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Ecological Effects of Overwater Structures on Subtidal Kelp, Northern Puget Sound, Washington

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ECOLOGICAL EFFECTS OF OVERWATER STRUCTURES ON SUBTIDAL KELP, NORTHERN PUGET SOUND, WASHINGTON

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by

E. Jhanek Szypulski

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ABSTRACT

ECOLOGICAL EFFECTS OF OVERWATER STRUCTURES ON SUBTIDAL KELP, NORTHERN PUGET SOUND, WASHINGTON

by

E. Jhanek Szypulski

November 2018

There are more than 9,000 overwater structures in the Puget Sound casting an estimated 9 km^{-2} of anthropogenic created shade to the seafloor. Subtidal kelp, over 20 species in total, are abundant in the Sound but little data exists on how they are impacted by these overwater structures. The purpose of this research is to quantify various overwater structures' impacts on the productivity and distribution of subtidal kelp beds and to create a subtidal kelp monitoring protocol. Three sets of floating docks and paired controls were sampled twice during the summer of 2017 for subtidal kelp distribution, biomass, photosynthetically active radiation (PAR), substrate, and fish presence. Georeferenced benthic video surveys were conducted along parallel transects to create 1 m grid cell maps encoded for subtidal kelp presence/absence at each site. Wet biomass and morphometric measurements were taken from kelp collected from 30 samples at each site. Light extinction coefficients were calculated using an array of 11 PAR sensors deployed at various depths and distances from each dock and within each paired control site. Substrate samples were analyzed for organic content and particle size distributions. Proportional coverages and densities of subtidal kelp were statistically compared for significant differences between the docks and their paired control sites and were correlated with related environmental conditions using nonparametric tests. Overall, subtidal kelp distribution and productivity were negatively related to dock presence. Significantly less kelp presence by transect was found at every dock site (medians = 0 – 20.4%) than paired controls (medians = 96.2 – 100%), as well as significantly less kelp biomass (dock medians = 0 – 199.6 g; control medians = 282.1 – 565.9 g), while available PAR was found to be less on the north of the docks (means = 26.2 – 193.4 μmol m^{-2} s^{-1}) than paired controls (means = 58.2 – 219.0 μmol m^{-2} s^{-1}) in all but one case. PAR appears to be the limiting environmental factor to kelp distribution and productivity while sediment size and percent organics do not appear to play a significant role.

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CHAPTER 1

INTRODUCTION

Problem

Kelp are structured into three main morphologies: the giant kelp which form floating canopies and are easily observed from the surface, the stipitate (subtidal) kelp that create sub-surface, understory canopies, and the prostrate (subtidal) kelp that form close to the substrate in mat-like structures (Aronson et al., 2009). Subtidal kelp (Order Laminariales), in a perpetually submerged state, exist as a foundation species in the Sound (Kain, 1989). These kelp provide many essential ecosystem services including buffering of wave energy, decreasing beach erosion, and the creation of habitat, nursery, and foraging grounds, in addition to being a food source for a vast number of species (Springer et al., 2007). In the Puget Sound, several species listed as endangered under the Endangered Species Act (ESA) routinely utilize kelp bed habitats including Chinook salmon (*Oncorhynchus tshawytscha*) and the southern resident killer whales (*Orcinus orca*, SRKW) (Mumford, 2007). Despite there being 25 species of kelp in the Sound, only the two canopy-forming, floating kelp, giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*), have been extensively researched, leaving a near total absence of data on the 23 subtidal kelp species found there (Bartsch et al., 2008; Mumford, 2007).

There are over 9,000 overwater structures in the Sound (Rehr et al., 2014) that have the potential to negatively affect the kelp that inhabit its waters (Mumford, 2007). While kelp are an algae, not a plant, they are photosynthetic and likewise greatly affected by light extinction caused by shading from overwater structures (Steneck et al., 2002). In fact, light extinction within the kelp forest is the limiting factor for kelp growth at high latitudes (Steneck et al., 2002). The Washington Department of Fish and Wildlife (WDFW) routinely encounters costly permit appeals by the citizen environmental group Sound Action for not adequately considering subtidal kelp when issuing Hydraulic Project Approval (HPA) permits for piers, docks, floats, and boathouses, collectively termed overwater structures, in the Puget Sound (Sound Action, 2014).

While light extinction is known to affect subtidal kelp, it is costly and time-consuming to monitor and measure. Mumford (2007) discusses the wide distribution of subtidal kelp in the Puget Sound and suggests that they may play a larger role in the ecosystem than the floating kelp yet cites a severe lack of monitoring data on their status and trends. The most effective methods for subtidal kelp monitoring are SCUBA-based surveys, drop cameras, remotely operated underwater vehicles, or side scanning sonar, all of which require significant time and extensive effort (Werdell and Roesler, 2003). This is, perhaps, why there is a little scientific literature on subtidal kelp and their environmental stressors (Kain, 1989; Mumford, 2007).

Because of limited data on subtidal kelp, it is useful to draw corollaries from species with similar environmental requirements, such as eelgrass (*Zostera marina*), which are often found in the same subtidal environments as kelp (Thom and Hallum, 1990). The effects of light extinction on eelgrass caused by shading from overwater structures has been extensively studied (Diefenderfer et al., 2009; Dyson and Yocom, 2014; Rehr et al., 2014). Rehr et al. (2014) determined that of all the methods considered in their study (i.e. removal of overwater structures, removal of shoreline armoring, or nutrient loading) that removal of overwater structures in the Puget Sound would have the greatest benefit to eelgrass recovery.

Purpose

The purpose of this research was to examine how overwater structures affect the distribution, and productivity of subtidal kelp, and to infer how this may influence the ecology of beds in northern Puget Sound, Washington, as well as to create a subtidal kelp monitoring protocol. This was accomplished by direct observation, measurements, experiments, and quantitative analysis of data collected from three impact sites, which were each paired with a control site. It is imperative to understand the relationships between environmental stressors and habitat quality to prevent degradation of this important indicator and foundation species in the Puget Sound (Uhl, Bartsch, and Oppelt, 2016). This research reports baseline data for future studies and assists in fulfilling Washington Department of Natural Resources (WDNR) and WDFW’s obligations under Washington State law to consider macroalgal habitats when permitting new, and monitoring existing overwater structures (WAC, 2004; WAC, 2015).

The research objectives addressed by this study were:

1) To measure the density, distribution, and productivity of subtidal kelp beds, at impact sites with overwater structures and their paired control sites.
2) To measure potential environmental controls of kelp productivity including light availability differences with depth, and to analyze the substrate at the paired sites.
3) To evaluate differences in fish activity and speciation between the dock and control sites.

To address these research objectives, the density, distribution, and productivity of the kelp beds at the impact and control sites was measured. This was accomplished by conducting georeferenced video surveys to record presence/absence of subtidal kelp, using projected lasers to capture scale measurements along a systematic grid (Carr, Syms, and Caselle 2001), and biomass sampling at each study site. Video surveys and biomass sampling were conducted twice at each site, once in early summer (July – early August) and once in late summer (late August – September), 2017. In addition, light availability differences with depth and distance from the docks were analyzed at the impact and control sites. This was accomplished by deploying an array of photosynthetically active radiation (PAR) sensors at depths of 1 cm below surface, 1 m below surface, just above the subtidal kelp canopy, and one in full light to measure light intensity differences between each site (Long et al., 2012). Measurements were taken at 2 min intervals for a complete high-to-high tidal cycle during peak subtidal kelp growth at each site visit from July through September 2017. Substrate was sampled once at each site and analyzed for organic content and particle size (Rosenberg et al., 2015). Finally, we examined fish use differences using standardized prey tethering experiments (MarineGEO, 2016) combined with video monitoring conducted concurrently with light extinction monitoring and recorded fish species and counts beneath docks and control sites. Geographic Information Systems (GIS) data layers were created for all recorded data.

Significance

This research quantifies various overwater structures' light extinction capacities and assesses their impacts on subtidal kelp. Analyses of these data will be given to WDNR and WDFW to facilitate management decisions on HPA permitting in the Puget

Sound. Expensive permit appeal processes and potential litigation could be limited by better understanding the effects that overwater structures exhibit on subtidal kelp. These data contribute to filling gaps in the current scientific literature on the ecological impacts of overwater structures to subtidal kelp beds (Maxell and Miller, 1996; Mumford, 2007). Additionally, these data serve as a baseline for further research that could be used to develop predictive models for estimating the impacts of proposed overwater structures on subtidal kelp habitats. Lastly, this research also develops a cost-effective, safe alternative to current subtidal kelp monitoring methods that is easily replicable, and rapidly assessed.

CHAPTER 2

LITERATURE REVIEW

The Ecological and Economic Importance of Kelp

Kelp are found in the nearshore environments on the coasts of all continents except Antarctica (Krumhansl et al., 2016). With 25 species of 12 genera, the Puget Sound is one of the most diverse kelp habitats anywhere on earth (Mumford, 2007). Kelp play a vital ecological role as a primary producer in the oceans, and their bottom-up trophic forcing supports an immense variety of species (Desmond, Pritchard, and Hepburn, 2015). It is estimated that over 200 species of fish utilize subtidal kelp habitats including ESA listed species of salmon, rockfish (Genus *Sebastes*), and Pacific herring (*Clupea harengus pallasi*) (Gelfenbaum et al., 2006). In addition to fish species, the kelp beds are regularly used by many marine mammals, notably the harbor seal (*Phoca vitulina*), stellar sea lion (*Eumetopias jubatus*), harbor porpoise (*Phocoena phocoena*), and orca (*Orcinus orca*) (Gelfenbaum et al., 2006). Kelp fill an invaluable role as an indicator species in the Sound due to their rapid growth rates, specific environmental conditions necessary to flourish, and their extreme susceptibility to local stressors (Uhl, Bartsch, and Oppelt, 2016). With growing concerns over climate change, perhaps kelp's greatest ecological benefit, and potential economic value, is that they are a carbon fixer with the potential to sequester carbon on par with the rainforests, if properly managed, and providing they have adequate, persistent habitat (Aronson et al., 2009; Chung et al., 2013, Vásquez et al., 2014).

Subtidal kelp, as a foundation species, not only provide a food source and habitat, but also affect the feeding patterns and distribution of fish and other animals (Siddon, Siddon, and Stekoll, 2008). Kelp's effects on water-flow and the shade they create are thought to direct faunal distribution patterns (Eckman and Siddon, 2003; Koehl and Alberte, 1988). In addition to their presence and abundance, the chemical composition of subtidal kelp has been shown to influence feeding patterns as well as the distribution of fish, and other animals, within the kelp beds (Levin and Hay, 1996). Siddon, Siddon, and Stekoll (2008) experimented with kelp canopy cover in Auke Bay Alaska to determine the effects of its removal to fish and invertebrates by season. While their experiment focused on canopy-forming kelp, they also surveyed subtidal kelp and classified any *Laminariales* under 30 cm as juvenile. Interestingly, Siddon, Siddon, and Stekoll (2008) found that subtidal kelp in Auke Bay remained present throughout all seasons although it was twice as dense in summer. They found that young fish preferred floating kelp canopy cover but remained near the benthos, within the subtidal kelp beds. Additionally, Kaszycki (2001) found abundance of several rockfish species and pacific herring to be proportional to kelp presence. Likewise, Hamilton and Konar (2004) found great fluctuations in kelp cover by season over a long-term study from May 2002 to September 2003 in Kachemak Bay, Alaska, with greater kelp cover being directly proportional to increased fish presence.

Acknowledging their substantial ecological import, many studies and reports discuss the great economic value of kelp forests as primary habitat for a diversity of commercially valuable urchin, mollusks, crustaceans, and rockfish (Foster and Schiel, 1985; Mann, 2000). Kelp forests also offer valuable recreational and educational services for diving, fishing, bird watching, boating, and photography (Aronson, et al., 2009). They provide essential nearshore regulating services as well, including nutrient cycling, buffering wave energy, and prevention of shoreline erosion (Krumhansl et al., 2016). Kelp are also a food source to a variety of species, including direct human consumption, and as additives in food products, cosmetic products, fertilizers, and as biofuels (Chung et al., 2013; Graham, Halpern, and Carr, 2008). Houghton et al. (2015) recently discovered that alginate, derived from kelp, is an effective treatment for combating obesity. Extracts from kelp have various other medical uses as well, including treatment of arthritis, hypertension, and cancer (Fitton, 2011; Stengel, Connan, and Popper, 2011).

Requiring only sunlight, seawater, and naturally derived nutrients but no fertilizer, pesticide, fresh water, or arable land, kelp are the fastest growing organisms on Earth (*M. pyrifera* grows up to 60 cm per day) (Foster and Schiel, 1985). As such, companies like Algea and Seaweed Energy Solutions are currently experimenting with mass production technologies and processing techniques to create carbon-neutral biofuels and sustainable food substitutes from kelp to meet the world's energy and food demands (Algea, 2016; SES, 2016). Some studies have assessed that other sources of biofuel feedstock, such as sugar cane, have a lower net carbon footprint than kelp, and therefore may be a more efficient biofuel source (Fry et al., 2012). However, this is currently due to the small-scale operations of kelp harvesting and does not consider the necessity of valuable land resources that must be devoted to terrestrial fuel stocks (Fry et al., 2012). Indeed, Fry et al. (2012) explain that the carbon footprint of kelp as a biofuel source would be greatly reduced as production is expanded.

Kelp harvesting on a mass scale may also play an imperative role in the reduction of ocean acidification. The Puget Sound Marine Waters report, conducted by the National Oceanic and Atmospheric Administration (NOAA) in 2015, explains that carbon dioxide in the Sound has been increasing at an alarming rate in recent years when compared to long-term trends (NOAA, 2015). Because kelp require carbon dioxide for growth and emit oxygen as it is processed, they thrive in the increasingly acidified waters of the Puget Sound. As such, The Puget Sound Restoration Fund was awarded the $1.5 million Paul G. Allen Family Foundation grant in 2015 to research if kelp farming and harvesting practices will aid in carbon dioxide reduction in the Puget Sound (Allen, 2015). In cooperation with NOAA and many other agencies, this project has a five-year timeline and is currently in the kelp planting stages in areas of Hood Canal where kelp do not typically grow (Allen, 2015). Kelp's ability to reduce acid, phosphorous, and nitrogen in ocean waters is an incredible asset in both ecological and economic capacities.

Despite the many studies on the economic value of kelp, its total economic value may never be fully calculated in a finite, objective value (Vásquez et al., 2014). This is because new products from kelp are constantly being developed, and many of the environmental services to which kelp contribute are not yet fully understood, including nutrient budgets, iodine cycling, and climate change. The total economic value of kelp ecosystems is quantified from their direct use, measured using market values, their value of indirect use, again measured using market values or proxies for market values, and their non-use, or existence values, calculated largely from revealed preference and stated preference methods (Vásquez et al., 2014).

While the total economic value of kelp can fluctuate, Vásquez et al. (2014) attempted to calculate the value of the kelp forests of northern Chile. They determined that due to their direct use, through harvesting, education, and tourism, importance to scientific inquiry, function as an oceanic purifier, and contributions to biological diversity, that the total economic value of the kelp stock in northern Chile for 2014 exceeded US $500,000,000. Additionally, this value was projected to increase, as revealed by the exponential rise of kelp's worth over the last ten years and the increased understanding of kelp's key role as a carbon sink. Similarly, Krumhansl et al. (2016) performed a comprehensive study of global kelp forest change over the last 50 years and estimated the ecosystem services which kelp provide are valued in the multiple billions of dollars annually.

