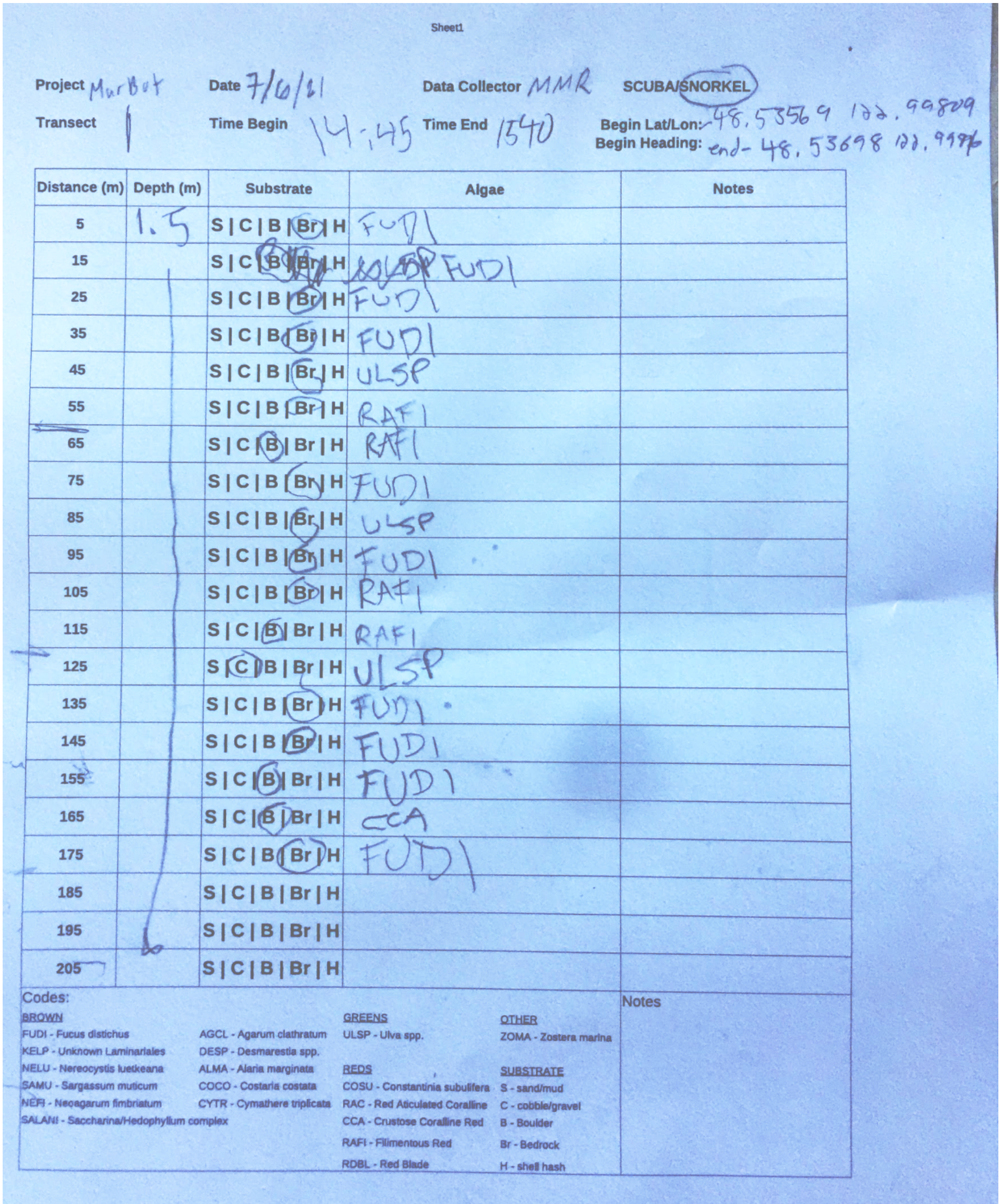
1. Using GPS, locate an original plot at either the far North or far South (depending on whether we are working N->S or S->N).
2. Snorkeler A (SnA) will carry all the transect tapes and the meter stick, Snorkeler B (SnB) will carry the GoPro and light rig and tow the diver down float with GPS, and if there is a third snorkeler (Snorkeler C; SnC) they will carry the clipboard with datasheet (if only two snorkelers, SnA will carry the clipboard).
3. Using the meter stick, SnA will locate an area near the GPS point that is approximately 1m deep.

