Effects of docks on total cover and community assemblage of marine algae

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Abstract

Overwater structures such as docks shade the benthic communities around them, which influences both the total cover and community assemblage of marine algae. We hypothesized that algal cover decreases, and community assemblage shifts, with proximity to the dock. To test this, we sampled twelve locations near the town of Friday Harbor using transects and photo-quadrats. Data were analyzed using multiple regression to separate the effects of distance from the dock and depth. Results indicate that total cover does decrease with proximity to the dock, while patterns in community assemblage were less clear. Our methods can be applied to assessing community assemblage on a practical scale, to inform regulations and policy regarding overwater structures.

Introduction

Algae are important primary producers and provide biogenic habitat in the Puget Sound, supporting a rich diversity of species (Mumford, 2007). Overwater structures, such as docks and wharfs, inhibit the growth of photosynthetic organisms, including marine macroalgae**,** primarily by shading them (Boyer, 2013; Kelty & Bliven, 2003; MacDuffee, 2014; Thom et al., 2005). Light under docks can be less than 10% of the light at the same depth away from docks (Campbell & Baird, 2009; Steinmetz et al., 2004). As of 2011, there were over 9,000 documented overwater structures in the Puget Sound, casting an estimated 9 km^2 of shade (Rehr et al., 2014). This represents approximately 977 acres of habitat lost due to docks (Szypulski, 2018), and equivalent loss of habitat for the myriad species relying on algae for biogenic habitat and food (Gelfenbaum et al., 2006; Mumford, 2007).

In addition to shading, docks can alter water flow and sediment transport, resuspension, deposition, and organic content (Kelty & Bliven, 2003; Logan et al., 2015). The magnitude of these effects is dependent on dock characteristics such as size, shape, aspect, how high they are built above the water and how deep the water is beneath them, the type of pilings used to support the dock, and the materials used in its construction (Sagerman et al., 2020; Schlenger et al., 2011). These changes to light availability, water and sediments can impact the distribution and productivity of many species, including algae (MacDuffee, 2014; Schlenger et al., 2011). Assumably, these variable stressors may influence competition between algal species, and impact community assemblages.

There is a dearth of research focusing on algae within the Puget Sound, perhaps due to the difficulty and cost of current sampling methods (Mumford, 2007; Szypulski, 2018; Vahtmäe et al., 2006; Werdell & Roesler, 2003). Studies on eelgrass and their response to docks are more abundant (Boyer, 2013; Mumford, 2007; Thom et al., 2005), which can be relevant to macroalgal research because seagrasses often live in the same areas and have similar abiotic requirements as algae (Vahtmäe et al., 2006). However, a 2018 study done by Szypulski evaluated the effect of docks on the distribution and productivity of kelp in the Puget Sound. Szypulski found that kelps were significantly more abundant at control sites than at the associated dock sites, and when present at the dock, their abundance and biomass increased as distance from the dock increased.

Szypulski’s 2018 research only evaluated subtidal kelps and did not consider changes in algal community assemblages across a gradient of distance from the dock. The distribution of macroalgae was found to be significantly reduced under docks in the Puget Sound compared to adjacent habitat (Parametrix & Battelle, 1996), though community structure was not assessed. In

Korea, two studies done at Inchon Dock have shown that algal communities are significantly different near the dock compared with those on the rocky shore (Yoo et al., 1996; Yu et al., 1999). Other studies have shown that boat traffic, not necessarily in association with a specific dock, causes algal community assemblages to change in favor of species that can tolerate the increased turbidity caused by the boats (Eriksson et al., 2004; Hansen & Snickars, 2014; Willby et al., 2001). No studies assessing algal community assemblage in relation to docks have been done in the Puget Sound (Sagerman et al., 2020). Understanding how docks affect overall community assemblages can help assess the overall ecological impact of a dock, and inform regulatory decision-making. Our work investigates whether docks have a quantifiable impact on algal cover and community assemblage in Friday Harbor. We hypothesize that algal cover will decrease, and the community assemblage will shift, with proximity to the dock.