Although kelp are highly valued, a pervasive and reoccurring theme in the current scientific literature is that more research and quantifiable data are needed to better understand their significance. This theme is noted by Vásquez et al. (2014) as well, as they explain that the full roles which kelp play and the processes which they facilitate in the nearshore ecosystem "are not well understood, and the available scientific data are not sufficient to quantify exactly the environmental services of kelp coastal communities."

Distribution

While the economic value of subtidal kelp is extensive, Mumford (2007) notes the lack of quantitative research and data on the impacts to the species in the Puget Sound from various environmental controls. Although there may be more total floating kelp biomass, they inhabit only an estimated 11% of the Puget Sound shoreline while the subtidal species inhabit an estimated 31%. The floating species of kelp have been extensively researched in the Pacific Northwest (PNW), including both bull kelp and giant kelp (WDNR, 2001; Donnellan, 2004; Rigg, 1912). This is primarily due to these species' higher visibility, the grandeur of the kelp forests they create of up to 30 m in height, and because both species are easily monitored by aerial photography or simple kayak surveys as they are readily observed floating on the surface of the water (Berry, Mumford, and Dowty, 2005; Bishop, 2016). However, kelp often occur in a tiered system with all three morphologies co-habiting the same locale, including floating, stipitate, and prostrate kelp species (Benes, 2015; Britton-Simmons, 2004). This is analogous to a terrestrial forest comprised of trees, shrubs, and grasses, where the trees are studied extensively, but the more common shrubs and grasses, while perhaps more abundant in terms of total biomass, and certainly no less important to the ecosystem, go overlooked and under-examined.

By comparison, seagrass distribution has been thoroughly researched, providing findings significant for subtidal kelp (Boyer, 2013; Rehr et al., 2014; Thom and Hallum, 1990). Seagrasses often cohabit the same nearshore beds and share environmental controls with kelp, including availability of light, suitable substrate, water temperature, and adequate salinity (Vahtmäe et al., 2006). Seagrasses are intertidal, perennial plants that are usually exposed at mean lower low water (MLLW), facilitating the ease of their study (Mumford, 2007). This exposure makes remote sensing techniques particularly useful in mapping and monitoring these grasses (Hossain et al., 2014; Thom and Hallum, 1990). Floating kelp canopies have likewise benefited from the use of remote sensing technology in their monitoring (Berry, Mumford, and Dowty, 2005; Werdell and Roesler, 2003), but this is not the case with subtidal kelp. With few exceptions, remote sensing has not been utilized in subtidal kelp study as the refraction of light and turbidity within nearshore waterbodies make these techniques largely inconclusive (McGonigle et al., 2011; Méléder et al., 2010; Uhl, Bartsch, and Oppelt, 2016).

Vahtmäe et al. (2006) investigated the feasibility of employing remote sensing techniques for kelp habitat research and found the results ambiguous at best. They discuss the importance of maintaining long-term, accurate information on indicator species, such as kelp, in coastal environments to assess the conditions of the nearshore habitat. They explain how assessment of macrophyte growth and productivity may be used as a proxy for a number of factors including eutrophication and nutrient concentration of coastal waters (Vahtmäe et al., 2006). Vahtmäe et al. (2006) also note the lack of studies on benthic macroalgal communities, as compared to seagrasses or corals, and that remote sensing techniques which have been successfully implemented for subaquatic algal mapping have occurred in clear waters, which are not typical of coastal environments with high wave energy like the waters of the Puget Sound. Furthermore, species differentiation is impossible after 1 m and inconsistent at best in shallower waters making on-site kelp research a necessity (Vahtmäe et al., 2006).

While limited in number, some studies have focused on subtidal kelp. Maxell and Miller (1996) studied the demographics of the floating bull kelp, the subtidal seersucker kelp (*Costaria costata*), and their relationship to one another. They focused their inquiry on a single subtidal species and their extent to where it occurs within the understory of the bull kelp canopy in the southern Puget Sound on the west side of Tacoma, Washington. This study measured both of the kelp’s growth rate and bed densities from recruitment, through reproduction, and into senescence recording the timing of all life stages. Maxell and Miller (1996), in their pioneering research, also noted the paucity of studies on subtidal kelp, a trend that continues to this day.

Environmental Controls

Kelp are subject to many abiotic controlling factors for their successful recruitment and growth including substrate, nutrients, wave energy, salinity, PAR, and temperature. Kelp are opportunists and will recruit on any solid surface, manmade or natural, with a general preference for substrate particles over 4 mm in size (Mumford, 2007). However, they are unable to recruit on very fine-grained particles or in areas where high sedimentation rates consistently cover the benthos (Mumford, 2007). The Sound is consistently recharged with cool nutrient-rich waters that feed growing kelp the nitrogen, phosphorous, and other minerals needed to thrive. The wave climate in the Sound is also conducive to kelp growth, with calmer waters occurring in the spring when recruitment begins (Dayton, 1985; Steneck et al., 2002). While it can fluctuate depending on river inflows, season, and wind levels, the Sound’s average salinity level of 2.9% is near the optimal level for kelp growth of 30-35 g/kg (NOAA, 2015; Steneck et al., 2002).

Bearham, Vanderklift, and Gunson (2013) found that light intensity and water temperature best-explained patterns of growth and productivity in the subtidal kelp *Ecklonia radiata*. Indeed, the most important environmental controls for successful kelp growth are water temperatures ranging from 5-20 °C (Bartsch et al., 2008) and adequate PAR ranging from 10-110 μmol m^{-2} s^{-1} across the day with longer days promoting more rapid recruitment and growth (Gao et al., 2005; Mohring et at., 2013; Steneck et al., 2002). The water temperature in the Northern Puget Sound typically ranges between 7-15 °C (Moore et al., 2012). With proper temperatures and cold upwelling waters from the Pacific delivering more than adequate nutrient loads, the Sound is an ideal habitat for kelp, and light is likely the primary limiting factor to its growth when adequate substrate is present (Bearham, Vanderklift, and Gunson, 2013). Additionally, the summer growth period in the Sound has natural light regimes that closely resemble ideal growth patterns under laboratory conditions for the kelp *Laminaria japonica* with a fluctuating intensity of light between 10-110 µmol m^{-2} s^{-1} in water depths where subtidal kelp are found, and a photoperiod of 14 hr of light daily (Gao et al., 2005).

When kelp have an adequate substrate and temperature, plentiful nutrients, proper wave climate, and optimal salinity, available light is likely the limiting environmental factor. In fact, available PAR is so critical that new recruitment and growth was noticed even outside of the typical growing season during particularly intense photic periods (Maxell and Miller, 1996). Confirming light availability as the primary limiting factor to critical kelp habitats, NOAA recognizes overwater structures as a threat to benthic habitats primarily due to light extinction (Kelty and Bliven, 2003). Decreased light from shading by overwater structures can cause reductions in productivity or the complete extirpation of kelp beds and other aquatic vegetation though more quantifiable field research is needed (Boyer, 2013; MacDuffee, 2014; Thom, Williams, and Diefenderfer, 2005). Dyson and Yocom (2014) add that harm from overwater structures to subtidal ecosystems may extend to vegetation reductions in nearshore terrestrial systems as well. They discuss that where overwater structures have included light penetrating design, such as glass block or grating, the impact to the subtidal ecosystem has been reduced, imploring the integration of environmentally considered infrastructure in future overwater construction. The cumulative ecological effects of overwater structures are a result of the structure's aspect, size, shape, height above water, depth of water beneath, and the type of pilings used to support it (Schlenger et al., 2011). By means of light reduction and interference with sediment transport and water-flow, overwater structures can have a profound effect on many species' distributions, behavior, and productivity including kelp, plants, and fish (MacDuffee, 2014; Schlenger et al., 2011).

The supporting pilings and shade created by overwater structures are thought to provide cover for piscivorous predators making it easier to catch their prey than in the open water (Rondorf et al., 2010). Normally, juvenile salmon stay close to shore in shallow waters where insects are more prevalent and predation by larger fish is less likely (Rondorf et al., 2010). However, many species of salmon have been observed altering their normal migration patterns by swimming into deeper water in order to avoid shadows cast by docks and consequently exposing themselves to greater risk of predation (Simenstad et al., 1999). Salmonids avoid large shadows due to the long periods (20-40 min) their eyes require to adjust to drastic changes in light (Simenstad et al., 1999). While individual overwater structures may not be incredibly significant to salmonid behavior, the aggregated effect of thousands of docks and miles of shoreline modifications in the Puget Sound is a contributing factor to current salmonid declines and will undoubtedly inhibit their recovery (Haas et al., 2002; Simenstad et al., 1999).

In addition to disrupting fish behavior, docks have been shown to reduce incoming light to levels incompatible with photosynthesis for salt marsh grasses and seagrass species in many studies (Eriander et al., 2017; Logan, Davis, and Ford, 2015;

Ralph et al., 2007). Sampling a large number of docks and controls (*n* = 212) in Massachusetts, Logan, Davis, and Ford (2015) found that docks block enough light to negatively affect photosynthesis in salt marsh grasses regardless of dock design. However, they did note that docks built with grating instead of decking had less of a negative effect. They determined that docks less than 50 cm from the surface of the water blocked up to 90% of light found in the controls, while docks that were greater than 150 cm from water surface blocked less than 40% of incoming light. Logan, Davis, and Ford (2015) observed overall patchiness to salt marsh grasses adjacent to docks with stem densities at 40% and stem biomass at 60% of what was observed in controls. Estimating 367 kg biomass loss for each hectare of dock coverage in Massachusetts, the cumulative impact of small-scale individual docks to salt marsh grasses is cause for alarm (Logan, Davis, and Ford, 2015). These concerns for light limitation and cumulative negative impacts of docks to photosynthetic communities are echoed worldwide with similar studies and results found in Sweden, Australia, and elsewhere (Eriander et al., 2017; Maxwell et al., 2017). Indeed, Eriander et al. (2017), found 100% extirpation of eelgrass beds under and around floating docks while docks raised above water, on pilings averaged only 42-64% eelgrass loss.

In addition to affecting fish behavior and blocking critical light necessary for kelp and aquatic vegetation, docks can affect water circulation and flushing, sediment transport and organic content, as well as potentially leach chemicals into the water (Logan, Davis, and Ford, 2015). Indeed, dock pilings have been shown to alter water flow and increase scour of the sediment around their base or increase sediment deposition depending on the specifics of the structure (Kelty and Bliven, 2003). Besides dock pilings, the dock floats can also affect substrate by suspending additional sediment in the water column from the suction created as they are lifted by the rising tide (Kelty and Bliven, 2003). Although these effects are relatively localized, they can be detrimental for benthic species including valuable shellfish communities. Reductions in salt marsh grasses caused by shading from docks have proven to destabilize sediment, which increases erosion (Kelty and Bliven, 2003). However, the research conducted on overwater structure's impacts on sediment has been focused on very large structures (625-2,500 ft) instead of smaller private docks or boat launches (Kelty and Bliven, 2003).

The negative effects from thousands of smaller, individual have a cumulative effect on aquatic biological communities, especially with the burgeoning human development along the coast and consequent nearshore construction. Indeed, Kelty and Bliven (2003) discovered that dock permits are the single most requested permit from coastal managers and that 90% of South Carolinians with aquatic bordering property desired a dock, believing that it is their "right" to build one. This attitude is likely translatable to most shoreline property owners in other areas as well, like the Puget Sound where there is a population of over four million, a growth rate of 1.5%, and urbanization of the shoreline is rapidly increasing (Fresh et al., 2011).

Attempting to ameliorate the known light blocking effects of docks, the current WDFW permitting process for docks and piers in Washington State includes requirements for dock height, width, and grating to alleviate shading of subaquatic communities (WAC, 2015). However, the impacts on subtidal kelp from these dock requirements, while potentially improvements, only apply to new structures and have not been quantitatively assessed.

Kelp exhibit extreme morphological variety even within a species. Maxell and Miller (1996) and Mumford (2007) explain that subtidal kelp in the Sound can occur in annual or perennial beds, determined by localized factors like wave energy or nutrient mixing, and not just by the species. This intraspecies variation and adaptability adds additional weight to the necessity of fully understanding the relationship between subtidal kelp and its various habitat stressors while simultaneously making it harder to do so.

Due to this morphological variation, the taxonomic classification of kelp based on structure has undergone significant change as they are better understood. As recently as 2006, a complete restructuring of the order Laminariales was suggested based on an extensive study into kelp morphology noting the lack of taxonomic work on many species of *Laminaria* and the usual confusion in the field of attributing morphologies to an individual species or to an ecotype of the same species (Lane et al., 2006). For example, Koehl and Alberte (1988) found that in sites protected from high current flow, bull kelp blades had ruffled edges to maximize photosynthesis. However, in sites experiencing rougher waters, the blades were smooth which reduces drag and susceptibility to breakage. Additionally, Dayton (1985) measured significantly different reproduction timing in identical *Laminaria* species that varied only by their geography. Bartsch et al. (2008) further recognize the difficulty of determining the relationship of environmental factors on the success of the subtidal *Laminaria* species due to the rarity of multifactorial experiments and suggest that future research should aim to fully encompass the various environmental controls in these kelp's habitats including substrate, light, salinity, nutrients, and water temperature.

CHAPTER 3

STUDY AREA

Geographical Setting

The study area for this research is the northern Puget Sound, located in northwestern Washington State between the Cascade Mountains to the east and the Olympic Peninsula to the west. The glacially carved Puget Sound emerged approximately 15,000 years ago when the Pacific Ocean filled the lowlands created by massive Pleistocene glaciers as they retreated northward (NOAA, 2014). These glaciers left abundant rocky substrate of pebbles and cobbles perfect for kelp recruitment (NOAA, 2014). The Puget Sound proper is the second largest estuary in the United States covering approximately 8,000 km^{-2}, including just over 4,000 km of shoreline (Gelfenbaum et al., 2006). Average subtidal depths in the northern Puget Sound range from 20-60 m with a maximum of 370 m (Gelfenbaum et al., 2006). The Sound is the southern-most component of the inland Salish Sea: a singular, bi-national estuarine ecosystem comprising the Georgia Strait, the Strait of Juan de Fuca, and the Puget Sound (Webber, 2012).

On November 12th, 2009, the name “Salish Sea” was officially adopted by the U.S. Board on Geographic Names to include the Strait of Georgia, the Strait of Juan de Fuca, the Puget Sound, and all their associated bays, inlets, and coves (Figure 1) (USGS, 2009). This name was already in use by the indigenous people of the area, yet was officially coined by the 70 tribes of the Coastal Salish Gathering in 2005 (Webber, 2012).