4. SnA will affix the end of the tape to the bottom (using a weight, tying loosely to vegetation, wrapping around a rock, etc.).
5. SnA will then follow a 1m contour depth using the meter stick as a guide, unspooling the transect tape behind them, taking care to touch the substrate as little as possible, and finning lightly to prevent disturbing sediment.
6. SnA/C - beginning at the 0m mark, UPC data will be collected by placing a finger/meter stick, directly on the tape, and recording all macroalgae directly underneath on the UPC datasheet. Substrate type will also be recorded. UPC data will be taken every 10m for the length of the transect (0, 10, 20, 30,...etc.).
7. SnB following at a distance behind SnA/C, will turn on the GPS unit and set it to record a route, placing it in the diver down float they will tow behind them. They will then turn on the GoPro and light, and follow the transect line with the camera pointed directly downward. The camera should be held as close to the surface as comfortably possible to maximize the frame area. It is important that SnB move as slowly as possible down the transect line, not going faster than ~20cm/sec.
8. Snorkelers will continue in this way until the end of the transect is reached, at which point SnA will attach the end of the first transect line to the beginning of the next one and continue until the furthest GPS point is reached.
9. At the end of the transect, snorkelers will turn off all electronic equipment, having made sure the relevant data is saved, then reel up the transect tapes.
10. Enter all hand-written data into a spreadsheet as soon as possible.

Figure 1: Diagram of snorkel transect method. Snorkelers indicated by pink stars. Top-down view.



Appendix C . Data Sheets



Sheet1

Project MarBot Date 7/6/21 Data Collector MMR SCUBA/SNORKEL

Transect 1 Time Begin 14:45 Time End 1540 Begin Lat/Lon: 48.53569 122.99809

Begin Heading: end- 48.53698 122.9996

Distance (m)	Depth (m)	Substrate	Algae	Notes
5	1.5	S | C | B | Br | H	FUDI	
15		S | C | B | Br | H	~~ULSP~~ FUDI	
25		S | C | B | Br | H	FUDI	
35		S | C | B | Br | H	FUDI	
45		S | C | B | Br | H	ULSP	
55		S | C | B | Br | H	RAFI	
65		S | C | B | Br | H	RAFI	
75		S | C | B | Br | H	FUDI	
85		S | C | B | Br | H	ULSP	
95		S | C | B | Br | H	FUDI	
105		S | C | B | Br | H	RAFI	
115		S | C | B | Br | H	RAFI	
125		S | C | B | Br | H	ULSP	
135		S | C | B | Br | H	FUDI	
145		S | C | B | Br | H	FUDI	
155		S | C | B | Br | H	FUDI	
165		S | C | B | Br | H	CCA	
175		S | C | B | Br | H	FUDI	
185		S | C | B | Br | H		
195	6	S | C | B | Br | H		
205		S | C | B | Br | H		

Codes:

BROWN
FUDI - Fucus distichus
KELP - Unknown Laminariales
NELU - Nereocystis luetkeana
SAMU - Sargassum muticum
NEFI - Neoagarum fimbriatum
SALANI - Saccharina/Hedophyllum complex
AGCL - Agarum clathratum
DESP - Desmarestia spp.
ALMA - Alaria marginata
COCO - Costaria costata
CYTR - Cymathere triplicata

GREENS
ULSP - Ulva spp.