Methods

Field Work

Docks were sampled in two locations around the town of Friday Harbor, San Juan Island, Washington: five locations within the Port of Friday Harbor were sampled (Figure 1A), and both sides of the dock at Friday Harbor Laboratories were sampled (Figure 2). Docks were chosen based mainly on proximity to the research station, and sites were selected if we could lay two transects 10 meters apart, perpendicular to the dock, and ideally also parallel to the shore to ensure a similar depth along each individual transect. We aimed to lay the transects about 10 meters apart to allow for drift of the rowboat. Four transects were sampled at Friday Harbor Laboratories, two on either side of the dock, and eight transects were sampled at the Port of

Friday Harbor. Two transects at the Port were unpaired because the second transect proved too deep. Two transects were performed perpendicular to the shore on one dock in the Port.

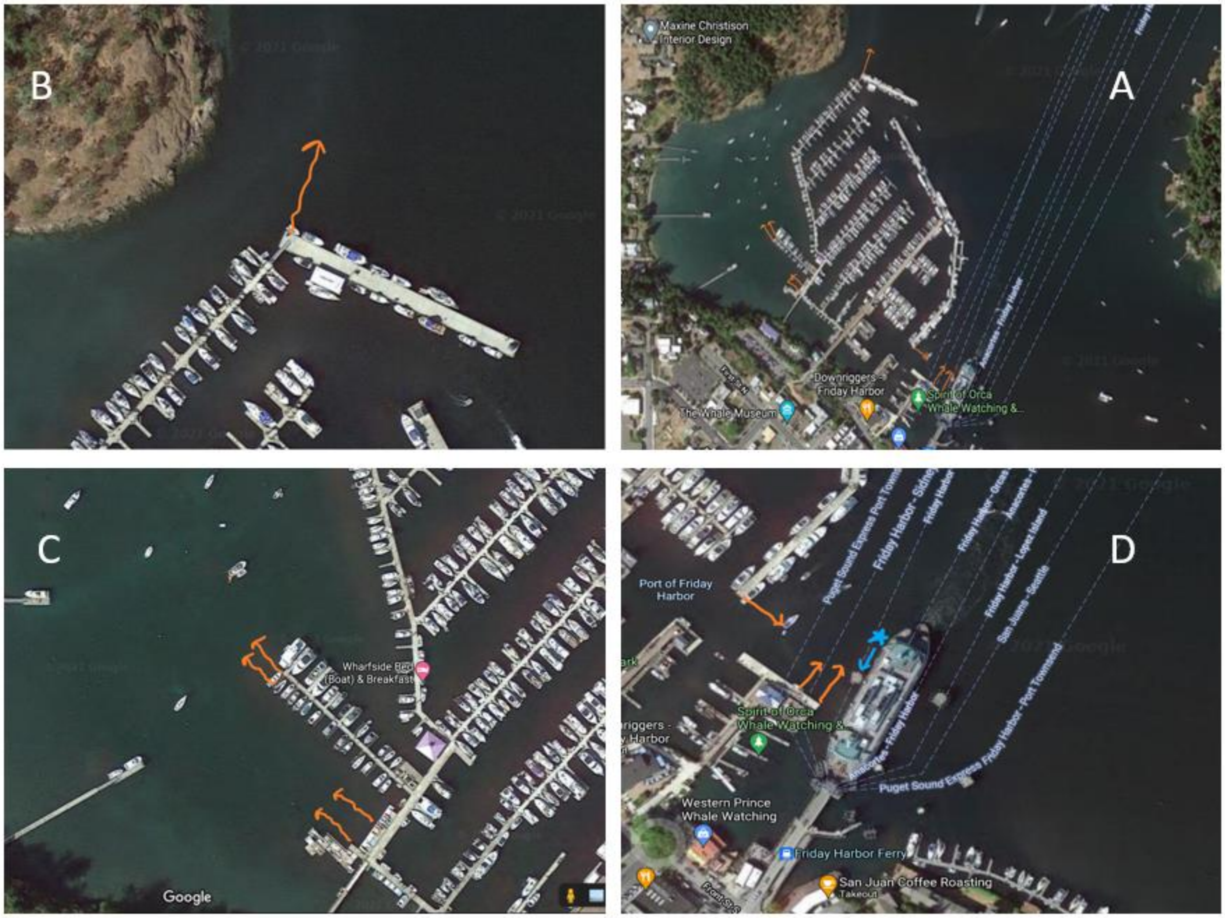

Figure 1. A: Port of Friday Harbor marina layout and sampling locations (8). B: the single transect done off the outer breakwater was deep and exposed, and a second transect could not be done due to depth. Large ships moor along this breakwater. C: the four transects measured here, corresponding to the bottom left of the marina, were all shallow and protected from waves. D: Three transects were measured close to the ferry, all of which were deep and not protected from either waves or the ferry prop wash. The right-most transect in the image was close to a set of pilings associated with the ferry, indicated by the blue arrow, 25 meters away from the dock.

Figure 2. Friday Harbor Laboratories dock layout and sampling locations (4). The two transects done on the left were each shallow, and protected behind the floating breakwater at the bottom of the dock. The nearshore transect done on the right was shallow, while the farther transect was deep. Wave exposure was significantly reduced by the breakwater for those transects on the left.