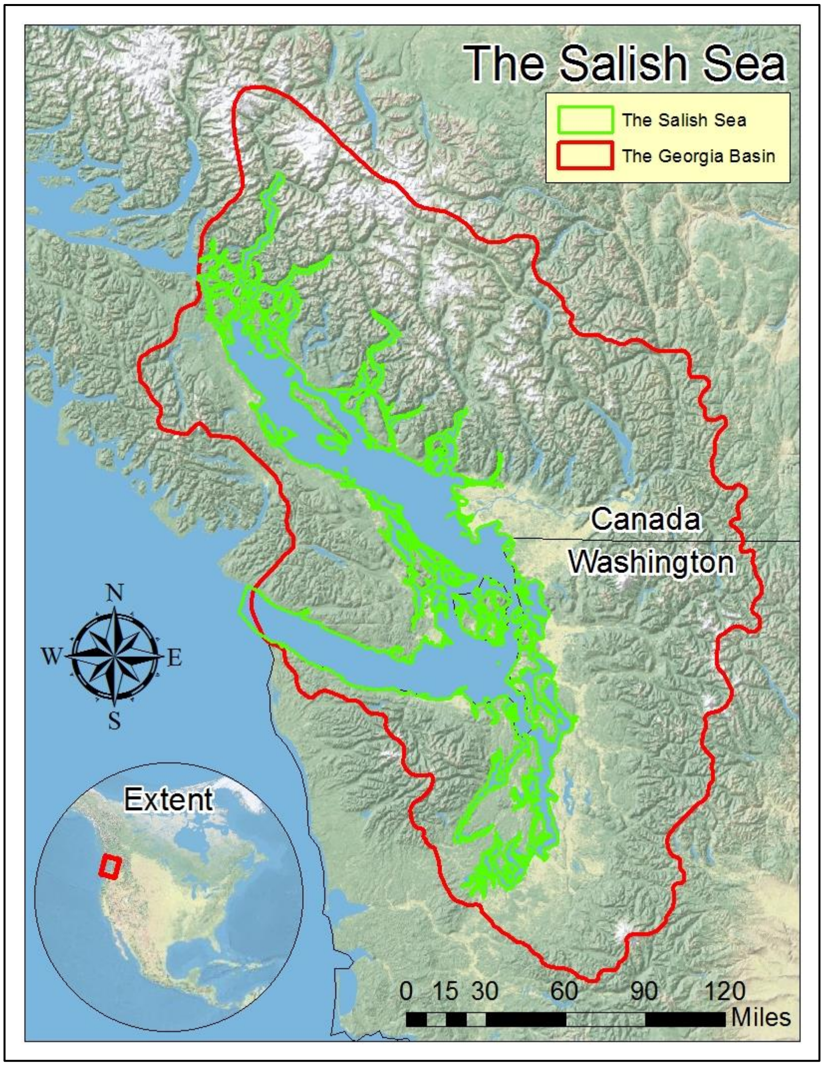


Figure 1. *The Salish Sea and the Georgia Basin.*

The adoption of the official name is significant to recognize the evidence that none of these bodies of water are independent of each other, but rather exist as one large international estuarine ecosystem with a connected fate (Webber, 2012). The Salish Sea is a glacially carved inland sea distinct from the Pacific Ocean, separated from it by Vancouver Island, British Columbia, and the Olympic Peninsula, WA (Webber, 2012). It spans from Olympia, WA, in the south, northerly to Desolation Sound, British Columbia, and westward to where the Strait of Juan de Fuca meets the Pacific Ocean.

There are two unequal high tides and low tides in a 24 hr period in the Puget Sound. These tides are named higher high water (HHW), lower high water (LHW), higher low water (HLW), and lower low water (LLW), and can change sea height up to 4 m (Lincoln, 2000; Sutherland et al., 2011). These tides are critical for nutrient cycling throughout the Salish Sea and for upwelling colder ocean waters into the nearshore environment which is necessary for kelp survival and productivity (Thom et al., 2001). The nearshore zone in the Puget Sound is loosely defined as the area extending seaward from the mean lower low water (MLLW) tide to approximately 15 m of depth (Lincoln, 2000).

Socio-Cultural Setting

For millennia, prior to European settlement around 1850, the Puget Sound and surrounding areas were home to many indigenous tribes, totaling approximately 20,000 individuals (Mumford, 2007). Throughout the 20th century, from colonization through statehood, the population of the Puget Sound area rapidly expanded (Gelfenbaum et al., 2006). Currently, there are nearly 8 million people that reside within the Salish Sea's watershed, the Georgia Basin (Figure 1) with 4.5 million residents occupying the 12 Washington counties that border the Puget Sound (Fresh et al., 2011). Major metropolitan centers of the Sound include Seattle, Everett, Tacoma, Bellingham, and Olympia.

Revealing the extreme anthropogenic modification of the Sound, more than 1,000 km of shoreline are currently armored, with an average of 3 additional km being armored each year (Washington Department of Ecology, 2010; Rehr et al., 2014). Shoreline armoring is any anthropogenic modification intended to harden a shoreline against the effects of erosion, including seawalls, sandbags, bulkheads, and rock or concrete pilings (NOAA, 1998). In addition to these modifications, there are more than 9,000 individual overwater structures in the Sound totaling at least 9 km^2 (most of which are smaller private docks), over 500,000 permanently moored boats, 600,000 visiting boats annually, and an extensive ferry system, all of which contribute to sub-aquatic shading (Rehr et al., 2014; Washington Department of Ecology, 2016).

Biota

As the boundary between the sea and the land, the Puget Sound nearshore ecosystem is vital to many species of fish, reptiles, mammals, birds, invertebrates, plants, and algae including 125 threatened or endangered species listed under the ESA (Zier and Gaydos, 2016). Zier and Gaydos (2016) and Gelfenbaum et al. (2006), describe the Salish Sea, and therefore the Puget Sound, as a system in decline, citing the alarming number of species being added to the ESA listing, with the list growing at 2.6% yearly since 2011.

Climate

The study area has a typical maritime climate associated with the Warm-Summer Mediterranean Köppen Classification characterized by no major extremes in temperature, relatively mild summers with a June-August average high temperature of 16 °C, and average low temperature of 11 °C (WRCC, 2016). Daily rain showers are typical throughout most of the year, though the drier summer months' average less than 50 mm of precipitation, with the least rainfall occurring in July (WRCC, 2016). The monthly water temperatures of the study area are well suited to kelp growth, as they steadily rise from an average January temperature of 7 °C to an average peak temperature of 11.4 °C in August (NOAA, 2016). While this area often experiences cloud cover, summer solar irradiance averages 5 kW-hr/day/m^{-2} (NOAA, 2015).

CHAPTER 4

METHODS

The methods used in this research determine the ecological effects of overwater structures on subtidal kelp in the northern Puget Sound and consisted of six main components: 1) locating and mapping study impact and control sites; 2) video-georeferenced surveys of subtidal kelp beds; 3) kelp biomass sampling; 4) deployment of an array of PAR sensors to measure light attenuation; 5) substrate sampling and analysis; and 6) a prey tethering experiment coupled with fish-use video monitoring. The methods of research and data acquisition for this study followed well-established standards in current use by government agencies and scientific organizations. Where applicable, permitting processes and Washington State laws were strictly obeyed.

Site Selection

This research was conducted in the nearshore environment of Fidalgo Island, Whidbey Island, and Camano Island. The study sites selected for this research each have an overwater structure, are located within a state park, and have the presence of subtidal kelp as determined by WADNR’s 2001 Nearshore Inventory data which was collected from 1994-96 from a helicopter traveling at 60 knots and 90 m above the shore (WDNR, 2001). These data were added into ArcMap (ESRI, 2011) and then overlaid with a Washington State Park data layer, retrieved from the Washington State Department of Revenue (Washington Department of Revenue, 2016). Preliminary site selection was restricted to where these three data layers intersected. After reviewing over 20 potential study areas, three were selected, as shown in Figure 2. Site selection was limited to State Parks to facilitate access, only requiring a research permit from one government agency instead of permission from many private dock owners. In addition, areas designated as State Parks or marine preserves typically have less anthropogenic modification than more populated areas, thereby reducing confounding variables in the study potentially created by extensive shoreline armoring (Washington Department of Ecology, 2010). After pre-study site investigation, the final sites chosen were Bowman Bay and Cornet Bay in Deception Pass State Park, and the boat launch at Camano Island State Park. These three sites were selected based on their ease of access, relative proximity to each other, and their differing benthic cover, substrate, and subtidal features.

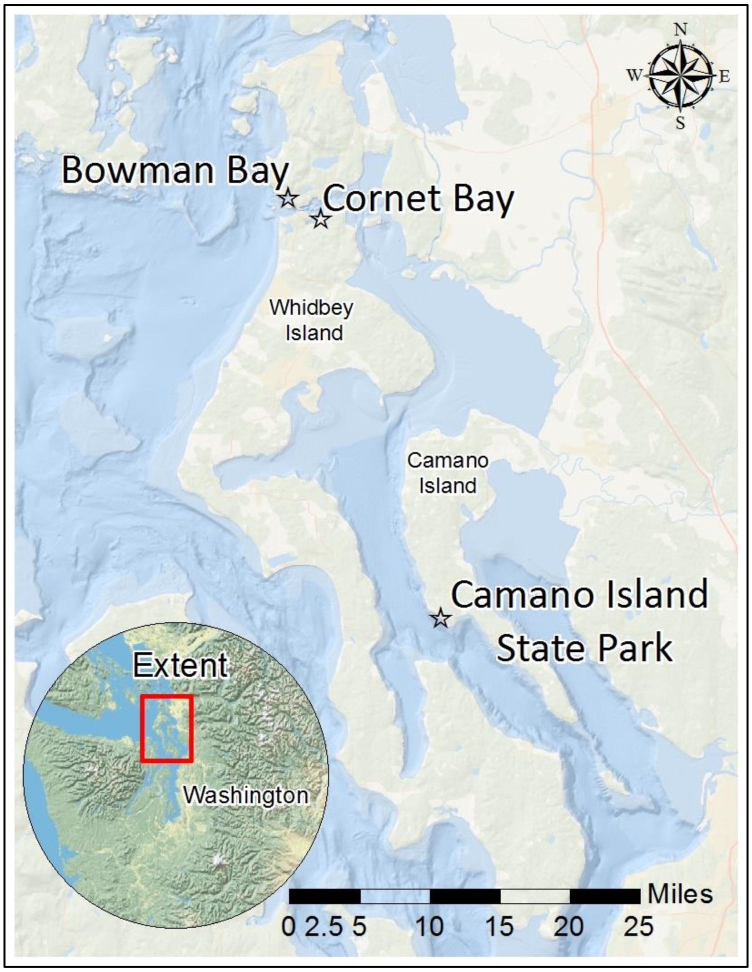


Figure 2. *Study area locations - Northern Puget Sound, Washington.*

Kelp beds can be persistent but are not always such, even when they are comprised of perennial varieties of kelp (Maxell and Miller, 1996; Mumford, 2007). This fact, coupled with 20-year-old kelp location data, necessitated field research prior to final site selection. Initial field research, to confirm presence of subtidal kelp, was conducted mid-May, 2017, and consisted of benthic video transects using a boat-towed video camera, and multi-beam echo-sounder mapping of potential study area bathymetry. This was accomplished with assistance of WDNR's Aquatics Assessment and Monitoring Team. The study area mapped was significantly larger than the dock sites, in order to capture depth variances and kelp presence nearby. This allowed for comparable control sites to be established out of range of the overwater structure's shading effects. Control sites were selected to replicate the size, depth, and aspect of the impact site as much as possible. Each control site was within 200 m of its paired impact site allowing water quality, temperature, and salinity to be assumed as equal due to homogenous mixing by tidal current. The WDNR bathymetry data was not received until research was nearly completed and did not fully cover the shallower areas near the docks. As such, Cornet Bay and Bowman Bay control sites were slightly outside of the mapped area and all of the docks had partial coverage. To correct this, additional bathymetric data was collected in March 2018, using an Eagle Sonar (model Fish Elite 480X; Tulsa, Oklahoma) to supplement bathymetric coverage from the WDNR dataset. Sonar accuracy was calibrated by a depth pole with 1 inch increments. Due to uncertainty of exact sonar ping locations and subtle boat movement even at slack tide, accuracy was estimated to be within 2 inches. Overlaps in measured bathymetry were comparable between WDNR and Eagle Sonar datasets.

Study Sites

Bowman Bay is located to the northwest of Deception Pass and is largely sheltered from its rapidly flowing waters. Bowman Bay is a pocket beach with a mainly western aspect and a sand and pebble shoreline that has recently experienced a restoration effort to remove riprap and return the bay to its natural erosional processes (Northwest

Straits Foundation, 2015). The Bay is designated by the United States Fish and Wildlife Service (USFWS) "as critical and essential habitat for foraging and migration bull trout" (*Salvelinus confluentus*) and maintains notable populations of eelgrass, various kelp species, as well as many fish, birds, and mammals (Northwest Straits Foundation, 2015). The daily average tidal range of the Bay is approximately 3 m. Bowman Bay has a large pier (130 m long and 3.5 m wide) supported by many creosote covered wood pilings. The floating dock attached to the end of the pier measured 10 m by 3.5 m and was used as an impact site in this research (Figure 3). The control site at Bowman Bay was established slightly to the north of the impact site (Figure 3).

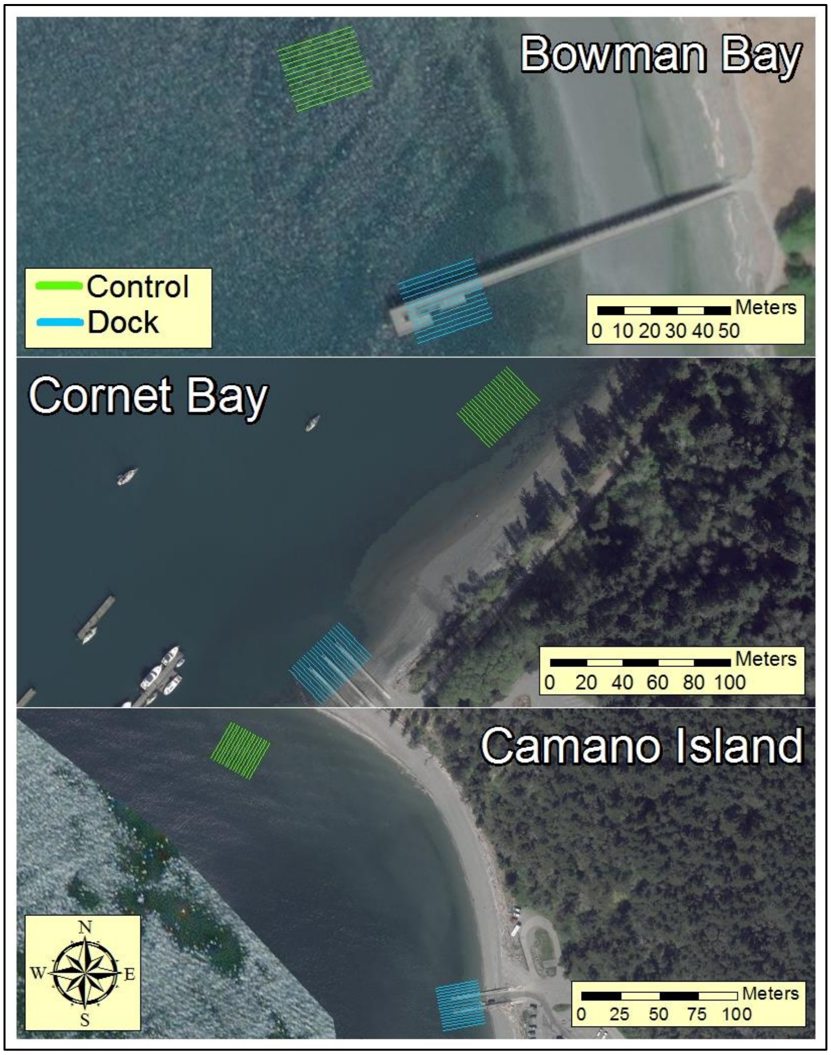


Figure 3. *Relative locations of controls and docks by site.*

Cornet Bay is located to the southeast of Deception Pass and experiences strong tidal currents from the massive amount of water that moves through the Pass daily. Cornet Bay also experienced a restoration effort that was completed in 2012 (Schmidt, 2015). The three floating boat docks at Cornet Bay were used as an impact site in this research, each of which is 2 m wide by approximately 34 m long, over water at higher high water. The docks total approximately 66 m^{-2} of overwater shading at lower low water and have a northwestern aspect with one large concrete piling anchoring the seaward end of each dock (Figure 3).

