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An analysis of mesophotic macroalgal species richness and abundance in Puget Sound

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by

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An analysis of mesophotic macroalgal species richness and abundance in Puget Sound

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Key words: temperate, SCUBA diving, coverage, transects

Abstract

Mesophotic ecosystems are important, light-dependent communities that act as an area of transition for shallow and deep-water organisms. Macroalgae are prominent members of these communities whose growth is influenced primarily by depth and light levels. Even though they are important community members and habitat-builders in these mesophotic ecosystems, macroalgae are highly understudied, especially in temperate environments. To examine these understudied communities, macroalgal coverage, richness, and light intensity at 3 different depth levels across 4 sites in Puget Sound, USA were compared using videos collected during SCUBA diving. All but three of the transects were within the surface irradiance limits classified as mesophotic zones. No clear trends between overall coverage and depth were identified with each site exhibiting unique patterns. These findings indicate that there may be interactions between site and depth or other factors influencing temperate mesophotic macroalgal ecosystems such as bathymetry and substrate composition.

Introduction

In recent years, research into both tropical and temperate mesophotic ecosystems has increased dramatically (Turner et al. 2019). Mesophotic ecosystems are light-dependent communities containing a variety of habitat-building species that help support a rich and diverse environment (Kahng et al. 2016; Enrichetti et al. 2019). Along with providing the structure of the habitat, depending on the location, a combination of macroalgae, corals, and sponges encompass a large portion of the overall biodiversity (Hinderstein et al. 2010). These mesophotic zones also provide an important area of transition with both shallow and deep-water organisms (Cerrano et al. 2010). Increasing study of these ecosystems' biodiversity can allow scientists to better predict the effect of invasive species on a community (Spalding 2012).

Distribution over depth and general species richness of macroalgae in Mesophotic Coral Ecosystems (MCEs) and Temperate Mesophotic Ecosystems (TMEs) is of special importance as it influences understanding of biological factors including energy flow and biogeography (Spalding et al. 2019). A somewhat arbitrary 30 m upper depth limit that corresponds with recreational SCUBA diving limits is most commonly used in studies focusing on MCEs (Kahng et al. 2016; Hinderstein et al. 2010). More recently, however, this upper depth limit has shifted in many places to correspond to the depth at which 1% surface irradiance is reached (Cerrano et al. 2019). This limit at 1% surface irradiance provides a more dynamic and accurate upper depth limit for sites in TMEs that often have less clear water than many of the MCEs (Cerrano et al. 2019). Previous research has suggested that depth and light are the two most influential factors in determining the benthic community present in mesophotic environments (Magalhães et al. 2015). Scott et al. (2019) found that macroalgae cover decreased with depth in Caribbean MCEs. Korpinen et al. (2007) also saw lower algal density in deeper water along the rocky sublittoral of the Baltic Sea, but they had much shallower maximum depths for macroalgae than Scott et al. (2019). Depth alone cannot be broadly used as an indicator of algae present because each location is distinct based on the amount of light penetration at a given depth (Lesser et al. 2009). Since algal depth is limited by light, areas with lower light penetration are likely to see shallower maximum depths for macroalgae presence and shallower upper limits of the mesophotic zone.

While research on mesophotic ecosystems in general has increased dramatically in the last decade, much of the research has been focused on MCEs and specific geographic areas (Turner et al. 2017). Cerrano et al. (2019) found that over 75% of the research on mesophotic ecosystems has been done in tropical or subtropical water with only 2.8% of literature being done on the "temperate north pacific." In addition to this focus on MCEs, much of the research centers on corals and other charismatic species (Turner et al. 2019; Spalding et al. 2019). Of the studies conducted in the temperate Mediterranean Sea, only 3% have focused on algae (Cerrano et al. 2019). This lack of attention signals that there is work to be done in the study of macroalgae as an equally important community member and habitat-builder in mesophotic communities. Given these gaps in the literature, I analyzed the species richness and abundance of macroalgae at multiple depths and locations in Puget Sound, USA.

Methods

In order to compare the diversity and abundance of mesophotic macroalgae to macroalgae found at shallower depths, 3 distinct depths (10, 20, and 30 m) at 4 different locations around Puget Sound, Washington, including Redondo Beach, Me-Kwa-Mooks Park, Mukilteo T Dock, and Seacrest Cove 2, were examined (Fig. 1). Each location is close to ship and boat traffic and is in an area open to public recreation. Based on preliminary SCUBA surveys, longer dives to video record and collect samples were conducted. At each depth, a 10 m transect was videotaped. With the videos, the presence or absence of algae, including which species (or higher-level taxon, if species identification is not possible based on appearance underwater) if present, was recorded for each cm along the transect. If multiple species of algae were overlapping, only the top specimen was recorded. Additionally, during the dives 3 samples of ulvoids were taken from each depth for species determination using standardized microscope identification techniques. In order to measure surface and subsurface irradiance at each site, a LI-1000 Datalogger was used.