REDS
COSU - Constantinia subulifera
RAC - Red Aticulated Coralline
CCA - Crustose Coralline Red
RAFI - Filimentous Red
RDBL - Red Blade

OTHER
ZOMA - Zostera marina

SUBSTRATE
S - sand/mud
C - cobble/gravel
B - Boulder
Br - Bedrock
H - shell hash

Notes

Page 1

Sheet1

Sheet 2

Project Har Box   Date 7/16/21   Data Collector MMR   SCUBA/SNORKEL

Transect 2   Time Begin 15:45   Time End 16:00   Begin Lat/Lon: 48.53698 122.99896
Begin Heading: end 48.53698 122.9963

	Distance (m)	Depth (m)	Substrate	Algae	Notes
185	5		S | C | B | Br | H	RAFI	
195	15		S | C | B | Br | H	FUDI	
205	25		S | C | B | Br | H	RAFI	
215	35		S | C | B | Br | H	RAFI	
225	45		S | C | B | Br | H	ULSP	
235	55		S | C | B | Br | H	ULSP	
	65		S | C | B | Br | H		
	75		S | C | B | Br | H		
	85		S | C | B | Br | H		
	95		S | C | B | Br | H		
	105		S | C | B | Br | H		
	115		S | C | B | Br | H		
	125		S | C | B | Br | H		
	135		S | C | B | Br | H		
	145		S | C | B | Br | H		
	155		S | C | B | Br | H		
	165		S | C | B | Br | H		
	175		S | C | B | Br | H		
	185		S | C | B | Br | H		
	195		S | C | B | Br | H		
	205		S | C | B | Br | H		

Codes:

BROWN
- FUDI - Fucus distichus
- KELP - Unknown Laminariales
- NELU - Nereocystis luetkeana
- SAMU - Sargassum muticum
- NEFI - Neoagarum fimbriatum
- SALANI - Saccharina/Hedophyllum complex
- AGCL - Agarum clathratum
- DESP - Desmarestia spp.
- ALMA - Alaria marginata
- COCO - Costaria costata
- CYTR - Cymathere triplicata

GREENS
- ULSP - Ulva spp.

REDS
- COSU - Constantinia subulifera
- RAC - Red Aticulated Coralline
- CCA - Crustose Coralline Red
- RAFI - Filimentous Red
- RDBL - Red Blade

OTHER
- ZOMA - Zostera marina

SUBSTRATE
- S - sand/mud
- C - cobble/gravel
- B - Boulder
- Br - Bedrock
- H - shell hash

Notes

Sheet1

Project Nashul **Date** 7/8/21 **Data Collector** RDBW SCUBA/SNORKEL

Transect 33 **Time Begin** 1030 **Time End** 1055 **Begin Lat/Lon:**
Begin Heading:

	~~Distance (m)~~ ft.	Depth (m)	Substrate	Algae	Notes
200	5	24.6	S | C | B | Br | H	none	hydroids/wall
195	15	21.8	S | C | B | Br | H	none	"
185	25	19.6	S | C | B | Br | H	none	took sample yourtells?
175	35	17.7	S | C | B | Br | H	callophyllis?	took sample
165	45	16.4	S | C | B | Br | H	NELU	
155	55	15.4	S | C | B | Br | H	NELU, CCA	
145	65	14.7	S | C | B | Br | H	NELU	
135	75	14.0	S | C | B | Br | H	NELU, Fryeela, Calla	took Fry sample
125	85	13.3	S | C | B | Br | H	NELU, Branchilla	
115	95	12.4	S | C | B | Br | H	Callo, Lacy red #1	took lacy sample
105	105	12.1	S | C | B | Br | H	NELU	
95	115	11.7	S | C | B | Br | H	lacy red #1, Kelp	baby (salani)
85	125	11	S | C | B | Br | H	lacy #1, big red blade → sample	
75	135	10.6	S | C | B | Br | H	Salani	yes & red blade near
65	145	10.0	S | C | B | Br | H	NELU, SALANI, COCO	Sparlingia nearby
55	155	8.9	S | C | B | Br | H	COCO (huge!), pinch red siphon	
45	165	7.8	S | C | B | Br | H	NELU, Mazzaella?	→ took sample
35	175	6.4	S | C | B | Br | H	huge red blade #1, maz?	Salani NELU near
25	185	4.7	S | C | B | Br | H	SALAN, NELU, CCA	lots of red turf
15	195	3.2	S | C | B | Br | H	NELU	KOCO SALA
5	205	1.3	S | C | B | Br | H	COSU	SAMU, NELU, ULVA

Codes:

BROWN
FUDI - Fucus distichus
KELP - Unknown Laminariales
NELU - Nereocystis luetkeana
SAMU - Sargassum muticum
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ULSP - Ulva spp.