The site chosen for Cornet Bay control is situated approximately 150 m to the north of the impact site (Figure 3). The center of Cornet Bay control is approximately 25 m from the average shoreline where there are many large boulders present. The narrow beach has a northwestern aspect, coarse cobble and boulder with finer interspersed sediment, and it is backed by thick deciduous trees. Much of the shoreline is covered with large logs at the storm surge water line. Cornet Bay control experiences stronger currents from Deception Pass which are tempered at the docks (Finlayson, 2006).

The Camano Island State Park boat launch is located on the western shore near the middle of Camano Island, WA. The floating boat docks, which have a western aspect, were used as an impact site in this research and measure 2 m by approximately 36 m, over water, at higher high water. Together, at lower low water, the floating docks average 50 m^{-2} of shade to the benthos and are anchored by two large concrete pilings each (Figure 3). The average tidal range at this site is approximately 3.5 m. The site chosen for the Camano Island control is located approximately 200 m to the northwest of the impact site and 25 m from the narrow, low-energy, mixed sand and gravel beach which is backed by a large feeder bluff with a 3 cm yr^{-1} erosion rate (Figure 3) (Finlayson, 2006).

As required by Washington State law HPA permitting procedures, proposed overwater structures must maintain a 25 ft horizontal and a 4 ft vertical buffer from existing kelp beds (WAC, 2015). This equates to 7.62 m, horizontally, but was rounded to 8 m, for this research, to ensure total capture of potential benthic shading by each impact site's overwater structure. Using ArcMap (ESRI, 2011), a 1 m grid was created within the 8 m bound of each overwater structure and replicated in the paired control (Figure 4). Survey transects, separated by 2 m, were created around each impact site and were replicated in the control sites (Figure 5). For each control and dock, there were a total of 12 survey transects at Bowman Bay, 20 at Cornet Bay, and 15 at Camano Island.

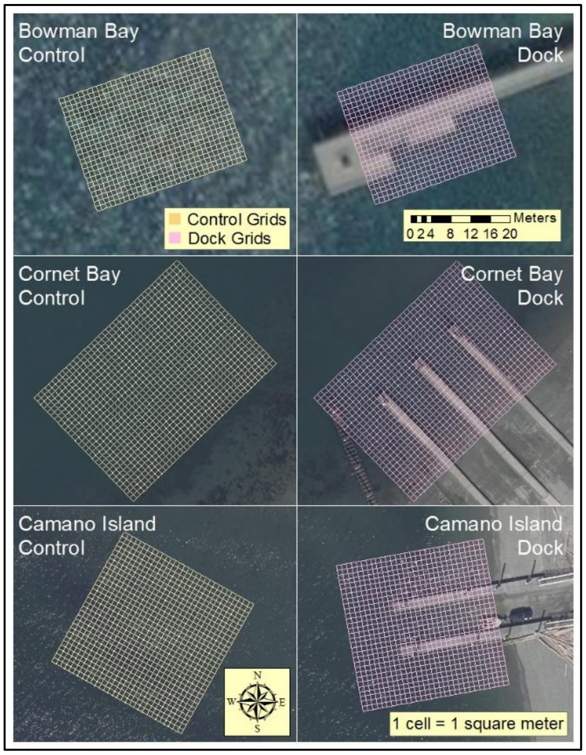


Figure 4. *Analysis grids by site.*

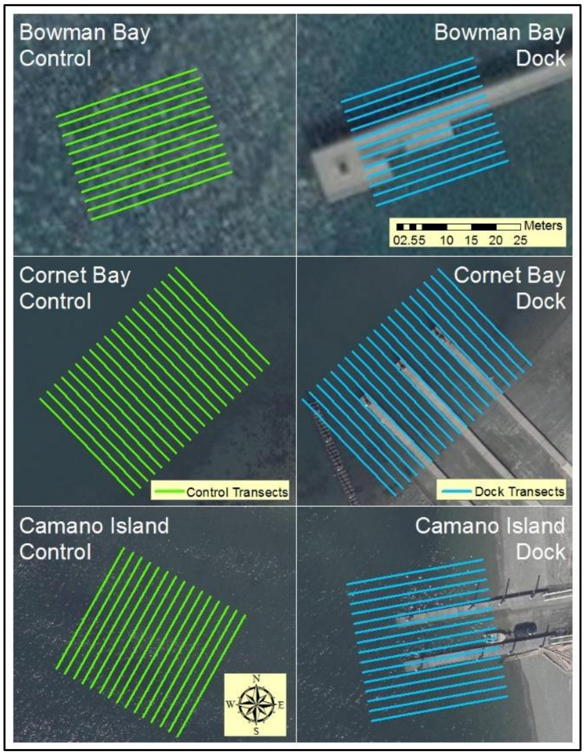


Figure 5. *Survey transects by site.*

Analysis transects were created from the survey transects at the docks, post-field, to fully analyze potential differences in shading impacts between the dock core (0-4 m from dock) and the dock perimeter (4-8 m from dock) (Figure 6). To further distinguish differences in light availability, the survey transects were split in half based on their relative water depth of deep (the seaward half of survey transects) and shallow (the shoreward half of survey transects) creating additional analysis transects for both the docks and the paired controls (Figure 7). These relative shallow and deep water depths varied between study sites.

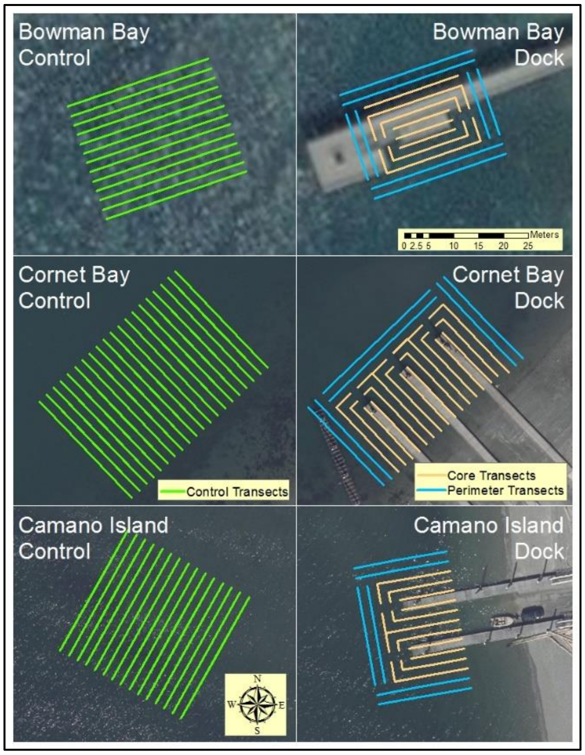


Figure 6. *Dock core and perimeter analysis transects by site.*

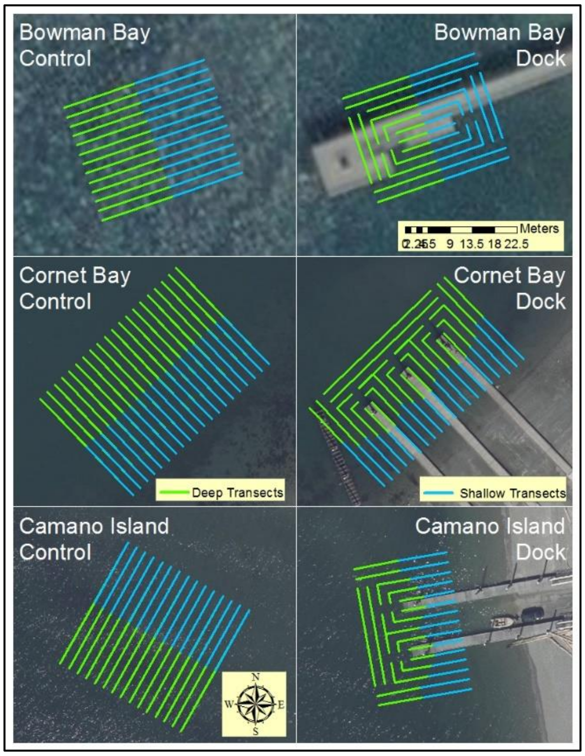


Figure 7. *Shallow and deep analysis transects by site.*

Kelp Cover

A floating research station was created to survey the benthos at each site (Figure 8). This consisted of a wooden platform attached to a floating, wind-surfboard with a Geographic Position System (GPS) unit and waterproof live feed monitor above water, and a depth-adjustable camera array including lighting

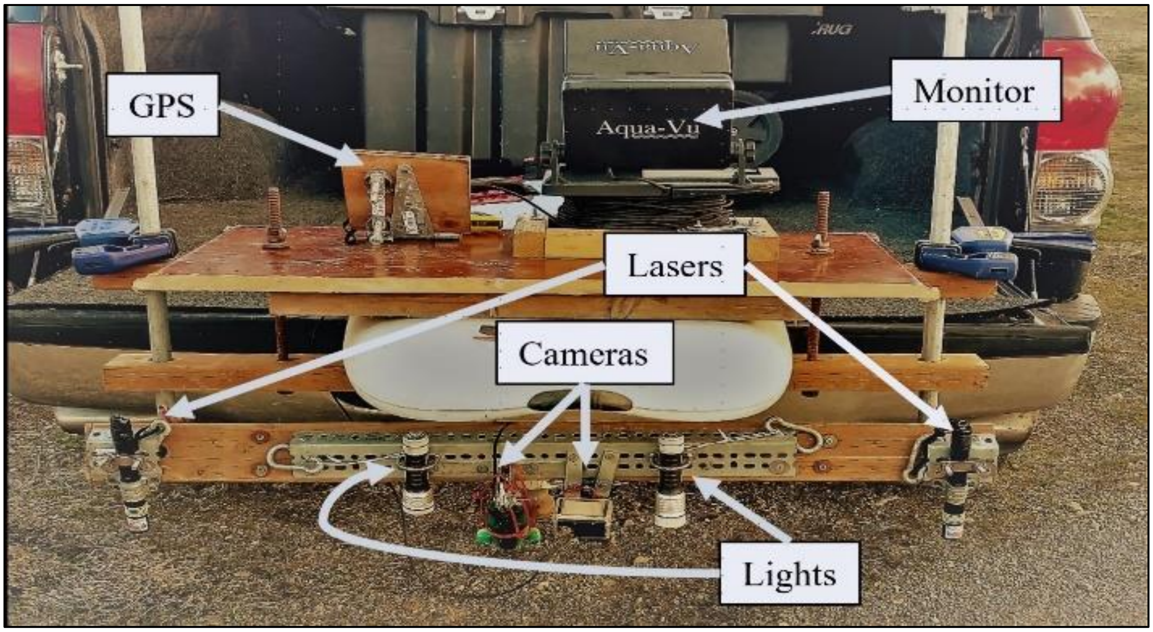


Figure 8. *Floating research station components.*

and calibrated lasers extending below the platform. The total depth capability of this video/laser array was just over 3 m. Two green beam underwater lasers were adjusted to cast their beam exactly parallel to each other, 1 m apart, creating a visual reference to calculate spatial measurements taken from the video recording. A GoPro camera was attached to the laser platform, directly beneath the GPS, to record video of the lasers projected onto the benthos. An Aqua-Vu camera (model AV760C; Crosslake, MN) provided a video signal to the live feed monitor onboard the surface platform for the researcher to ensure proper depth and functionality of the array as the depth of the benthos fluctuated along each transect. Transect shapefiles were transferred to a Trimble Juno SB GPS, housed in a waterproof bag, for navigation during the video-georeferenced subtidal kelp survey. Depth of the video/laser array was manually adjusted when necessary.

Donning cold-water snorkel gear, the researcher propelled the board along each transect, guided by the onboard GPS while it simultaneously recorded the path of the video/laser array. Multiple passes were made on each side of the overwater structure to fully record the 8 m buffer. This process was repeated for each paired control site.

A Python script was written to extract images from the recorded video surveys at 1 sec intervals. These images were georeferenced by correlating their timestamps with the timestamps of the recorded GPS path and reviewed in the lab to determine proportions of spatial coverage based on presence/absence of subtidal kelp within the 1 m grid of each study site. Overlap redundancies due to drift of the floating research station were removed from the analysis as well as errant GPS recordings.

Biomass

To facilitate biomass sampling from the surface of the water, a sampler was constructed using polyvinyl chloride (PVC) pipe, clothes-line cable (plastic over wire), a swivel, stopper, and fishing anchors (Figure 9). The sampler was split into three threaded sections that were each 2 m long. The sampler was operated like a lasso through the PVC pipe. The coated cable was pulled from the bottom end of the sampler for each sample attempt until a stopper, attached to the cable and calibrated for a ¼ m^{-2} sample area, prevented additional cable from being pulled from the unit. The sampler was then lowered to the seafloor as the anchors pulled the

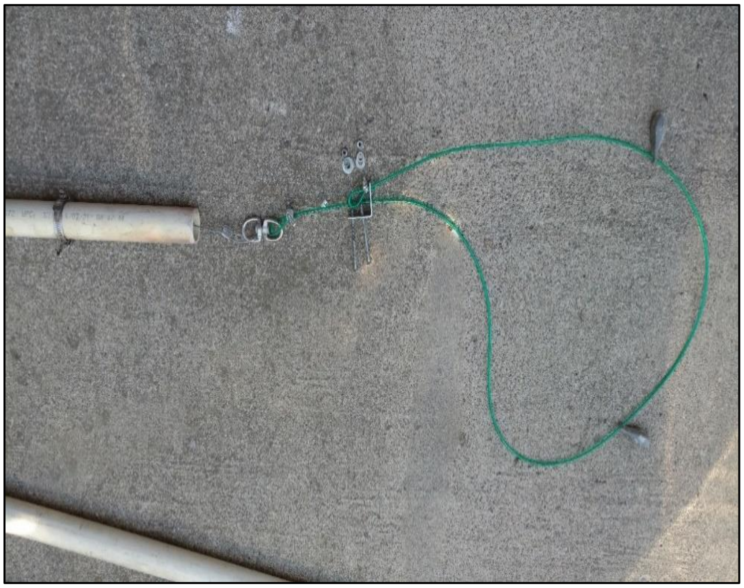


Figure 9. *Biomass sampler’s internal construction.*

cable to the benthos and allowed the ¼ m^{-2} sampling cable to wrap around any benthic species present. The cable was then pulled through the opposing end of the sampler, tightening around the sampling area's contents. Once all slack was pulled from the cable, the entire sampler was carefully lifted from the seafloor. If no sample was present on the first attempt, a second attempt was made at the same location.

Biomass sampling was conducted at lower low tide by walking the same transects created for the video-georeferenced survey and guided by GPS. For each study area's control site, 10 samples were attempted at approximately 2 m intervals, as limited by GPS accuracy, along each end transect and the center transect, totaling 30 sampling locations. At the docks, samples were similarly collected at regular intervals in the perimeter (7.5 m from the dock) and the core (2.5 m from the dock) to fully assess differences in biomass between the areas, again totaling 30 sampling locations. GPS locations were recorded as the sample was taken. When water depth prevented walking the transects, another section of the sampler was threaded on to add length, and sampling was conducted from the research boat. Thirty biomass samples were attempted at each dock and paired control, totaling up to 60 samples per research area, and were collected during both visits to each site. Retaining only kelp species, limited amounts of *Sargassum muticum*, red algae, eelgrass, and other vegetation was discarded. Each sample was then bagged, labeled, placed on ice and transferred to Central Washington University's Aquatic Systems and Hydrology Lab for wet weight measurements.

On-site morphometric measurements were recorded for five random sub-samples at each dock and control site including stipe count, blade length and width, as well as kelp species identification. An additional five sub-samples of kelp biomass were randomly selected to be dried and re-weighed to determine a wet-weight to dry-weight carbon content ratio.