Once the algal coverage based on species was determined for each site and depth, an overall percent coverage for each individual depth was calculated. Species richness at each site depth was also determined, while species composition was compared qualitatively. Macroalgal abundance at each depth and at each site was compared using a randomized block design ANOVA. Four sites (random block factor) of 3 depths each (N = 12 transects) were used, and depth was a fixed factor. A principal components analysis (PCA) was conducted comparing 15 variables including species and overall coverage. A regression of the natural logarithm of light intensity versus depth was conducted in Excel for each site based on light intensity at several depths to confirm which depths were at mesophotic light levels. The coefficient of extinction found in each regression was then used to predict % surface irradiance at 10, 20, and 30 m such that:

$$I_z = I_0 e^{-kz}$$

where I_z is light intensity at depth, I_0 is light intensity at the surface, k is the coefficient of extinction, and z is depth in m. These values were then characterized as euphotic or mesophotic levels based on the traditional <1% of surface light (Kirk 2011) and newly proposed <0.29% (Tamir et al. 2019). All other statistical tests were performed in SPSS 28 (IBM Corp).

Results

The calculated overall coverage for each depth varied between sites with 30 m having both the greatest coverage across samples and the lowest coverage across samples (Table 1). Seacrest Cove 2 30 m hosted the greatest species richness with 11 species, while the lowest species richness (2 taxa) was noted at both Me-Kwa-Mooks Park 10 m and Mukilteo T Dock 30 m (Table 1). Using a randomized block design ANOVA, I found that neither site ($F_{3,6} = 0.71$, $p = 0.579$) nor depth had a significant influence on percent coverage ($F_{2,6} = 0.26$, $p = 0.776$; Table 2, Fig. 2). Species composition was varied across site and depth (Fig. 3).

The random collections of ulvoids at each transect showed only two species overall. Seacrest Cove 2 had all *Ulvaria obscura* var. *blyttii* at 30 m, all *Ulva* "*lactuca*" at 20 m, and no ulvoids at 10 m. Me-Kwa-Mooks Park sites had 2/3 *Ulvaria* and 1/3 *Ulva* at deep, all Ulvaria and medium, and none at shallow depths. Deep at Mukilteo T Dock had all *Ulvaria*, medium had 2/3 *Ulvaria* and 1/3 *Ulva*, and shallow was 1/3 *Ulvaria* and 2/3 *Ulva*. Finally, 1/3 *Ulva* and 2/3 *Ulvaria* in deep, all *Ulvaria* in medium, and 2/3 *Ulvaria* and 1/3 *Ulva* at shallow were found at Redondo Beach. In the PCA, principal components (PC) 1 and 2 accounted for 90.89% of the among-group variance of site-depth combinations with PC1 having 83.39% of total variance and PC2 having 7.51% of total variance (Fig. 4).

The regressions showed a significant decrease in light with depth at all sites (Table 3). At all four sites subsurface irradiances at 30 m depth was found to be <1% and therefore mesophotic (Fig. 5). Additionally, Redondo Beach 20 m, Mukilteo T Dock 10 and 20 m, as well as Me-Kwa-Mooks Park 10 and 20 m were also at mesophotic intensities (Fig. 5). A majority of the sites were predicted to be at mesophotic levels whether the 1% or 0.29% cutoff were used (Table 4).

Discussion

In examining the macroalgal communities at three depths over four sites, no consistent patterns were found between depth and overall coverage or species present. Given the previous research suggesting a decrease in algal density with depth, it is surprising to see such opposite trends at different site. This suggests that there must be other factors contributing to the presence of macroalgae at these sites. At Redondo Beach, the 10 and 20 m transects were on a very steep slope with few attachment points. This suggests that there was nothing for algae to grow and attach on there, so it was simply sliding down the sandy, steep grade into deeper water. This would help explain the high level of coverage found at 30 m, but very low level found at 10 m. A similar pattern in coverage and underwater landscape was present at Me-Kwa-Mooks. A decline in algal coverage with depth at both Seacrest Cove 2 and Mukilteo T Dock, where there was no similar steep grade, was found. In some areas the mesophotic zone hosted the greatest coverage and diversity, while others had the smallest. It is notable that the transect with the highest coverage of growing macroalgae was Me-Kwa-Mooks 30 m, which was expected to have lower coverage given its deep depth and resulting low light intensity. Additionally, there was no clear group of algae (red, green, or brown) that seemed to dominate at certain depths or light intensities.

The transects at Mukilteo and Seacrest exhibited similar topographies and the same pattern of coverage decrease with depth. However, Mukilteo had much lower percent coverages than Redondo at each depth. This may be influenced by the much lower light intensities predicted at Mukilteo. The site in Mukilteo is impacted by the influx of Snohomish and other rivers into the area creating a high level of silt and plankton in the water between 5 and 10 m influencing visibility and subsurface irradiance. The 20 and 30 m depths at Redondo were also similar in coverage to that of Seacrest. The difference in coverage at 10 m may be due to the aforementioned steep grade.