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RAFI - Fillimentous Red
RDBL - Red Blade

OTHER
ZOMA - Zostera marina

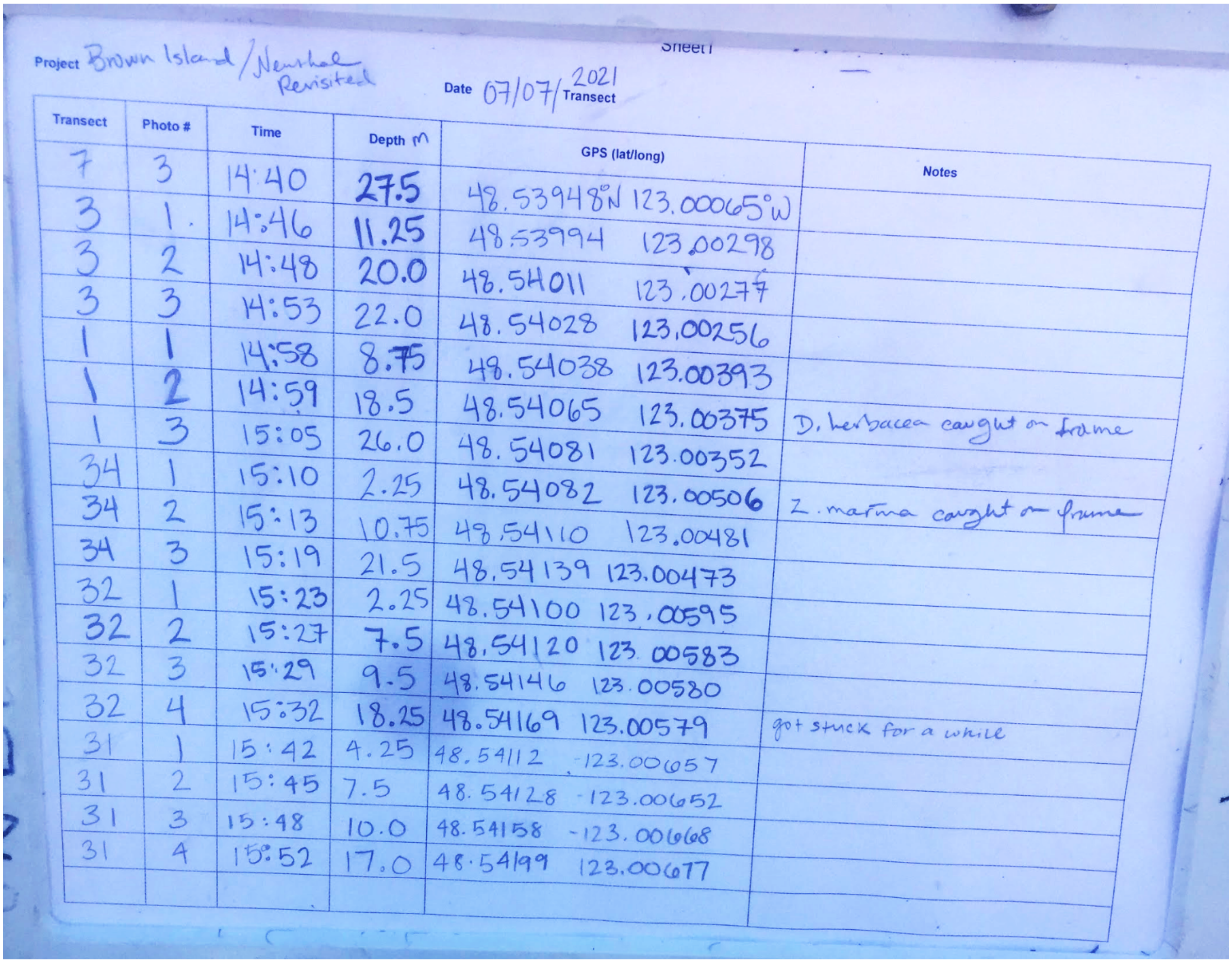
SUBSTRATE
S - sand/mud
C - cobble/gravel
B - Boulder
Br - Bedrock
H - shell hash

Notes
Ros speed & ... drift
red tubes
scuzzy → low flow?