Light Attenuation

A total of 11 Odyssey (Christchurch, New Zealand) photosynthetic irradiance recording systems (PAR sensors) were used for this research. Each PAR sensor is comprised of a light sensor, an integrator amplifier, and a data logger all contained within a waterproof housing. The sensor receives incoming solar radiation in the wavelength range of 400-700 nm which is transmitted to the amplifier. The amplifier interprets the incoming PAR and creates a pulse output, directly proportional to the irradiant light energy striking the sensor. This pulse output is recorded by the data logger at the end of the user-defined sampling period in “operational amperage” units. In this study, the sampling period was set for 2 min intervals. The ‘operational amperage’ unit is a count which is equivalent to the total PAR reaching the sensor during the sampling period. Because the Odyssey PAR sensors are shipped uncalibrated, they require calibration with a reference meter for meaningful data interpretation. In this study, a Li-Cor LI-250A Light Meter (Lincoln, NE) and Li-Cor LI-190R Quantum sensor were used for the calibration process which supplied actual PAR levels to correlate with the integrator amplifier’s unitless pulse output counts. Once calibrated, the unitless counts were converted to quantum flux units (μmol m^{-2} s^{-1}) to give total PAR levels from each sampling period. Each sensor was carefully cleaned between sampling periods to minimize potential biofouling by accumulation of sediment or debris. (WDNR, 2014; Long et al., 2012; Odyssey, 2018).

Figure 10. *Floating PAR sensor rig for 1 cm from surface readings.*

At each study site, the 11 PAR sensors were set up as follows: one in open air above the impact structure to record total incoming solar radiation; one attached to a float to maintain sensor depth at 1 cm beneath water surface which was anchored in open water at the control site (Figure 10); and two attached to floats to maintain sensor depth 1 m below water surface, one of which was anchored in open water at the control site with the other rigged to remain beneath the overwater structure and within the structure's shadow (Figure 11). The seven remaining PAR sensors were attached to anchored PVC poles to maintain sensor heights just above the subtidal kelp canopy at each site (Figure 12). Six

Figure 11. *Floating PAR sensor rig for 1 m from surface readings.*

Figure 12. *Benthic PAR sensor rig for seafloor readings.*

of these sensors were dispersed around the dock site at equal heights above bottom, two per each of the structure’s three sides, at 2.5 m and 7.5 m away from the overwater structure (Figure 13). The remaining sensor was deployed at the control site at an equal height above bottom to the benthic sensors at the impact site. A marker float was attached to each sensor for ease of deployment and retrieval by boat, ensuring enough slack was present for sensors to be retrieved at any tidal range. Data recordings were taken every 2 min for a minimum 24 hr cycle during both visits to each site during the summer of 2017.

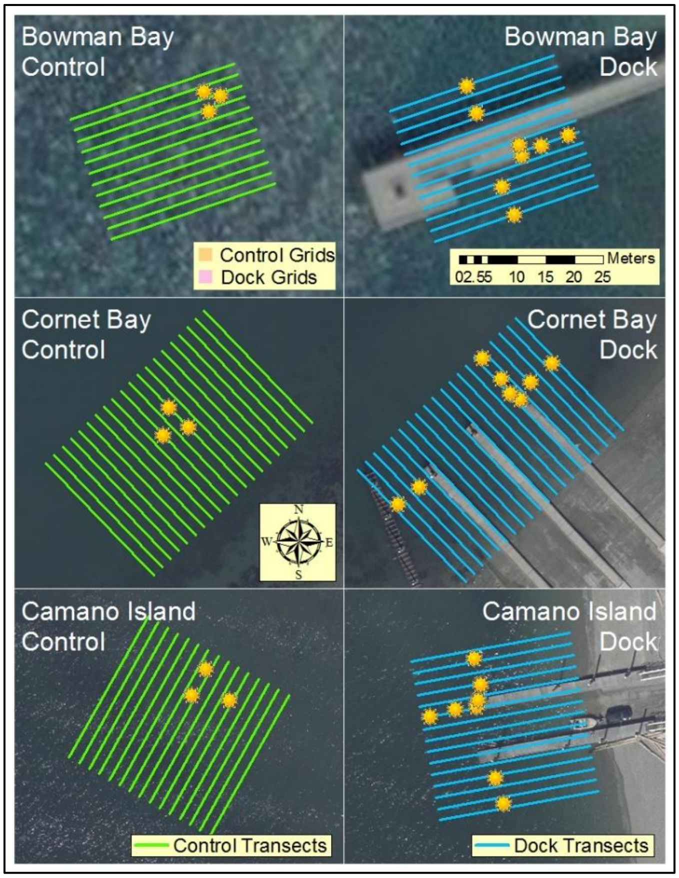


Figure 13. *PAR sensor locations by site, late summer, 2017. Locations were nearly identical for early summer except for Bowman Bay control which was in a different area and its data was discarded. Two of the three control sensors were floating, attached to long lines to maintain depth from surface with tidal fluctuations resulting in dynamic positions but within the control survey area.*

Two min data logs, retrieved from each PAR sensor, were summed into 10 min intervals. Depths for each benthic PAR sensor were calculated from bathymetry data while the depth of the water column above each sensor, for each 10 min interval, was calculated from tide measurements at each site retrieved from the University of South Carolina’s Biological Sciences Tide/Current Log website (Pentcheff, 2017). Total PAR

(μmol m^{-2} s^{-1}) was recorded by each sensor and analyzed for concurrent recording. The benthic PAR sensor totals were compared to the above water total resulting in a percent of full PAR calculation for each benthic sensor. These differences were then used to calculate light extinction coefficients at each benthic sensor location, for each 10 min interval using the Lambert-Beer equation:

$k = -(\ln I_o - \ln I_z)/z$ where:

k = the extinction coefficient of the water,
I_o = light intensity at the surface, and
I_z = light intensity at depth z.

These values were then averaged for the full range of recordings to give a total light extinction coefficient for each PAR sensor location.

The benthic PAR sensors were initially deployed at a 1 m height from the seafloor to reduce shading potential by any kelp present. However, this was reduced to 0.5 m to prevent sensor exposure during low tide in the shallower water depths found around the dock at Cornet Bay. The 0.5 m height was used in subsequent survey periods to allow for more accurate comparisons between sensor locations and sites. This height likely still captured the light being received at the top of the kelp canopy as the large, relatively heavy kelp stipes and blades tended to be lying flat on the benthos in large mats at the relatively calm sample sites. This was observed in the field by the underwater cameras during both the kelp coverage and fish surveys, as well as during biomass and sediment sampling. The 0.5 m sensor heights also provide a good estimate of the average light conditions for the fish found at these sites. Given the length of the kelp blades found during the biomass surveys, a 0.5 m difference in height would not have eliminated kelp shading if currents had been strong enough to mobilize the kelp blades.

Substrate

Substrate samples were collected once, after all other research was concluded to prevent potential corruption of light attenuation measurements and kelp coverage mapping by clouding the water column. A ¼ m^{-3} Petersen grab sediment sampler dropped from the research boat, was used for substrate sampling (Figure 14). Substrate samples were collected at equal intervals along three transects for each control site, three samples from each end transect and three in the center transect totaling nine samples for each control (Figure 15). Dock samples were collected

Figure 14. *The ¼ m^{-3} Petersen grab sediment sampler.*

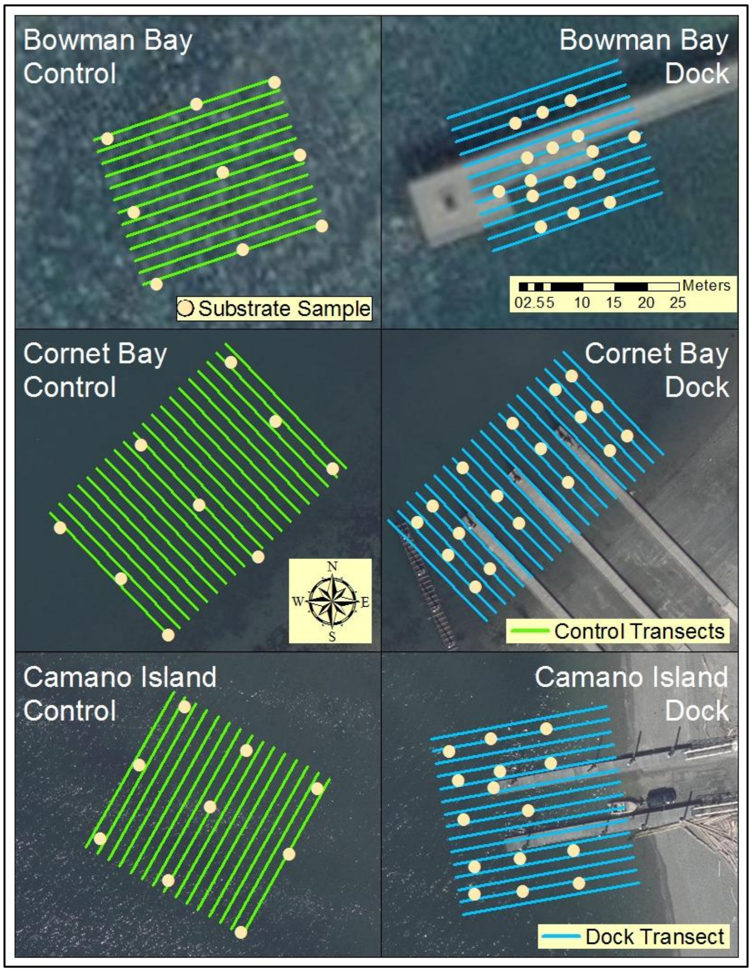


Figure 15. *Substrate sampling locations by site.*

2.5 m and 5 m from each overwater structure at regular intervals along perimeter and core transects, in addition to samples collected from as close to beneath each structure as possible (Figure 15). The total number of dock samples to ensure representative coverage of the perimeter and core areas varied by site size, ranging from 15-18 samples. Samples were bagged, labeled, and transported on ice to the lab. Sub-samples were dried and analyzed for particle size using standardized sieves (ranging from 2.5 cm to 63 microns) and a Ro-Tap (Mentor, OH) machine ran at 5 min intervals. Each sieve's contents were weighed, and proportions of substrate particle size were calculated for each site. For samples with substrate too large for particle size analysis, mean medial axes were recorded. Organic content of each substrate sample was determined by organic loss on ignition by drying samples at 60 °C for 24 hr, recording weights, and then heating samples to 550 °C for 2 hr and reweighing (Kavanaugh et al. 2009).

Sediment sampling locations were buffered in ArcMap (ESRI, 2011) by 2 m, creating a circle with nearly a 13 m^{-2} area. These buffers were used for intersecting with depth, biomass, and kelp cover measurements for the same area at each site and analyzed for correlations between environmental conditions.

Fish Use

Prey tethering experiments (e.g. Eggleston et al., 1990; Heck and Thoman, 1981; Martin and Martin, 2012) are common and varied but have recently been standardized by the Smithsonian Institute for global citizen-science input and creation of fish predation "Bitemaps" (MarineGEO, 2016). A modified version of Smithsonian's "Squidpop

Protocol" was followed for each impact site and its paired control site to determine fish use of the surveyed subtidal kelp beds (MarineGEO, 2016).

This study's Squidpop protocol was modified to be implemented from a research boat instead of the required SCUBA or snorkeling deployment of the original Smithsonian version. Fifteen mm circles of squid were punched out of a whole dried squid using a cork-borer and attached to 2 ft garden stakes by fishing line knotted to the squid and taped to the stake with electrical tape (Figure 16). On one end of each garden stake, a 1-inch natural cork float was attached to keep the stakes erect in the water (Figure 16). The other end of each garden stake was tethered, using wire, to a 50 ft heavy chain with an anchor and marker float at each end (Figure 16). Twenty-five stakes were attached to each chain at 2 ft intervals. One end of the chain was lowered into the water until the anchor reached the bottom. The other end of the chain was pulled by the research boat until it was as straight as possible. The following measurements were recorded at each deployment: deployment time, GPS coordinates, weather conditions,

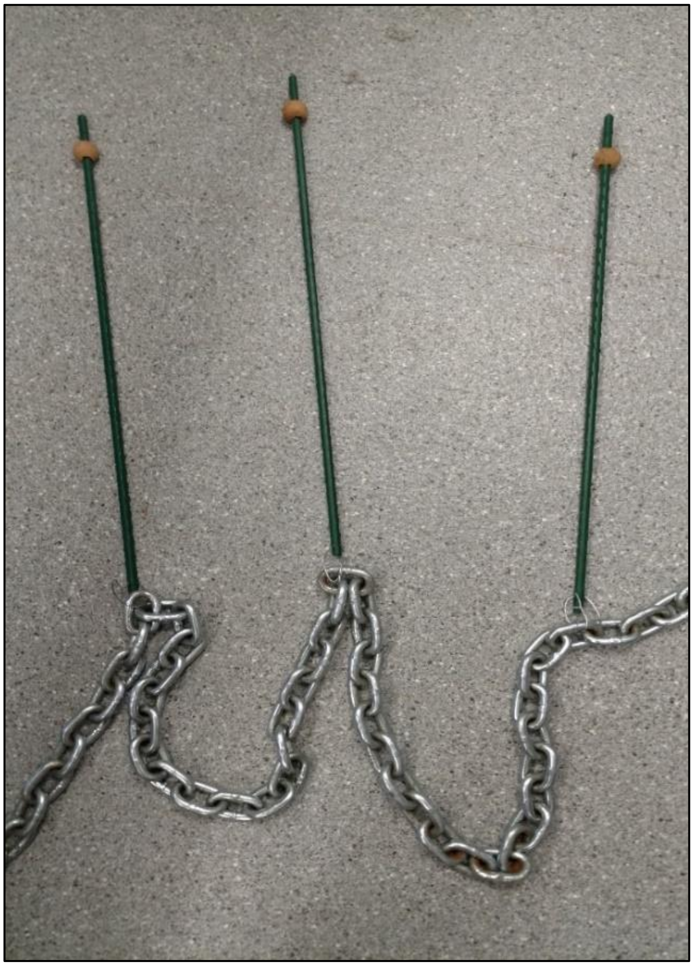


Figure 16. *Squidpop construction.*

and water temperature (MarineGEO, 2016). Bait loss was recorded as all-or-nothing at 1 hr after deployment and again at 24 hr after deployment when the Squidpop chains were then retrieved. This process was replicated at each visit to each study site during the summer of 2017. These data were uploaded to MarineGEO's Google Form spreadsheets for open-source, global dissemination.

To monitor fish use further, and to facilitate fish counts and species identification, GoPro cameras were attached to anchored PVC poles and positioned to record fish-use activity along each Squidpop chain (Figure 17). Between two and four cameras were deployed at each site recording for at least 2 hr while the Squidpops were deployed. Deviation from proposed methods of continuous recording occurred when intervalometers failed to function properly on the first deployment. Because double counting a fish is possible as they move in and out of frame on video, a Python script was written to extract images from these videos at 2 min intervals. These images were reviewed for total fish counts as well as species identification when possible.