We laid 25 meter transects perpendicular to each dock site, and collected photo-quadrats of the benthos using a Hero-7 Black GoPro and pyramidal PVC frame as a subtidal sampling device that could be deployed from the surface, with the base forming a 50cm x 50cm quadrat. The rope used to lower the sampling device was marked at half-meter intervals to estimate depth at the time of the photo, and NOAA tide data were used to calculate the true depth of each quadrat with respect to MLLW. We sampled along two transects per dock, except when depth exceeded the length of our rope (13 meters). Each transect was photographed at 5-meter intervals starting 5 meters away from the dock, resulting in 5 photo-quadrats per transect.

Analysis

We used Image-J to calculate the area of each quadrat and the respective total areas within the quadrat taken up by each major phylum of algae, Rhodophyta ("reds"), Ochrophyta ("browns"), and Chlorophyta ("greens"). The angle and height of the picture were often slightly different, resulting in a different total area calculation for each photo. To correct for this discrepancy, we converted our measurements of area taken up by each phylum into proportions of the total area measured.

To assess whether there was a relationship between the percent cover of algae and the distance from the dock, while accounting for natural variation in cover with increasing depth, we used a multiple regression analysis. Because proportion data does not have a normal distribution, we arc-sine transformed our data. We used several multiple regression analyses, again with our data arc-sine transformed, to assess whether community assemblage shifted with proximity to the dock. We tested both the cover of each individual phyla and the number of phyla present in each quadrat against distance from the dock, accounting for depth.

Results

Table 1. Multiple Regression Analyses. Coefficients associated with significant p-values ($p<0.05$) are highlighted, with green indicating a positive relationship and red indicating a negative relationship.

	TOTAL COVER	BROWNS	GREENS	REDS	TOTAL PHYLA PRESENT
ADJUSTED R^2	0.42	-0.0017	0.47	0.25	0.00041
DISTANCE COEFFICIENT	0.025	0.0020	0.025	-0.0011	0.016
DISTANCE P-VALUE	0.0077	0.26	0.0047	0.22	0.21
DEPTH COEFFICIENT	-0.077	0.0018	-0.081	0.0053	0.011
DEPTH P-VALUE	6.8E-08	0.45	4.9E-09	3.8E-05	0.55