NELU = Ashes m

Page 2

w/ bumps → sample



Project Brown Island / Newhall Revisited

Sheet1

Date 07/07/2021

Transect

Transect	Photo #	Time	Depth m	GPS (lat/long)	Notes
7	3	14:40	27.5	48.53948°N 123.00065°W	
3	1	14:46	11.25	48.53994 123.00298	
3	2	14:48	20.0	48.54011 123.00277	
3	3	14:53	22.0	48.54028 123.00256	
1	1	14:58	8.75	48.54038 123.00393	
1	2	14:59	18.5	48.54065 123.00375	D. herbacea caught on frame
1	3	15:05	26.0	48.54081 123.00352	
34	1	15:10	2.25	48.54082 123.00506	Z. marina caught on frame
34	2	15:13	10.75	48.54110 123.00481	
34	3	15:19	21.5	48.54139 123.00473	
32	1	15:23	2.25	48.54100 123.00595	
32	2	15:27	7.5	48.54120 123.00583	
32	3	15:29	9.5	48.54146 123.00580	
32	4	15:32	18.25	48.54169 123.00579	got stuck for a while
31	1	15:42	4.25	48.54112 -123.00657	
31	2	15:45	7.5	48.54128 -123.00652	
31	3	15:48	10.0	48.54158 -123.00668	
31	4	15:52	17.0	48.54199 123.00677	

UNDERWATER

Sheet1

heading 035
length 200ft
depth 18m

Project Vesuvel Date 20210709 Data Collector KIASW SCUBA/SNORKEL

Transect 3 Time Begin Time End Begin Lat/Lon:
Begin Heading:

	Distance (m)	Depth (m)	Substrate	Algae	Notes
155	5	18.5	S | C | B | Br | H	none	Pinkel red, [illegible] se, fry
145	15	18.2	S | C | B | Br | H	none	[illegible] red NAFI
135	25	17.7	S | C | B | Br | H	11	red [illegible], [illegible] → samples
125	35	17.2	S | C | B | Br | H	FRGA	NAFI [illegible], [illegible]
115	45	16.7	S | C | B | Br | H	FRGA	feathered red [illegible]
105	55	16	S | C | B | Br | H	NAFI	red fils
95	65	15.4	S | C | B | Br | H	NAFI	red [illegible], big [illegible] FI
85	75	14.7	S | C | B | Br | H	Lg red blade (sample)	[illegible] NAFI
75	85	13.8	S | C | B | Br | H	red feather	NAFI [illegible] Fry sample
65	95	11.2	S | C | B | Br | H	NAFI	wall, [illegible]
55	105	8.9	S | C | B | Br | H	NAFI	SALANI [illegible]
45	115	7.3	S | C | B | Br | H	NAFI COSU? sample	CCA SALANI, [illegible]
35	125	5.4	S | C | B | Br | H	SALANI, NAFI, MASP?	→ sample [illegible]
25	135	4.3	S | C | B | Br | H	SALANI NAFI, [illegible]	→ sample
15	145	2.7	S | C | B | Br | H	MASP NAFI	COSU
5	155	1.5	S | C | B | Br | H	NAFI, SALANI	FUDI | SAMU, ULVA, MASP
	165		S | C | B | Br | H		
	175		S | C | B | Br | H		
	185		S | C | B | Br | H		
	195		S | C | B | Br | H		
	205		S | C | B | Br | H		

Codes:

BROWN
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RDBL - Red Blade

OTHER
ZOMA - Zostera marina

SUBSTRATE
S - sand/mud
C - cobble/gravel
B - Boulder
Br - Bedrock
H - shell hash

Notes

NAFI on cobbles
[illegible]
small drift

UNDERWATER

13 / 15 / 10 K

vert 30 more ft to shal

heading } 330
length 450ft
depth 14m

Sheet1

Project Meridal   Date 20210708   Data Collector RDBW   SCUBA/SNORKEL

Transect 27   Time Begin   Time End   Begin Lat/Lon:
Begin Heading:

	Distance (m)	Depth (m)	Substrate	Algae	Notes	
195	5	13.2	S | C | B | Br | H	ULVA	SPPE SALANI, red pinch	
185	15	13.0	S | C | B | Br | H	"red desmar" sample	red pinch, desp	red clump
175	25	12.9	S | C | B | Br | H	DESP	red pinch, DESP	↓
165	35	12.7	S | C | B | Br | H	red pinch	ULVA DESP	sample
155	45	12.6	S | C | B | Br | H	none	" " red pinch	NAFI
145	55	12.4	S | C | B | Br | H	NAFI	DESP, red pinch	
135	65	12.2	S | C | B | Br | H	MASP	DESP, ULVA, red pinch	
125	75	12.1	S | C | B | Br | H	NELU, DESP, red pinch	DESP, red pinch, red	
115	85	12.0	S | C | B | Br | H	none	fry ULVA, red pinch	branch ↓
105	95	11.8	S | C | B | Br | H	red pinch	ULVA, DESP	clump
95	105	11.7	S | C | B | Br | H	none	COCO DESP	
85	115	11.6	S | C | B | Br | H	DESP	SALANI, ULVA *	red frill samp
75	125	11.3	S | C | B | Br | H	red pinch, ULVA	ULVA	
65	135	11.1	S | C | B | Br | H	NAFI	DESP SALANI red pinch	
55	145	11.1	S | C | B | Br | H	ULVA	SPPE DESP SALANI	
45	155	11.0	S | C | B | Br | H	SPPE	NEFI DESP red pinch	
35	165	10.8	S | C | B | Br | H	none	DESP, MASP, ULVA	
25	175	10.6	S | C | B | Br | H	red pinch	NELU DESP SALANI	
15	185	10.3	S | C | B | Br | H	SALANI	DESP NAFI red pinch	
5	195	9.9	S | C | B | Br | H	red pinch	DESP SALANI	#
	205		S | C | B | Br | H			

-5 8.5 DESP

-15 8.5 DESP

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- RAFI - Fillimentous Red
- RDBL - Red Blade

OTHER
- ZOMA - Zostera marina

SUBSTRATE
- S - sand/mud
- C - cobble/gravel
- B - Boulder
- Br - Bedrock
- H - shell hash

Notes

line came loose

-55 3.7 red pinch   -65 3.0 DESP

-75 2.5 SAMU

-25 Brack 7.8   -35 6.5 red pinch

Page 1

-45 5.7 Bare   -55 1.6 MASP

* red sheet on shell sample

WHIPPO

Sheet 2

Project Mar Bay Date 7/6/21 Data Collector MMR SCUBA/SNORKEL

Transect 2 Time Begin 15:45 Time End 16:00 Begin Lat/Lon: 48.53698 122.99896
Begin Heading: end 48.53698 122.99963

	Distance (m)	Depth (m)	Substrate	Algae	Notes
185	5		S | C | B | Br | H	RAFI	
195	15		S | C | B | Br | H	FUDI	
205	25		S | C | B | Br | H	RAFI	
215	35		S | C | B | Br | H	RAFI	
225	45		S | C | B | Br | H	ULSP	
235	55		S | C | B | Br | H	ULSP	
	65		S | C | B | Br | H		
	75		S | C | B | Br | H		
	85		S | C | B | Br | H		
	95		S | C | B | Br | H		
	105		S | C | B | Br | H		
	115		S | C | B | Br | H		
	125		S | C | B | Br | H		
	135		S | C | B | Br | H		
	145		S | C | B | Br | H		
	155		S | C | B | Br | H		
	165		S | C | B | Br | H		
	175		S | C | B | Br | H		
	185		S | C | B | Br | H		
	195		S | C | B | Br | H		
	205		S | C | B | Br | H		

Codes:

BROWN
- FUDI - Fucus distichus
- KELP - Unknown Laminariales
- NELU - Nereocystis luetkeana
- SAMU - Sargassum muticum
- NEFI - Neoagarum fimbriatum
- SALANI - Saccharina/Hedophyllum complex
- AGCL - Agarum clathratum
- DESP - Desmarestia spp.
- ALMA - Alaria marginata
- COCO - Costaria costata
- CYTR - Cymathere triplicata

GREENS
- ULSP - Ulva spp.