Figure 17. *GoPro video set-up for fish use monitoring.*

Statistical Analysis

Due to smaller sample sizes, differences in kelp coverage, productivity (i.e. biomass), and environmental conditions were compared between dock and control sites, as well as predominantly shaded (core) and less-shaded (perimeter) portions of each impact site using the non-parametric Mann-Whitney U test. Similarly, correlations between kelp coverage and productivity and potential environmental controls, such as variations in light extinction and substrate characteristics were conducted using Spearman Rank correlations. Specific correlations analyzed included all potential relationships between the following variables; kelp cover by transect, water depth by transect, kelp biomass by sample, substrate size, and substrate organic content. Water depth and kelp cover were correlated by each individual 1 m^{-2} grid cell, while biomass was correlated with water depth at the location of the sample. Differences in fish feeding activity were similarly compared between site locations and environmental variables. Kruskal-Wallis tests were applied to compare dock core, dock perimeter, and the paired control at all sites to determine if dock perimeter areas were more similar to controls than dock core areas. For further comparisons, relative water depths, for deep and shallow analysis transects at each site, were analyzed using the Wilcoxon Rank-Sum test. PAR readings and light extinction coefficients were compared using paired t tests.

CHAPTER 5

RESULTS

Analysis of collected field data focuses on kelp cover, kelp biomass, light attenuation, light extinction coefficients, substrate grain size, substrate organic content, fish use differences, and Spearman rank correlations between docks and controls at each of the three sites; Bowman Bay, Cornet Bay, and Camano Island. Results of statistical tests are reported for each environmental factor analyzed including any significant differences between early and late summer visits to the same site. Additionally, morphometric measurements of kelp blade length, kelp blade width, and individual organism (stipes) counts are reported here along with any significant correlations between variables. Tables are presented in-text while example graphs are used for illustrative purposes with the remainder of the graphs found in the appendix.

Kelp Cover

Bowman Bay

Total Area Comparisons.

Early summer. Survey data from early summer at Bowman Bay control was discarded as no kelp was found to be present after video analysis requiring the control to be relocated for the late summer survey. Bowman Bay dock, however, revealed 1.3% kelp cover (Figures 18 and 19, Table 1), ranging from 0-13.3% cover by transect (Figure 20). Data from the dock was retained so that early and late summer visits could be compared. The benthos surrounding Bowman Bay dock was mostly covered with green

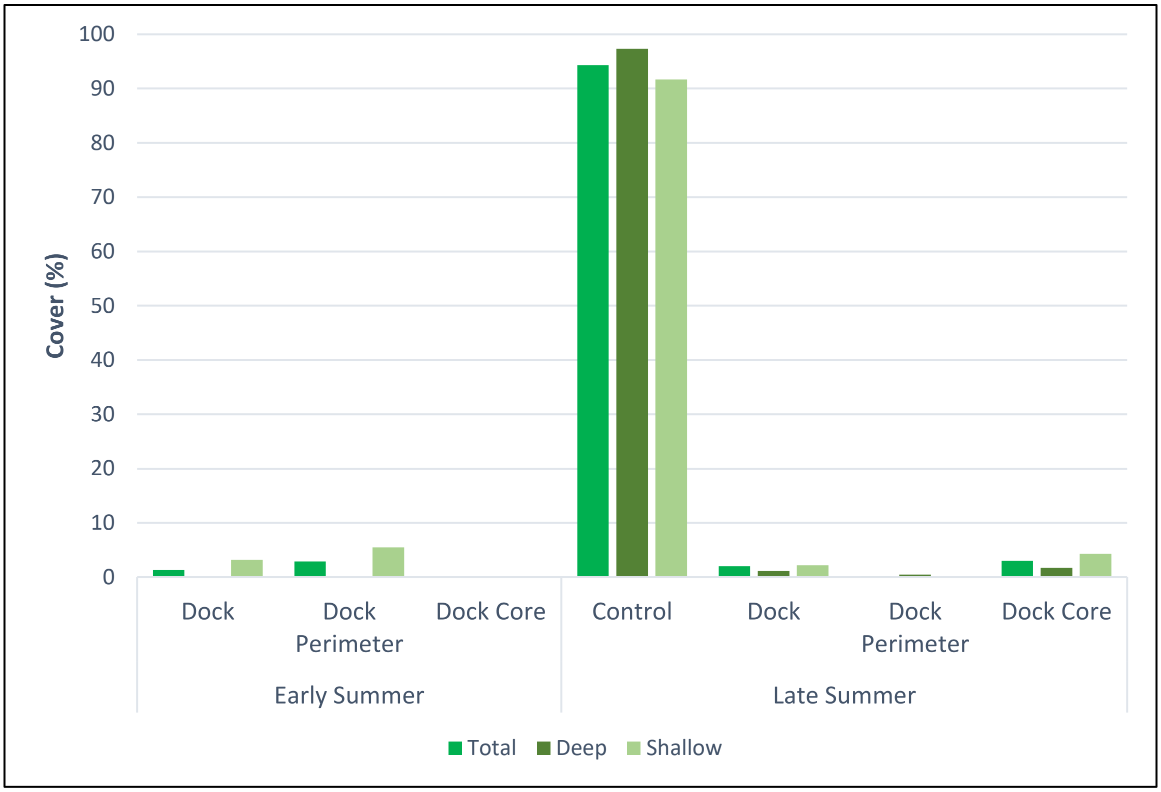


Figure 18. *Kelp cover (%) at Bowman Bay for total area and relative water depths, early and late summer, 2017.*

filamentous algae, occasionally interspersed with patches of eelgrass, *S. muticum*, or bare sediment. Kelp that was present was small and appeared to be detritus with very little healthy living kelp. All kelp species identifiable from video were sugar kelp (*Saccharina latissimi*).

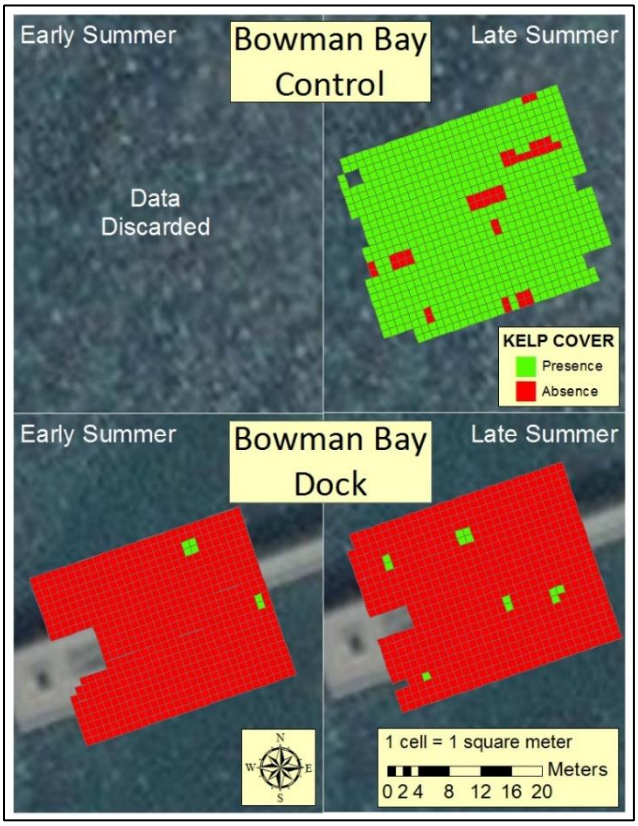


Figure 19. *Kelp cover at Bowman Bay, early and late summer, 2017.*

Table 1. *Kelp coverage (percent by site).*

	Bowman Bay		Cornet Bay		Camano Island	
	Early	Late	Early	Late	Early	Late
Control						
Total	<Null>	94.3	62.3	97.6	88.1	80.1
Deep	<Null>	97.3	71.0	97.3	96.6	81.8
Shallow	<Null>	91.7	59.0	97.9	79.1	74.1
Dock						
Total	1.3	2.0	39.8	39.9	1.8	<Null>
Deep	0	1.1	43.5	46.5	2.0	<Null>
Shallow	3.2	2.2	20.4	13.3	0	<Null>
Dock Perimeter						
Total	2.9	0.2	43.1	46.5	1.4	<Null>
Deep	0	0.5	70.5	91.7	3.4	<Null>
Shallow	5.5	0	40.3	52.5	0	<Null>
Dock Core						
Total	0	3.0	21.9	19.1	0.9	<Null>
Deep	0	1.7	33.4	32.3	1.3	<Null>
Shallow	0	4.3	15.5	5.9	0	<Null>

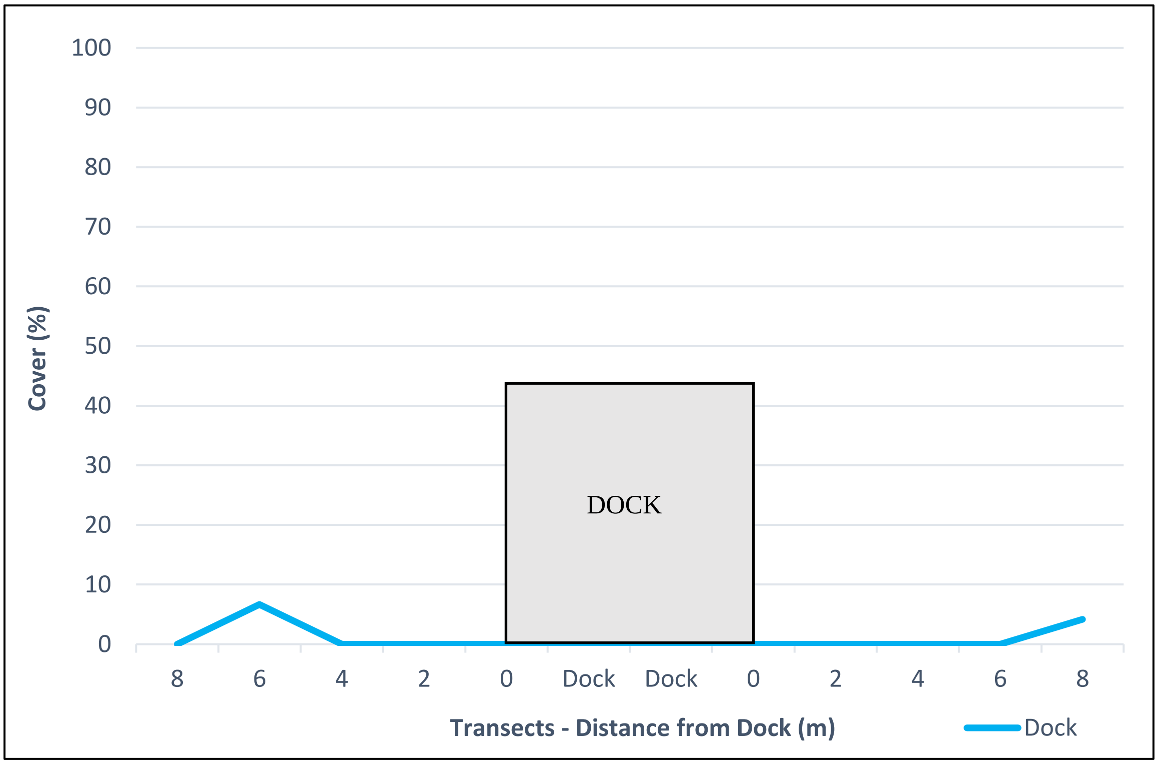


Figure 20. *Kelp cover (%) by transect at Bowman Bay dock, early summer, 2017.*

In the perimeter, the dock had 2.9% kelp cover, ranging from 0-8.3% cover by transect, and 0% cover in the core (Figures 18 and 21, Table 1). No significant differences were found in kelp cover between the dock perimeter and core (Mann-Whitney U, $p > 0.05$) (Table 2).

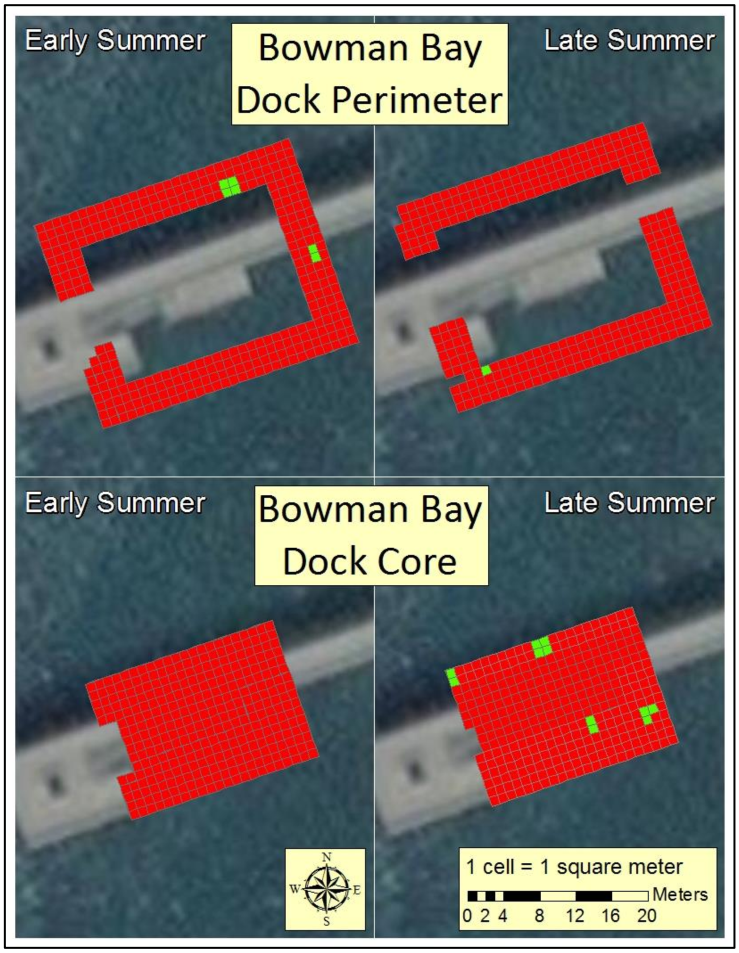


Figure 21. *Kelp cover (%) at Bowman Bay dock, early and late summer, 2017.*

Table 2. *Differences in kelp coverage by transect [median (IQR)] between dock core and perimeter by total area and relative water depths, early and late summer, 2017.*

Site	Early Summer (%)		Site	Late Summer (%)	
	Core	Perimeter		Core	Perimeter
Bowman Bay			Bowman Bay		
Total	0 (0)	0 (0)	Total	0 (4.4)	0 (0)
Deep	0 (0)	0 (0)	Deep	0 (0)	0 (0)
Shallow	0 (0)	0 (8.5)	Shallow*	1.7 (8.5)	0 (0)
Cornet Bay			Cornet Bay		
Total*	3.4 (42.9)	51.1 (60.4)	Total*	9.9 (27.2)	81.7 (30.7)
Deep	33.3 (44.3)	69.3 (33.5)	Deep*	27.7 (34.6)	95.0 (16.7)
Shallow*	0 (5.9)	27.2 (51.1)	Shallow*	0 (8.3)	50.0 (17.0)
Camano Island			Camano Island		
Total	0 (0)	0 (0)	Total	<Null>	<Null>
Deep	0 (0)	0 (0)	Deep	<Null>	<Null>
Shallow	0 (0)	0 (0)	Shallow	<Null>	<Null>

** = significant difference (Mann-Whitney U, p < 0.05).*

Late summer. The control site was established in a different area within Bowman Bay, on the north side of the dock, for late summer. All kelp identifiable from video was sugar kelp lying in thick beds cohabited by small patches of eelgrass. There were very few, small patches of bare sediment. The control had kelp cover of 94.6% (Figures 18 and 19, Table 1), ranging from 79.7-100% cover by transect (Figure 22), which was significantly more than the dock which had 2.9% cover (Figures 18 and 19, Table 1), ranging from 0-11.2% cover by transect (Figure 22) (control median = 100%, IQR = 4.7%; dock median = 0%, IQR = 0%) (Mann-Whitney U, $p < 0.05$) (Table 3).