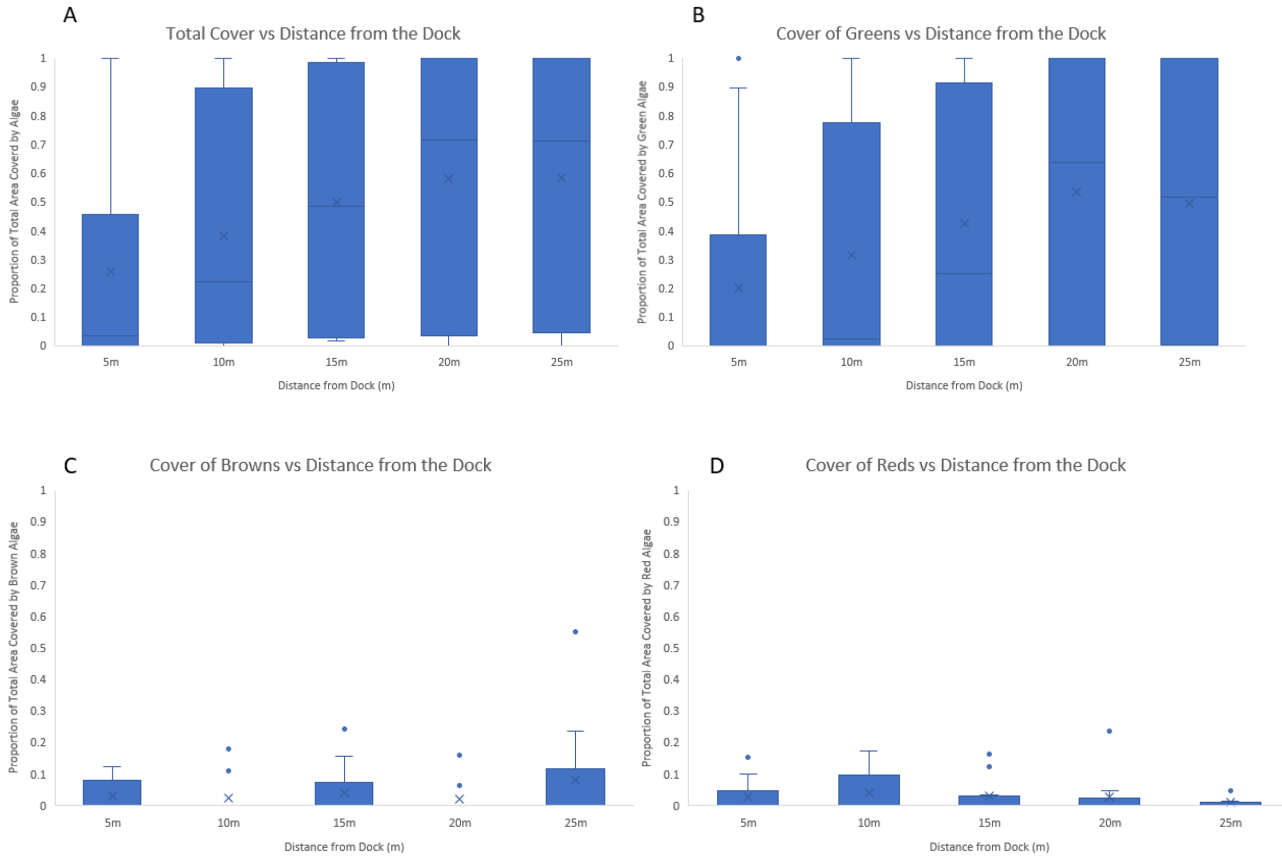

Figure 3. A: As distance from the dock increased, the total cover of algae increased. B: As distance from the dock increased, the proportional cover of green algae increased. C: Proportional cover of brown algae did not show a pattern in relation to distance from the dock. D: Proportional cover of red algae did not show a pattern in relation to distance from the dock.

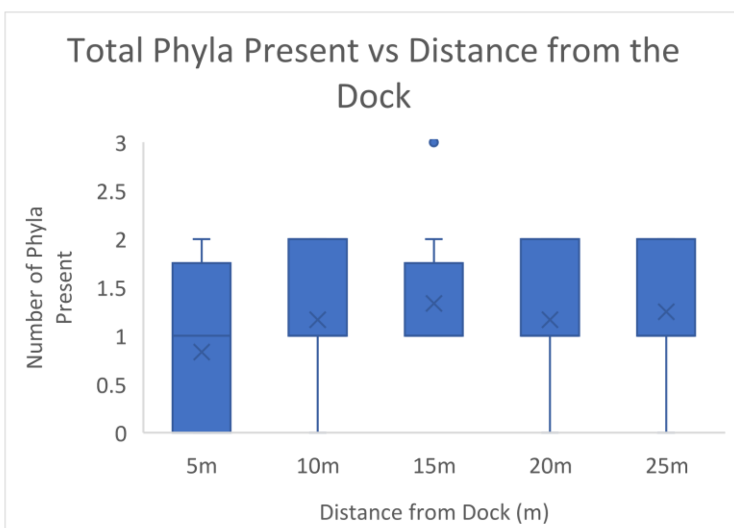

Figure 4. The total number of phyla present in each quadrat does not show a discernable change as distance from the dock increases.