In examining the PCA, Mukilteo 10 and 20 m, Redondo 30 m, and Me-Kwa-Mooks 20 m were all clustered together even given their differences in depth and site. This reflects similarities in algal composition. Seacrest 20 m and Me-Kwa-Mooks 30 m also placed nearby each other given their overlap in macroalgae species present. Me-Kwa-Mooks 10 m seems to be quite distinct likely due to its lack of *Saccharina*. More specific information cannot be determined given the scattered nature of each site.

Using the traditional cutoff of <1% surface irradiance, this placed all but three of the transects (S1, S2, and R1) in the mesophotic zone. Even when using the <0.29% as the cutoff only R2 and M1 were reclassified as euphotic. This confirms that whether or not the new cutoff is used, the depths included are much shallower than the traditional 30 m mesophotic zone.

Given the inconsistencies in coverage across depths, further research is needed to examine how underwater landscape impacts macroalgal growth and presence. Past study has shown that nutrients such as nitrogen may be influencing how much algae can grow and which species are present (Pedersen and Borum 1997, Alwyn and Rees 2007). Pedersen and Borum found that the areas with high N levels were more likely to host ephemeral species, while low N levels allowed slow-growing species to thrive (1997). Substrate and bathymetry also may be important factors to consider given the inability of algae to grow in certain areas because of physical constraints. Previous study has shown that even though depth is often the biggest factor, a variety of environmental variables influence algal growth and presence (Eriksson and Bergström 2005). Given these other influences, an analysis of the impact of underwater slope on the presence of algal growth would be a beneficial addition to the literature. As ocean temperatures continue to change and impact TMEs (Micaroni et al. 2021), a better understanding of both mesophotic and photic algae growth patterns will be important in maintaining these ecosystems.

Acknowledgements

I would like to acknowledge Dr. Tim Nelson for providing guidance and advising throughout the research process as well as countless hours spent diving. Thanks to Dr. Eric Long for his assistance in data analysis and collection. Additionally, I want to thank Claire Geiman who volunteered her time to assist in field work. Laboratory space and funding for the study were provided by Seattle Pacific University. Finally, I want to thank the Fauntleroy ferry workers who were gracious enough to let me collect measurements off the terminal dock.

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Tables and Figures

Table 1. Percent coverage and species richness of macroalgae from video surveys at Seacrest Cove 2, Me-Kwa-Mooks Park, Mukilteo T Dock, and Redondo Beach at three depths.

Site	Depth (m)	Coverage	Percent Coverage	Richness
Seacrest Cove 2	30	32	0.032	3
	20	403	0.403	5
	10	821	0.821	11
Me-Kwa-Mooks Park	30	1000	1	9
	20	490	0.49	9
	10	13	0.013	2
Mukilteo T Dock	30	13	0.013	2
	20	75	0.075	4
	10	111	0.111	4
Redondo Beach	30	148	0.148	3
	20	242	0.242	6
	10	43	0.043	3

Table 2. Randomized block design ANOVA table for effects of depth (fixed factor) and site (randomized block) on macroalgal percent coverage (N = 12).

Source	SS	df	MS	F	Sig.
Depth	6.17	2	3.08	0.26	0.776
Site	24.92	3	8.31	0.71	0.579
Error	69.83	6	11.64		

Table 3. Regression analysis of surface and subsurface irradiance for 4 sites.

Site	N	R^2	p	Coefficient of Extinction
Seacrest Cove 2	11	0.978	< 0.001	0.199
Me-Kwa-Mooks Park	6	0.991	< 0.001	0.485
Mukilteo T Dock	4	0.982	0.009	0.658
Redondo Beach	3	0.999	0.017	0.278

Table 4. Predicted mesophotic depths based on traditional <1% surface irradiance (SI) and newer <0.29% SI values.

	Depth (m)	
Site	1% SI	0.29% SI
Seacrest Cove 2	23.11	29.32
Me-Kwa-Mooks Park	9.50	12.05
Mukilteo T Dock	7.00	8.88
Redondo Beach	16.54	20.99

Figure 1. Four sites where transect videos were conducted in Puget Sound, WA.