REDS
- COSU - Constantinia subulifera
- RAC - Red Aticulated Coralline
- CCA - Crustose Coralline Red
- RAFI - Filimentous Red
- RDBL - Red Blade

OTHER
- ZOMA - Zostera marina

SUBSTRATE
- S - sand/mud
- C - cobble/gravel
- B - Boulder
- Br - Bedrock
- H - shell hash

Notes

SITE 2

end 1106

Project Nashel Date 20210710 Data Collector Ross SCUBA/SNORKEL

Transect T2/3/4 Time Begin Time End Begin Lat/Lon: Begin Heading:

Distance (m)	Depth (m)	Substrate	Algae	Notes
5	1.6	S | C | B | Br | H	SALAN MAEGK	SALU SAMU
15		S | C | B | Br | H	SAMU COSU	SALAN ULLV
25		S | C | B | Br | H	SAMU SALAN	
35	5	S | C | B | Br | H	SALANI SAMU MASK	COSU
45	10	S | C | B | Br | H	SAMU MASP	COSU
55	15	S | C | B | Br | H	SALANI MAENR	SAMU
65	20	S | C | B | Br | H	NEFI	
75	25	S | C | B | Br | H	COCO SAMU SALAN	
85	30	S | C | B | Br | H	SALANI	SAMU
95	35	S | C | B | Br | H	SAMU SALANI	
105	40	S | C | B | Br | H	SAMU	
115	45	S | C | B | Br | H	SALANI MASP	SAMU
125	50	S | C | B | Br | H	COCO SALANI RAFI	SAMU
135	55	S | C | B | Br | H	SAMU MAENR	ULVA NEFI
145	60	S | C | B | Br | H	MASP remand	sample
155	5	S | C | B | Br | H	SAMU COCO	
165	10	S | C | B | Br | H	SALAN OPCA	SAMU
175	15	S | C | B | Br | H	SALAN MAENR	SAMU
185	20	S | C | B | Br | H	MASP	SALANI NEFI
195	25	S | C | B | Br | H	SALAN NEFI	remand
205	30	S | C | B | Br | H	SALANI NEFI	OPCA wall

50 55 60

T3 1123 Start

1130

T4 1140

end 1151

COCO SALAN

55 B
60 B

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Notes: SALANI

35 Br NEFI
40 Br COSU
45 Br NEFI
50 Br COSU

Project Neushul Dropcam – MarBot Date 2021/07/01 Transect

Transect	Photo #	Time	Depth m	GPS (lat/long) dec Deg	Notes
18	1	1435	3.5	48.53569 -122.99780	
18	2	1440	30+	48.53560 -122.99751	steep dropoff, lowered to 30m couldn't feel bottom
33	1	1445	8.25	48.53617 -122.99773	
33	2	1448	13.5	48.53621 -122.99760	
33	3	1451	16.5	48.53621 -122.99737	
13	1	1458	7.0	48.53684 -122.99848	
13	2	1502	16.25	48.53712 -122.99836	1 single attached bull kelp
13	3	1506	30+	48.53766 -122.99778	
10	1	1514	2.5	48.53780 -123.00055	a couple small attached bull kelp, can see bottom
10	2	1518	4.25	48.53807 -123.00050	
10	3	1521	7.0	48.53837 -123.00012	floating zostera marina w/ [illegible]
10	4	1528	7.0	48.53844 -122.99999	
10	5	1533	9.25	48.53860 -122.998[illegible]	
7	1	1537	6.0	48.53897 -123.00117	
7	2	1531	14.0	48.53927 -123.00085	