As tabulated in Table 1, total algal cover (Figure 3A) and cover of green algae (Figure 3B) increased with distance from the dock, while no significant pattern was detected between distance from the dock and cover of brown (Figure 3C) or red algae (Figure 3D), nor between distance from the dock and total number of phyla present (Figure 4). We noted that total cover and cover of green algae decreased with depth, while cover of red algae increased (Table 1).

To decouple the effects of depth and distance from the dock, assemblage was plotted as two separate depth-groups which encompassed all data (Table 3, Figures 5 and 6), with shallow defined as less than 3 meters below MLLW and deep defined as greater than 8 meters below MLLW (Table 2).

Table 2. Depth Groupings

	Shallow	Deep
Maximum Depth (m)	2.15	13.3
Minimum Depth (m)	1.43	8.6
Mean	1.71	11.9
Standard Deviation	0.28	1.6

Table 3. Averages of proportion of area covered by each phyla, grouped by depth.

	Shallow				Deep			
Distance from Dock	Brown	Red	Green	Bare	Brown	Red	Green	Bare
5 m	0.015	0	0.34	0.64	0.047	0.064	0	0.89
10 m	0.026	0.016	0.54	0.42	0.022	0.075	0.0038	0.90
15 m	0.023	0	0.68	0.30	0.068	0.072	0.069	0.79
20 m	0.032	0.00065	0.86	0.10	0	0.063	0.072	0.87
25 m	0.056	0	0.84	0.10	0.11	0.023	0.0075	0.86

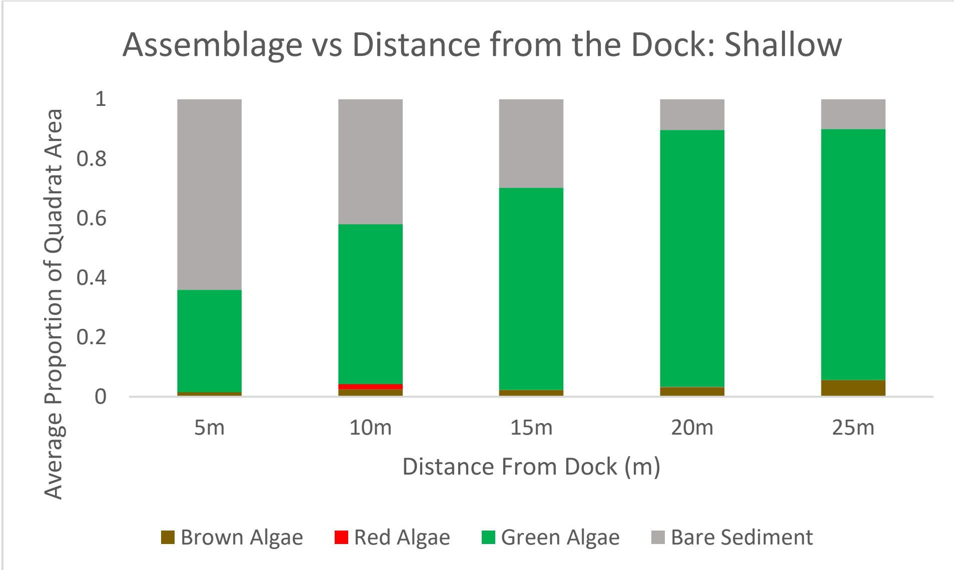

Figure 5. The assemblage of the phyla present in each shallow quadrat, represented as proportions of the total quadrat area.