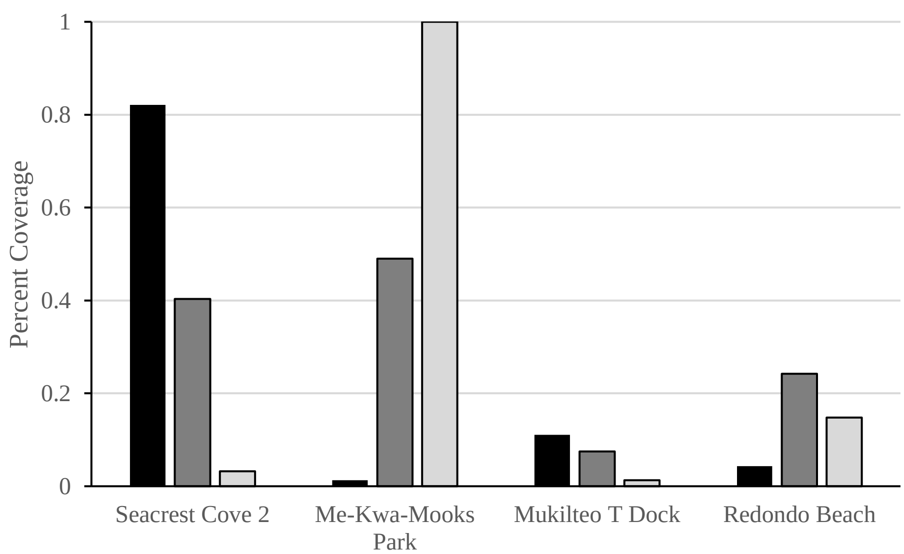

Figure 2. Percent coverages of 12 transects at 3 different depths. 10 m depth indicated by black, 20 m by dark grey, and 30 m by light grey.

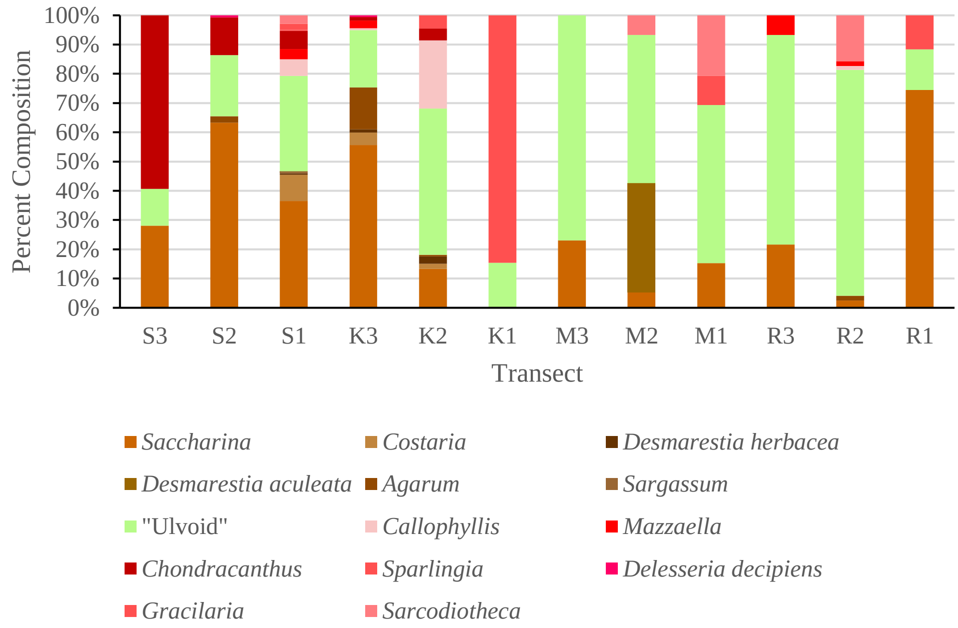

Figure 3. Percent composition for each transect at each site and depth. Coloration indicates brown, red, or green algae along with individual species. S indicates Seacrest Cove 2, K for Me-Kwa-Mooks Park, M for Mukilteo T Dock, and R for Redondo Beach. Depths indicated by 3 for 30 m, 2 for 20 m and 1 for 10 m.