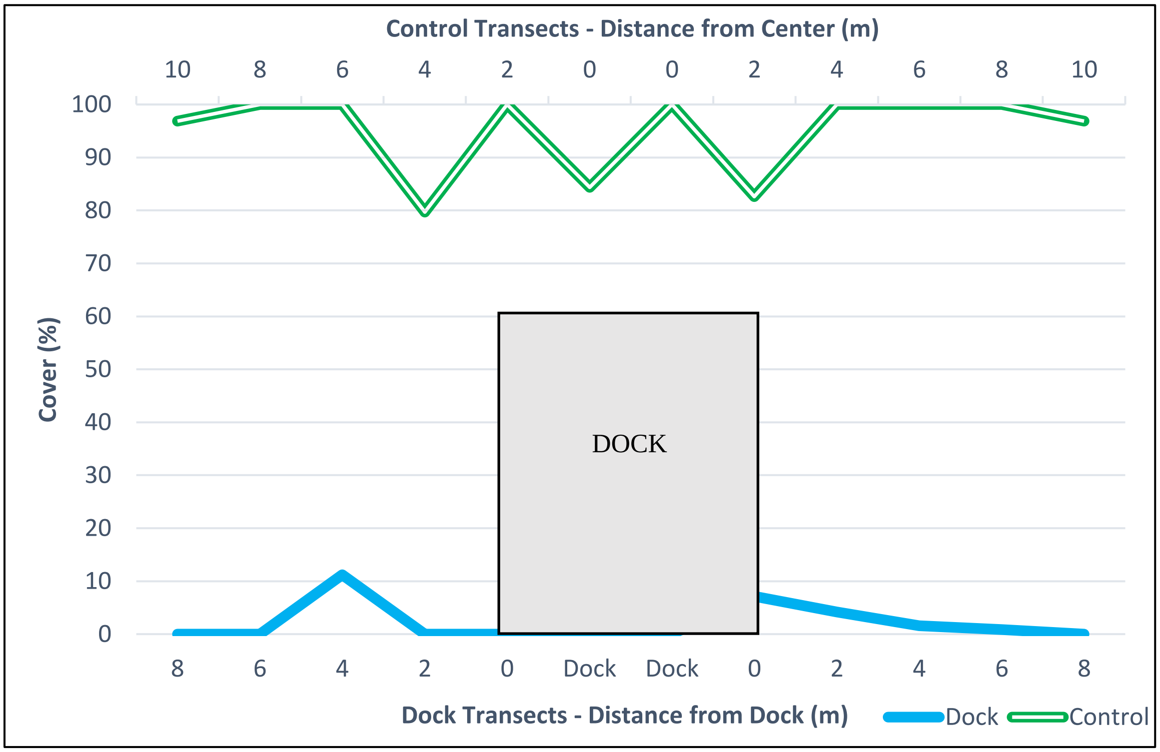


Figure 22. *Kelp cover (%) by transect at Bowman Bay, late summer, 2017.*

Table 3. *Differences in kelp coverage by transect [median (IQR)] between controls and docks, early and late summer, 2017.*

Site	Early Summer (%)		Site	Late Summer (%)	
	Control	Dock		Control	Dock
Bowman Bay	<Null>	0 (0)	Bowman Bay*	100 (4.7)	0 (0)
Cornet Bay*	100 (86.5)	20.4 (57.1)	Cornet Bay*	100 (0)	19.5 (45.0)
Camano Island*	100 (10.0)	0 (0)	Camano Island	96.2 (34.7)	<Null>

** = significant difference (Mann-Whitney U, p < 0.05).*

At the dock perimeter, kelp cover was 0.2%, ranging from 0-3.6% cover by transect, while in the core, cover was 3%, ranging from 0-14.3% cover by transect (Figures 18 & 21). No significant differences were found in kelp cover between dock perimeter and core (Mann-Whitney U, $p > 0.05$) (Table 3)

Kelp cover by transect was found to be significantly greater at the control (median = 100%, IQR = 12.6%) than at the dock perimeter (median = 0%, IQR = 0%) and the dock core (median = 0.8%, IQR = 4.9%) (Kruskal-Wallis, $p < 0.05$) which were a homogenous group (comparison of mean ranks, $p < 0.05$) (Table 4).

Table 4. *Differences in kelp coverage by transect [median (IQR)] by location, early and late summer, 2017.*

Site	Control (%)	Core (%)	Perimeter (%)
Early Summer			
Cornet Bay*	84.9 (76.5)^{a}	20.7 (33.6)^{b}	77.5 (50.9)^{ab}
Camano Island*	100 (16.4)^{a}	0 (0)^{b}	0 (0)^{b}
Late Summer			
Bowman Bay*	100 (12.6)^{a}	0.8 (4.9)^{b}	0 (0)^{b}
Cornet Bay*	100 (0)^{a}	20.0 (13.3)^{b}	80.0 (17.4)^{ab}

** = significant difference (Kruskal-Wallis, p < 0.05). Superscript letters identify homogenous groups (Comparison of mean ranks, p < 0.05)*

*Early summer vs late summer***.** There were no significant differences in kelp cover between early and late summer at the dock (Mann-Whitney U, $p > 0.05$) (Table 5).

Table 5. *Differences in control and dock kelp coverage by transect [median (IQR)] between early and late summer by total area and relative water depths.*

	Control Transects (%)			Dock Transects (%)	
Site	Early	Late	Site	Early	Late
Bowman Bay			Bowman Bay		
Total	<Null>	100 (4.7)	Total	0 (0)	0 (0)
Deep	<Null>	100 (0)	Deep	0 (0)	0 (0)
Shallow	<Null>	100 (6.3)	Shallow	0 (0)	0 (2.4)
Cornet Bay			Cornet Bay		
Total*	100 (86.5)	100 (0)	Total	20.4 (57.1)	19.5 (45.0)
Deep*	100 (86.2)	100 (0)	Deep	40.3 (54.8)	33.3 (53.1)
Shallow*	69.7 (88.4)	100 (0)	Shallow	0 (29.2)	5.3 (20.1)
Camano Island			Camano Island		
Total	100 (10.0)	96.2 (34.6)	Total	0 (0)	<Null>
Deep	100 (0)	100 (9.2)	Deep	0 (0)	<Null>
Shallow	100 (28.3)	80.0 (41.7)	Shallow	0 (0)	<Null>

** = significant difference (Mann-Whitney U, $p < 0.05$ for Total; Wilcoxon signed rank, $p < 0.05$ for Deep/Shallow).*

Relative Depth Comparisons. When split into deep and shallow areas, there were no significant differences in water depths at Bowman Bay (MLLW, ft) between the control (median -10.0 ft, IQR = 1.1 ft) and the dock (median = -10.3, IQR = 1.7) (Mann-Whitney U, *p* > 0.05) (Table 6). However, there was indeed a significant difference in water depth (MLLW, ft) between the deep and shallow areas for both the control (deep median = -10.6 ft, IQR = 0.6 ft; shallow median = -9.5 ft, IQR 0.4 ft) and the dock (deep median = -11.3 ft, IQR = 0.9; shallow median = -9.5 ft, IQR = 1.2 ft) (Mann-Whitney U, *p* < 0.05) (Table 7).

Table 6. *Differences in transect water depths (MLLW) [median (IQR)] by site.*

Site	Control (ft)	Dock (ft)
Bowman Bay	-10.0 (1.1)	-10.3 (1.7)
Cornet Bay*	-7.4 (-0.3)	-5.6 (-0.5)
Camano Island*	-6.0 (1.8)	-5.0 (2.6)

** = significant difference (Mann-Whitney U, $p < 0.05$).*

Control. During late summer at Bowman Bay, the control had 97.3% kelp cover in the deep area, ranging from 71.4-100% cover by transect, and 91.7% cover in the shallow area, ranging from 59.4-100% cover by transect (Table 1). There were no significant differences in kelp cover between the deep and shallow areas of the control (Wilcoxon signed rank, $p > 0.05$) (Table 8).

Table 7. *Differences in transect water depths (MLLW) [median (IQR)] between relative depths by site.*

Site	Deep (ft)	Shallow (ft)
Control		
Bowman Bay*	-10.6 (0.6)	-9.5 (0.4)
Cornet Bay*	-8.0 (0.4)	-6.0 (0.3)
Camano Island*	-7.0 (0.9)	-5.9 (0.8)
Dock		
Bowman Bay*	-11.3 (0.9)	-9.5 (1.2)
Cornet Bay*	-6.6 (0.9)	-4.8 (0.4)
Camano Island*	-6.0 (0.8)	-4.3 (0.5)

** = significant difference (Mann-Whitney U, p < 0.05).*

Table 8. *Differences in control and dock kelp cover by transect [median (IQR)] between relative water depths, early and late summer, 2017.*

	Control Transects (%)			Dock Transects (%)	
Site	Deep	Shallow	Site	Deep	Shallow
Bowman Bay			Bowman Bay		
Early	<Null>	<Null>	Early	0 (0)	0 (0)
Late	100 (0)	100 (6.3)	Late	0 (0)	0 (2.4)
Cornet Bay			Cornet Bay		
Early	100 (86.2)	69.7 (88.4)	Early*	40.3 (54.8)	0 (29.2)
Late	100 (0)	100 (0)	Late*	33.3 (53.0)	5.3 (20.0)
Camano Island			Camano Island		
Early*	100 (0)	100 (28.3)	Early	0 (0)	0 (0)
Late	100 (9.2)	80 (41.7)	Late	<Null>	<Null>

** = significant difference (Wilcoxon Signed Rank, p < 0.05).*

Dock. During early summer, the dock had no kelp cover in the deep area, which increased only slightly to 1.1% for late summer, ranging from 0-13.3% cover by transect (Table 1). In the shallow area, kelp cover was 3.2% during early summer, ranging from 0-26.7% cover by transect, and 2.2% for late summer, ranging from 0-14.3% cover by transect (Table 1). There were no significant differences in kelp cover between the shallow and deep areas for either visit to Bowman Bay dock (Wilcoxon Signed Rank, $p >$

0.05) (Table 8). Additionally, no significant differences in kelp cover were found between early and late summer for either water depth (Wilcoxon signed rank, $p > 0.05$) (Table 5).

Dock perimeter. Kelp cover during early summer at Bowman Bay was 0% in the deep area of the dock perimeter and only 0.5% during late summer, ranging from 0-3.6% cover by transect (Figure 18, Table 1). In the shallow area, kelp cover was 5.5% during early summer, ranging from 0-26.6% cover by transect, which decreased to 0% for late summer (Figure 18, Table 1). No significant differences in kelp cover were found between the deep and shallow areas of the dock perimeter for either visit to Bowman Bay (Mann-Whitney U, $p > 0.05$) (Table 9). Likewise, no significant differences were found in kelp cover at the dock perimeter between early and late summer for either water depth (Mann-Whitney U, $p > 0.05$) (Table 10).

Table 9. *Differences in dock core and perimeter kelp coverage by transect [median (IQR)] between relative water depths, early and late summer, 2017.*

Site	Dock Core (%)			Dock Perimeter (%)	
	Deep	Shallow	Site	Deep	Shallow
Bowman Bay			Bowman Bay		
Early	0 (0)	0 (0)	Early	0 (0)	0 (8.5)
Late	0 (0)	1.5 (8.5)	Late	0 (0)	0 (0)
Cornet Bay			Cornet Bay		
Early*	33.3 (44.3)	0 (5.9)	Early	69.3 (33.5)	27.2 (51.1)
Late*	27.5 (34.6)	0 (8.3)	Late*	95.0 (16.7)	50.0 (17.0)
Camano Island			Camano Island		
Early	0 (0)	0 (0)	Early	0 (0)	0 (0)
Late	<Null>	<Null>	Late	<Null>	<Null>

** = significant difference (Mann-Whitney U, $p < 0.05$).*

Table 10. *Differences in dock core and perimeter kelp coverage by transect [median (IQR)] between early and late summer by total area and relative water depths.*

Site	Dock Core (%)		Site	Dock Perimeter (%)	
	Early	Late		Early	Late
Bowman Bay			Bowman Bay		
Total*	0 (0)	0 (4.4)	Total	0 (0)	0 (0)
Deep	0 (0)	0 (0)	Deep	0 (0)	0 (0)
Shallow*	0 (0)	1.6 (8.5)	Shallow	0 (8.5)	0 (0)
Cornet Bay			Cornet Bay		
Total	3.4 (42.9)	9.9 (27.2)	Total	51.1 (60.4)	81.7 (30.7)
Deep	33.3 (44.3)	27.5 (34.6)	Deep	69.3 (33.5)	95.0 (16.7)
Shallow	0 (5.9)	0 (8.3)	Shallow	27.2 (51.1)	50.0 (17)
Camano Island			Camano Island		
Total	0 (0)	<Null>	Total	0 (0)	<Null>
Deep	0 (0)	<Null>	Deep	0 (0)	<Null>
Shallow	0 (0)	<Null>	Shallow	0 (0)	<Null>

** = significant difference (Mann-Whitney U, $p < 0.05$).*

Dock core. At the dock core, there was no kelp cover in the deep area during early summer which increased to only 1.7% for late summer, ranging from 0-13.3% cover by transect (Figure 18, Table 1). The shallow area of the dock core similarly had no kelp cover for early summer and only 4.3% cover during late summer which ranged from 0-14.3% cover by transect (Figure 18, Table 1). No significant differences in kelp cover were found between the deep and shallow areas of the dock core for either visit to Bowman Bay (Mann-Whitney U, $p > 0.05$) (Table 9). There was, however, significantly less kelp cover during early summer than late summer at the dock core for both the total area (early median = 0%, IQR = 0%; late median = 0%, IQR = 4.4%) and the shallow area (early median = 0%, IQR 0%; late median = 1.6%, IQR 8.5%) (Mann-Whitney U, $p < 0.05$) (Table 10).

There were no significant differences in kelp cover between the perimeter and the core for the total and deep areas during either visit to Bowman Bay (Mann-Whitney U, *p*

> 0.05) (Table 2). However, there was significantly more kelp cover in the shallow area of the dock core (median = 1.7%, IQR = 8.5%) than in the shallow area of the dock perimeter (median = 0, IQR = 0) during late summer at Bowman Bay (Mann-Whitney U, $p < 0.05$) (Table 2).

Kelp cover was categorized as present or absent for each 1 m^{-2} grid cell and correlated with the water depth at that cell. The only significant correlation found between kelp cover and water depth during early summer was a moderate positive relationship for the total dock area (0.433 r_s) (Spearman rank, $p < 0.05$) (Table 11). There were no significant differences found between kelp cover and water depth at Bowman Bay control nor any area of Bowman Bay dock during late summer (Spearman rank, $p > 0.05$).

Table 11. *Spearman rank correlations (r_s, $p < 0.05$), early summer, 2017.*

Site	Variable	Area	Bowman Bay Depth	Cornet Bay Depth	Camano Island Depth
Control	Biomass	Total	X	-0.4256	-0.588
	Cover	Deep	X	-0.6664	X
	Cover	Shallow	X	-0.5805	X
Dock	Cover	Total	0.433	-0.4743	X
	Biomass	Total	X	-0.6344	X
	Cover	Deep	X	-0.7069	X
Dock Perimeter	Biomass	Total	X	-0.6298	-0.4298
Dock Core	Cover	Total	X	-0.4404	X
	Biomass	Total	X	-0.8456	X
	Cover	Deep	X	-0.5026	X

X = no significance.

Cornet Bay

Total Area Comparisons.