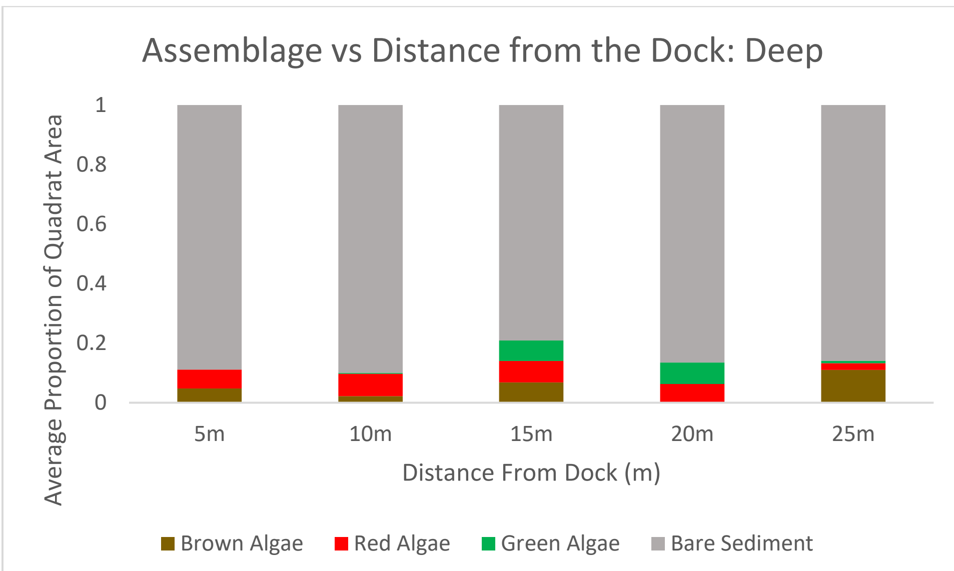

Figure 6. The assemblage of the phyla present in each deep quadrat, represented as proportions of the total quadrat area.

Figure 5 shows an increase in total algal cover and cover of green algae as distance from the dock increased, reflective of the results of the multiple regression analyses in Table 1. Comparison of Figures 5 and 6 confirms that total cover decreases, cover of greens decreases, and cover of reds increases with depth (Table 1).

Discussion

Our results supported our hypothesis that total cover declines with proximity to the dock (Table 1, Figure 3A), though this pattern was much clearer in the shallow transects than the deep ones (Figures 5 and 6). Results regarding whether community assemblage shifted with proximity to the dock were less clear (Tables 1 and 3, Figures 3, 4, 5 and 6). There was no correlation between the number of phyla present and distance from the dock (Table 1, Figure 4). Shallow transects were almost entirely dominated by the green alga *Ulva*, which did decrease in cover closer to the dock, but was replaced with bare sediment instead of other phyla (Figure 5). Thus, these data are more informative of *Ulva* patterns than community patterns. Deep transects did not show a clear shift in assemblage with proximity to the dock, perhaps because algae were sparse altogether (Figure 6). Though Szypulski (2018) determined that response of kelp to the dock was independent of depth, and though our multiple regression analysis treated the effects of the dock and depth as independent variables, it may be worthwhile to investigate whether the two may be synergistic at greater depth. This may require extending the transect further than 25 meters off the dock, despite Szypulski's (2018) conclusions that effects on kelp are negligible past 6 meters from the dock, and new docks only are required to be built 25 feet away from existing kelp beds in Washington State (WAC, 2015). Alternately, all measurements were taken off of floating docks, which shade more than those raised above the water (Burdick & Short, 1999; Eriander et al., 2017). Perhaps shifts in assemblage could have been more effectively measured at an intermediate depth, at a time of year when *Ulva* was not as abundant, or off a raised dock when assessing depths greater than 8 meters.