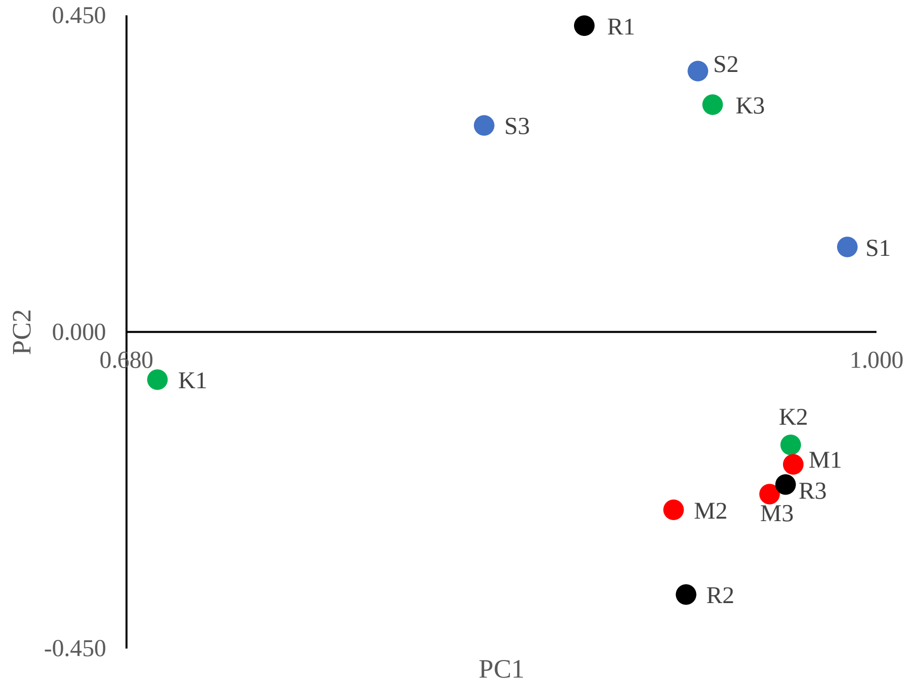

Figure 4. Differentiation of algal communities on the first two axes (90.89% of the among-group variance) of the PCA performed on a set of 15 variables of species present and 12 site and depth locations. S indicates Seacrest Cove 2, K for Me-Kwa-Mooks Park, M for Mukilteo T Dock, and R for Redondo Beach. Depths indicated by 3 for 30 m, 2 for 20 m and 1 for 10 m.

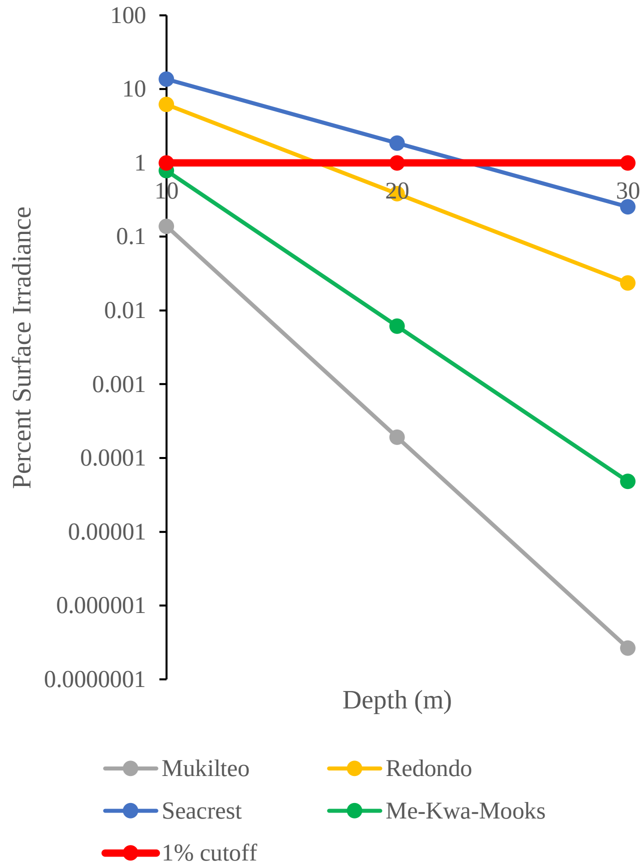

Figure 5. Percent surface irradiance at 10, 20, and 30 m. Mesophotic cutoff indicated by red line.

Honors Research Symposium Presentation, May 21, 2022, Seattle Pacific University

My honors research project in biology explores the richness and abundance of mesophotic macroalgae species in Puget Sound, but in my presentation I want to share more than just my scientific findings. I will also explore how my project fits into the broader body of knowledge of scientific research and examine the implications of historical exclusivity in my area of marine biology field research. A viewer often only sees conclusions about the data examined in a scientific study, but in reality these "results" are only a small part of how a researcher explores and examines their subject. As a scientist, I need to consider how my cultural contexts often shape how I choose a "scientific" topic, how I explore that topic "scientifically," and how I communicate these "scientific" findings. By developing a greater awareness of the cultural contexts that shape my view of scientific research, I hope to gain a better understanding of the limits and unintended impacts of my methods and practices.

Mesophotic ecosystems are unique areas of transition hosting both shallow and deep water species of corals, fish, algae, and other organisms (Cerrano et al. 2010) They are characterized by having very low light intensities, typically less than 1% surface irradiance (Tamir et al. 2019). Two common categories of mesophotic ecosystems are coral mesophotic ecosystems commonly found in tropical and subtropical waters and temperate mesophotic ecosystems (Turner et al. 2019). Macroalgae are some of the vital members of mesophotic communities acting as a food source and habitat builder for many creatures (Spalding et al. 2019). Macroalgae growth is highly dependent on depth and light intensity with different species being able to tolerate greater depths and lower light (Magalhães et al. 2015). Past research has shown that with increasing depth comes a decrease in algal density (Korpinen et al. 2007). Additionally, an increase in depth decreases the amount of light present (Lesser et al. 2009). So this would suggest that areas with lower light intensities have lower algal densities. As of 2019, 75% of the research on mesophotic ecosystems has been conducted in tropical or subtropical water with only 2.8% of studies occurring in the temperate north Pacific (Cerrano et al. 2019). Because of this lack of previous study and macroalgae's vital role in mesophotic ecosystems, I chose to focus my research on two questions: what types of algae are present in the temperate mesophotic ecosystems of Puget Sound, and how abundant are those types of algae there?

Figure 1. Four sites where transect videos were conducted in Puget Sound, WA.