Only one transect was sampled at shallow depth on an exposed side of the dock (Figure 2), and it displayed a pattern distinct from the other transects. Though we did not strictly classify whether a location was protected or exposed, and both the Port and the Laboratory dock could be considered protected geographically, here I loosely define protected as being somewhere behind a breakwater, not directly exposed to wave action. All five of the deep transects were exposed, and six of the seven shallow transects were protected (Figures 1 and 2). Along the single shallow, exposed transect, cover and diversity were both observed to be notably higher than any other transect, and *Ulva* was not dominant, unlike all other shallow transects. It would appear that marinas and breakwaters facilitate the dominance of *Ulva*, because marinas are generally characterized by poor substrate and water quality, resulting in changes in benthic communities (Nightingale & Simenstad, 2001). Because *Ulva* grows in a sheet over other benthic organisms, when abundant, *Ulva* species are known to create an anoxic environment and reduce light enough to shade out their competition (Hernández et al., 1997; Hull, 1987; Wilson, 1993). High levels of nitrate (Murray et al., 2015), likely from the Friday Harbor sewage outfall located between the Port and Laboratory, could also have contributed to the dominance of *Ulva*. Regardless, the effects of the dock on community assemblage and total cover may have been better evaluated with more transects covering shallow, exposed areas.

The three deep transects located by the ferry (Figure 1D), upon review, appear to be within 25 meters of another shading structure, either another dock or a set of pilings associated with the ferry. However, these three transects showed more cover than the other two deep transects (Figure 1B; Figure 2). We expected the ferry's prop wash to scour the nearby sediment, resulting in the lowest total cover. While total cover was low, as it was for all deep transects, perhaps cover was not lowest here because turbulence caused by the ferry relieved poor water conditions associated with marinas. Alternately, measurements at the breakwater (Figure 1B) may have been skewed as the largest boats dock there, including tour boats, meaning the shade footprint of that breakwater could have routinely exceeded 25 meters. The deep transect sampled at the Laboratory (Figure 2) was sampled when the mooring chains were being replaced, which could have resulted in disturbance affecting cover and assemblage. Thus, there may have been too much variation among deep transects to be comparable.

Szypulski (2018) found that shading caused kelps to be less abundant near docks than at paired control sites, and less abundant nearest the dock when present, independent of depth. These results were also found to be independent of sediment size and percent organics. In fact, the effect of shading was so pervasive that in some cases, kelps were more abundant at control sites that had finer grained substrate than at the paired dock site of the same depth with substrate that was larger and therefore more preferable for recruitment (Mumford, 2007). Several factors that were not measured here could have affected our results, including but not limited to sediment size (Klein, 1997; Sagerman et al., 2020; Szypulski, 2018), the orientation of the dock in relation to the sun (Blanton et al., 2001; Burdick & Short, 1999; Campbell & Baird, 2009), the total area of the shade footprint generated by the dock and its boats, and the residency times and traffic of these associated boats, including the adjacent ferry. Boats influence algae in many ways, including but not limited to direct damage by propellers and anchors, resuspension of sediments resulting in shading or smothering, and increased chemical pollution (Sagerman et al., 2020). Importantly, boats increase the shade footprint of the structure for as long as they are moored at the dock (Nightingale & Simenstad, 2001; Parametrix & Battelle, 1996; Thom et al., 1996; Weitkamp, 1980). Sagerman et al. (2020) found that the effects of docks and their associated boat traffic was highly variable across sites. Levels of boat traffic may vary by site and season; variation in sensitivity can be specific to species, life-history phase, or growth-form; and abiotic factors influencing algal communities by site could include sediment size, water depth, and wave exposure (Sagerman et al., 2020). As reviewed by Sagerman et al. (2020), there are an insufficient number of studies to either develop a metric to measure boat traffic and human influence, or predict the effects of different structures on their surrounding habitats. It was noted at both of our study sites, and by Szypulski (2018), that large specimens of all phyla can be found anchored near the surface on the dock itself, even if absent from the substrate below. This may indicate that either shading or sediment size are the main explanatory factors for this absence, versus water quality or movement, though these variables could be different at depth than at the surface.

Establishing a classification system for different dock types based on dock attributes, use, and local conditions will facilitate assessment of dock impacts on total cover and assemblage of algal communities (Sagerman et al., 2020). Szypulski's (2018) work developed a practical method to survey a dock's effect on algae, with the permitting process in mind. While this method focused on kelp, it could be extended to all algae. Our study illustrates an approach for analyzing community assemblage of algae using photo quadrats. This approach could be used or modified by others to collect information pertinent management needs and the development of regulations. Shoreline development will only increase with time, and the cumulative effects of overwater structures with it (EnviroVision et al., 2007).

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