The map shows the four locations in Puget Sound where I collected data: Seacrest Cove 2, Me-Kwa-Mooks Park, Mukilteo T Dock, and Redondo Beach (Fig. 1). These locations are in close proximity to ship and boat traffic and are areas open to public recreation. At each of these sites, I collected data at three depths: 10, 20, and 30 m.

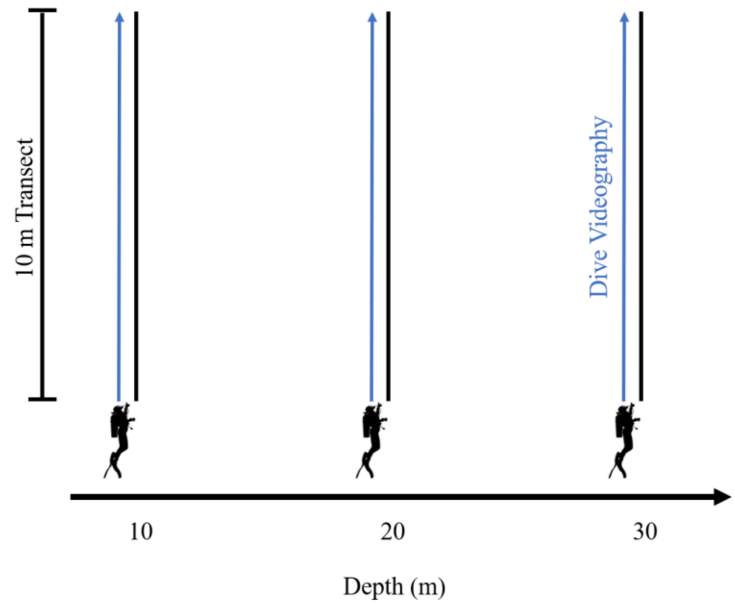

Figure 2. Experimental design of dives to collect video footage of transects.

My project consisted of four main parts. First, I collected video recordings of 10 m transects, or straight lines across the ocean floor, while SCUBA diving at each of the depths and sites shown on the map (Fig. 2). These videos were then viewed to determine whether there was macroalgae present on that transect for each cm, and if there was, what species or genus the algae belonged to. For the third part of my project, I collected light intensity measurements from the surface which were later used to calculate subsurface irradiance, or the percent of light hitting the surface that reaches each of the depths. Finally, I conducted a statistical analysis of the data including: 1) the overall percent coverage and species richness for each transect, 2) a randomized block design ANOVA comparing the three depths across each site, 3) a principal component analysis which identifies overlap in macroalgal community composition, and 4) regressions of light intensity.

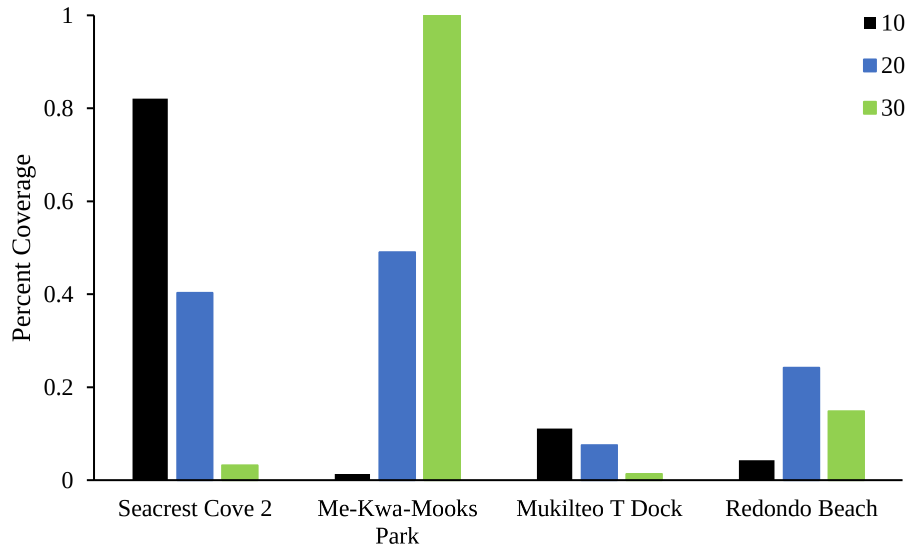

Figure 3. Percent coverages of 12 transects at 3 different depths. 10 m depth indicated by black, 20 m by dark grey, and 30 m by light grey.

You can see looking at the overall percent algal coverage at each site and depth that there was no consistent pattern across all sites (Fig. 3). Some showed the expected decline in algal density, while others exhibited the opposite. Given this, the ANOVA comparing the average coverage at one depth across all sites to the average at the other two depths found no significant relationship. Additionally, species richness did not seem to increase or decrease with depth, but more closely matched overall coverage with areas of high coverage having higher species richness. And no clear group of algae (red, green, or brown) seemed to dominate at certain depths or photic zones.

Figure 4. Video footage from Me-Kwa-Mooks 30 m transect.

My analysis of the percent surface irradiance present at each of the transects indicated that, using the 1% cutoff, the only locations that were not mesophotic were Redondo 10 m and Seacrest 10 m and 20 m. The photo shows a portion of the 30m transect at Me-Kwa-Mooks which hosts the highest coverage of any site (Fig. 4). This is notable given that it is in the deepest depth category and was expected to have low coverage. Traditionally, it was thought that no algae could grow below 0.01% surface irradiance. However, that is very much not the case here given that the light intensity is well below that percentage. The algae I saw and that you can see in this photo is vibrantly colored and attached to the seafloor indicating that it was growing at depth (and hosting creatures like the crab visible in the photograph). In contrast, the same depth at Mukilteo had the lowest coverage of any of the sites matching the extremely low light intensity. As you can see in the second photo (Fig. 5), a majority of the surface was sandy bottom, completely different from the coverage at 30 m at Me-Kwa-Mooks.

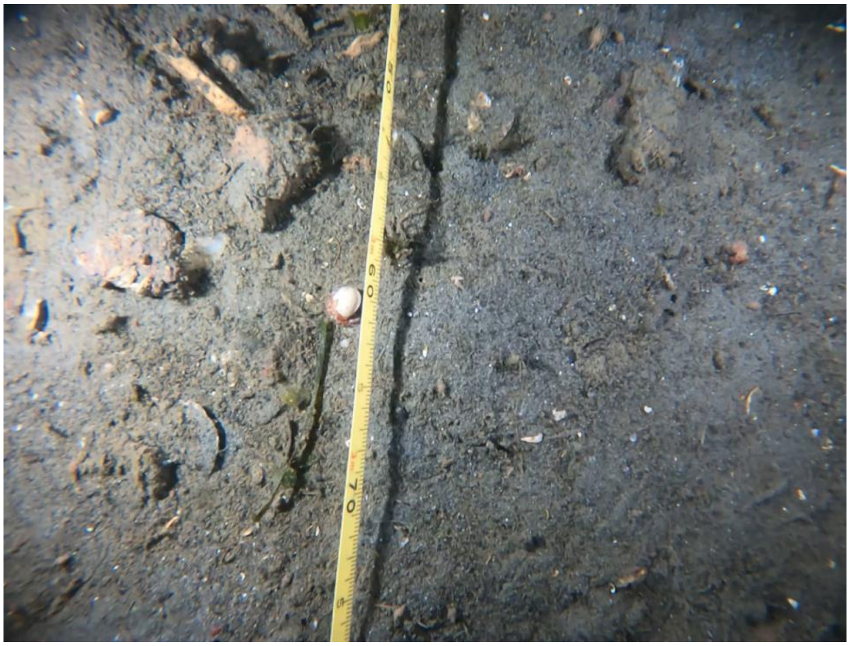

Figure 5. Video footage from Mukilteo 30 m transect.

The principal component analysis found that some transects were clustered together because of overlap in algal community, but there was no consistency in depth or site within those groups.

Given the inconsistencies in coverage across various depths, further research is needed to examine how underwater site landscape also impacts macroalgal growth and presence. One visible feature I noticed which may be causing lower algal coverage is the steep grade from shallow to deep water found at Redondo and Me-Kwa-Mooks where the 10 m transects were located. Additionally, Mukilteo had much lower percent coverage at each depth than the other sites; this may be influenced by the much lower light intensity found at Mukilteo. The site is likely impacted by the influx of the Snohomish and other rivers into the area creating a high amount of silt and plankton in the water between 5 and 10 m decreasing visibility and subsurface irradiance.

There are other factors that could be influencing the site-to-site variability I saw including the availability of substrate with most algae not being able to grow on the constantly shifting sandy bottom (Eriksson and Bergström 2005). Related to the steep grade I witnessed at some of the sites, the bathymetry, or seafloor topography, of a site may be a factor. Local currents may play a role at some of the shallower depths. And finally, the concentration of nutrients such as nitrogen can influence which algae are present in a certain area (Pedersen and Borum 1997). While the concentrations would likely be consistent across depths at a single location, different locations may exhibit different nutrient concentrations.

As ocean temperatures continue to change and impact temperate mesophotic ecosystems (Micaroni et al. 2021), this project can provide a preliminary baseline for the variety of algal ecosystems in Puget Sound. This project is a small contribution to an understudied area of research, and a better understanding of both mesophotic and photic macroalgae growth patterns will be important in maintaining these ecosystems and mitigating decreasing biodiversity.

While up to this point in my presentation I have been communicating primarily through a scientific vernacular with a few brief explanations of terminology, this style of communication often presents an exclusive barrier to many who could benefit from the knowledge gained in a study. This specialized language allows scientists and other specialists to communicate in clear and accurate ways to other members within their regimes of knowledge. As scientists and scholars though, it is equally important that we communicate in inclusive and accessible ways especially to those that are most impacted by the scientific findings. By sharing new knowledge with others, a community of people from all disciplines can collaborate to make valuable changes through education and policy based on the scientist’s discoveries. However, if the research I just presented to you was not conducted in inclusive and ethical ways, then effective science communication would not remedy the fact that the research itself was flawed. As Barber et al. state, the "key to success [in study] is integration of research and education, a model that fosters sustained collaboration by focusing on the process of conducting biodiversity research as well as research results" (Barber et al. 2014).

Successful research includes both the act of conducting collaborative inquiry and the sharing of the findings with a wide audience. Multiple scientists have critiqued the field of marine biology as being riddled with exclusive research. Just two days ago an issue of Conservation Science and Practice was published focusing on this issue (Globalizing Conservation 2022). Dr. Asha de Vos, a prominent Sri Lankan marine biologist, describes how marine biology research often involves outside researchers visiting a location to complete their study and then leaving without investing in the community they are working in or even accepting help from local experts (de Vos 2020). This practice Dr. de Vos describes has come to be known as "parachute science" in which "work is driven by the outsiders' assumptions, motives and personal needs" (de Vos 2020). To reiterate, parachute, or colonial, science refers to research or study that occurs in developing areas or countries and which is conducted by scientists from outside the community who do not engage with local individuals or widely share their findings with members of the community.

This long-term practice of parachute science (whether intentional or not) has led to selective research and lack of collaboration. Stefanoudis et al. (2021) found that of the top 10 countries publishing the most papers on coral reef biodiversity, only two are among the top 10 countries with the most coral reefs. Additionally, a majority of the publications on the subject were completed by scientists from high-income countries who traveled internationally to conduct research, often without a home-nation collaborator (Stefanoudis et al. 2021). In 2003, Dahdouh-

Guebas et al. found that, more widely, 70% of papers on research of any kind done in the least "developed" countries did not include an author from a research institute in that country. Another study by Maas et al. (2021) found that publication on ecology is still very low in 2021 for authors from the "global south" and from women. These disparities highlight who has historically been allowed and included in scientific research. By preventing those from poorer countries, the global south, and women from participating in research, this not only limits the perspectives brought to a project, but also sends a message about who is able to have and create knowledge.

Local and indigenous knowledge is often neglected or ignored when trying to answer questions of science (Smith 2021). As Linda Tuhiwai Smith (2021) suggests, this seems due to a combination of both historical dismissal as well as present-day ignorance. Historically, knowledge from local and indigenous peoples has often been considered unscientific folklore.[17] These peoples were previously placed at the bottom of the social hierarchy with some being considered less than human and therefore incapable of having or creating knowledge. Today, this knowledge is often still dismissed because it was not gained through the "scientific method" or published in a peer-reviewed journal. This ignoring of both the everyday experiences of people living in a community along with the generational knowledge of an environment has recently been called into question by many scientists (e.g. Gewin 2021; Urassa et al. 2021). By not considering this knowledge, scientists today are perpetuating the racial and ethnic biases established in the past.

To begin to address these issues, we should collaborate with historically underrepresented scientists and countries and increase communication between scientists and non-scientist members of that community. It is possible to use the already established regimes of knowledge, such as past research and the scientific method, to test, formulate, and embrace new knowledge in a just way as long as it is reconstructed to involve a representative group of the places being studied and the inclusion is not simply tokenism. Given the current biodiversity crisis, Barber et al. (2014) argue this aspect of science is needed especially in certain areas where limited research has already been done. This is especially true since often the places with the most parachute science are those being impacted the most by environmental issues (Stöfen-O'Brien et al. 2022). As Asase et al. (2021) suggest, it is necessary to enable "developing world scientists" to study the decreasing biodiversity in their own countries.

Understanding of the cultural role of science and of the limitations of the scientific system is invaluable for a scientist and is just as important to being a scientist as knowledge of research techniques and past discoveries. This is especially true as scientific discovery is employed in efforts of conservation and management. As a Christian there is extreme importance in seeing the intrinsic value of all creatures whether human, animal, or plant. Additionally though, recognizing the interconnected nature of all creation helps one see how caring for the algae of the deep sea can ultimately serve the people interacting in that ecosystem too.

As scientific study continues to be employed when examining a groaning creation, we must be diligent in attempting to pursue "global science" rather than "colonial science." To do this, researchers must collaborate with individuals from their area of study and acknowledge their work. If I were to conduct my research project again in a context outside of and without the limitations of an undergraduate honors project, I might consider communicating with both government and nonprofit environmental researchers and implementing citizen science opportunities for other divers. Then, like other scientists, I would have to ensure that the knowledge acquired moves beyond a scientific publication and into a wider audience that includes the people living in the area studied. As Pope Francis (2015) states, ecology "involves protecting the cultural treasures of humanity in the broadest sense. More specifically, it calls for greater attention to local cultures when studying environmental problems, favouring a dialogue between scientific-technical language and the language of the people." By pursuing this inclusive scientific care of creation, we can help address the wider injustices done to our neighbor.

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