Early summer. Cornet Bay control had kelp cover of 62.3% (Figures 23 and 24, Table 1), ranging from 3.5-100% cover by transect (Figure 25), with a large portion of the benthos being either bare sediment or thick eelgrass beds with no underlying kelp. Small portions of green filamentous algae were present within both kelp and eelgrass beds. All kelp specimens identifiable by video were sugar kelp. Cornet Bay dock showed 32.8% kelp cover (Figures 23 and 24, Table 1), ranging from 0-88.9% cover by transect (Figure 25). There was significantly more kelp cover at the control (median = 100%, IQR = 86.5%) than at the dock (median = 20.4%, IQR 57.1%) (Mann-Whitney U, $p < 0.05$) (Table 3). Again, all kelp specimens identifiable from video at the dock were sugar kelp.

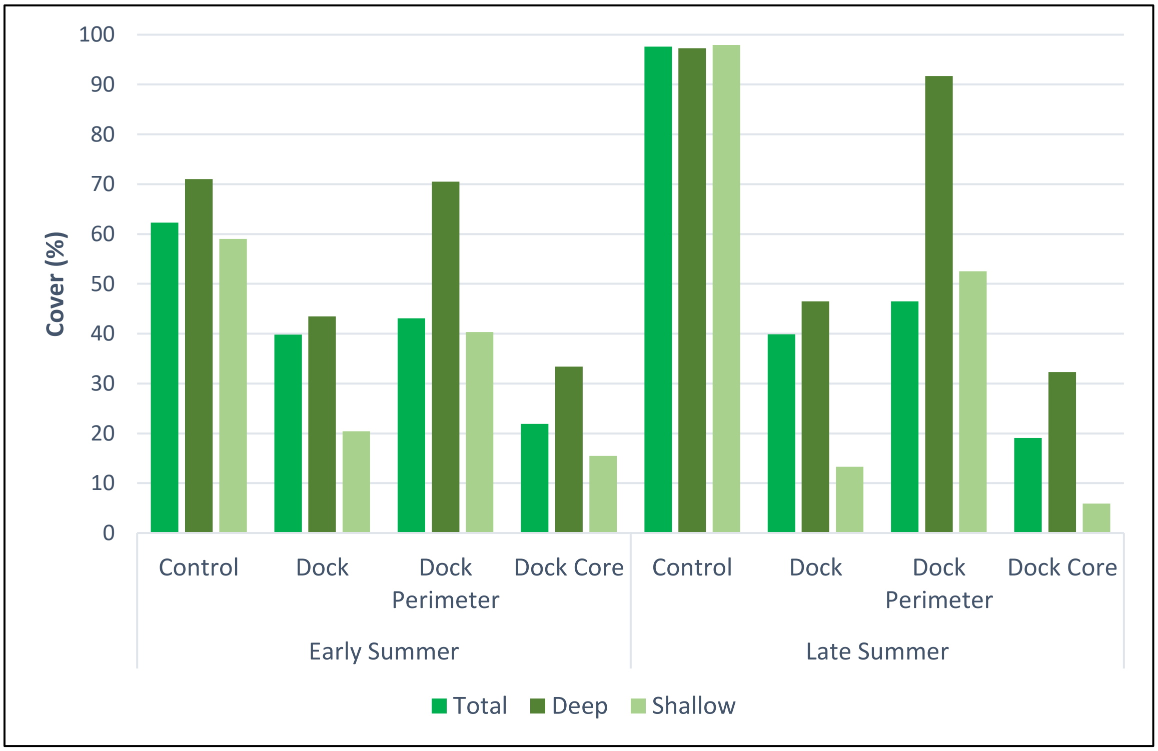
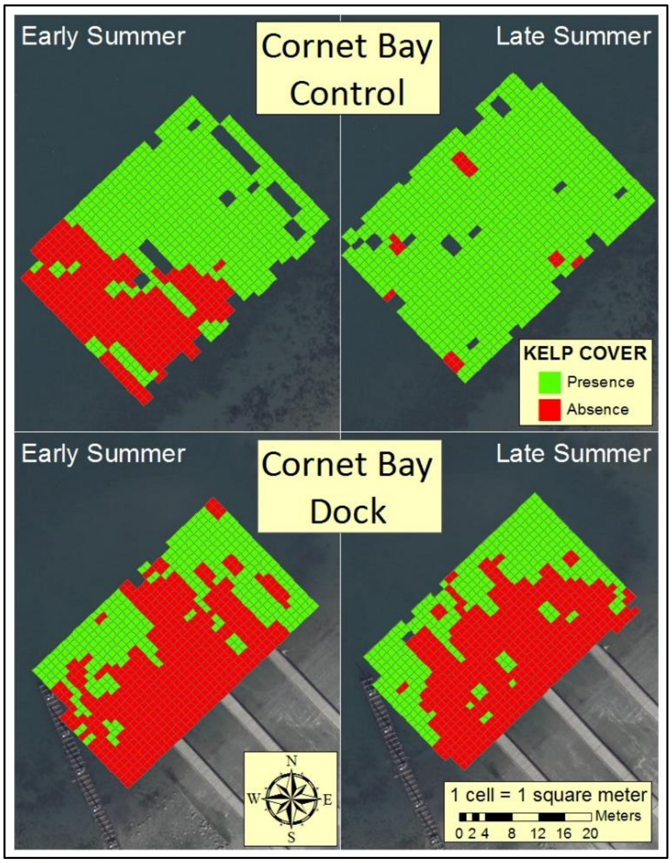


Figure 23. *Kelp cover (%) at Cornet Bay for total area and relative water depths, early and late summer, 2017.*

Figure 24. *Kelp cover (%) at Cornet Bay, early and late summer, 2017.*



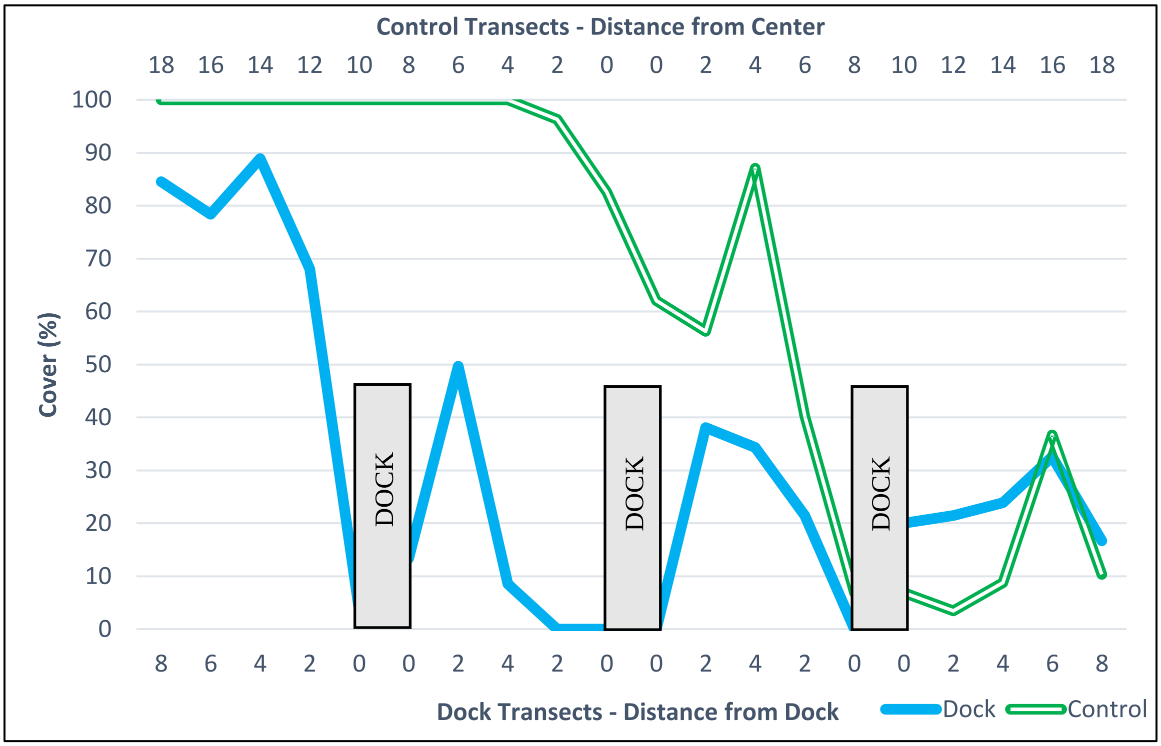


Figure 25. *Kelp cover (%) by transect at Cornet Bay, early summer, 2017.*

Additionally, there were many large specimens of sugar kelp in thick cover attached to the floating docks themselves (Figure 26).

Figure 26. *Sugar kelp attached to the floating dock at Cornet Bay.*

At the dock perimeter, kelp cover was 43.1%, ranging from 6.7-100% cover by transect, while at the core, kelp cover was 21.9%, ranging from 0-100% cover by transect (Figures 23 and 27, Table 1). There was significantly more kelp cover in the dock perimeter (median = 51.1%, IQR = 60.4%) than in the dock core (median = 3.4%, IQR = 42.9%) (Mann-Whitney U, $p < 0.05$) (Table 2).

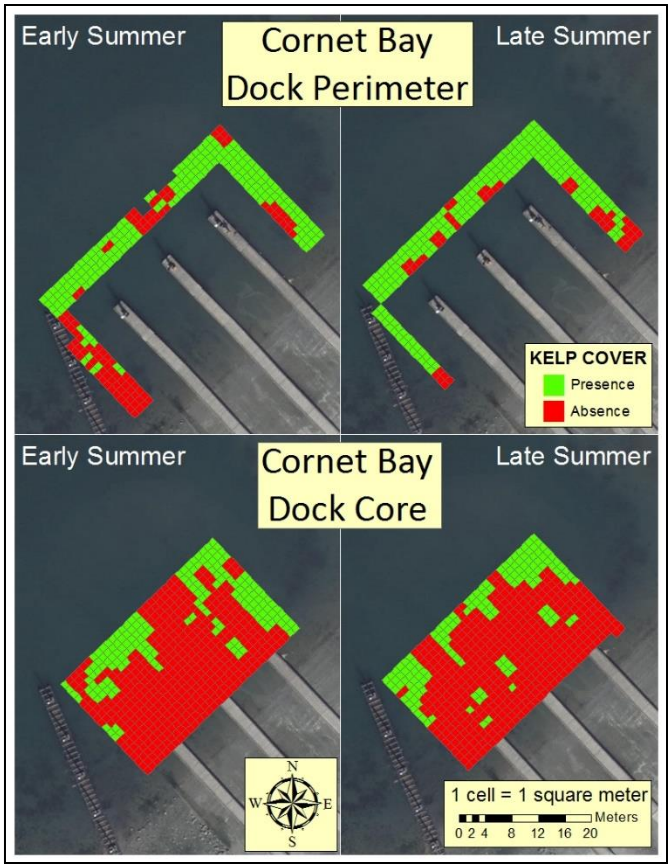


Figure 27. *Kelp cover at Cornet Bay dock, early and late summer, 2017.*

There was a significant difference in kelp cover between the control (median = 84.9%, IQR = 76.5%), the dock perimeter (median = 77.5%, IQR = 50.9%), and the dock core (median =

20.7%, IQR = 29.6%) (Kruskal-Wallis, $p < 0.05$). Comparison of mean ranks revealed two homogenous groups where the control and core were distinct from each other but not from the perimeter, which was similar to both (comparison of mean ranks, $p < 0.05$) (Table 4).

Late summer. The control showed a substantial growth of kelp throughout the summer increasing to cover of 97.3% (Figures 23 and 24, Table 1), ranging from 79.3-100% cover by transect (Figure 28), and showed very little benthic cover other than sugar kelp. The dock remained consistent with 32.9% kelp cover (Figures 22 and 23, Table 1), ranging from 0-95% cover by transect (Figure 28).

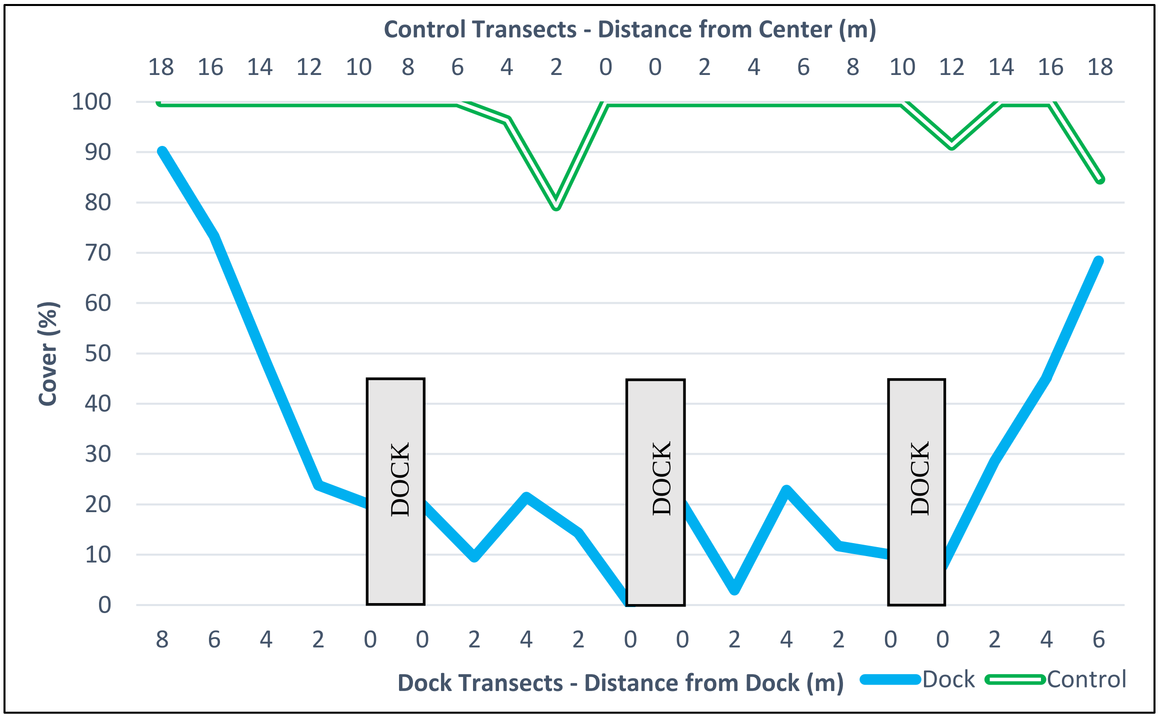


Figure 28. *Kelp cover (%) by transect at Cornet Bay, late summer, 2017.*

There was significantly more kelp cover at the control (median = 100%, IQR = 0%) than at the dock (median = 19.5%, IQR = 45.0%) (Mann-Whitney U, $p < 0.05$)

(Table 3). All kelp specimens identifiable from video at both control and dock were sugar kelp. Additionally, there were large specimens of sugar kelp in thick cover attached to the floating docks themselves (Figure 26).

At the dock perimeter, kelp cover ranged from 32.8-100% cover by transect, totaling 46.5% overall while it was 19.1% in the core, ranging from 0-96.4% cover by transect (Figures 23 and 27, Table 1). There was significantly more kelp cover in the dock perimeter (median = 81.7%, IQR = 30.7%) than in the dock core (median = 9.9%, IQR = 25.2%) (Mann-Whitney U, $p < 0.05$) (Table 2).

There was a significant difference in kelp cover between the control (median = 100%, IQR = 0%), the dock perimeter (median = 80.0%, IQR = 17.4%) and the dock core (median = 20.0%, IQR = 13.3%) (Kruskal-Wallis, $p < 0.05$). Comparison of mean ranks revealed two homogenous groups where the control and core were distinct from each other but not from the perimeter, which was similar to both (comparison of mean ranks, $p < 0.05$) (Table 4).

Early summer vs late summer. There was significantly less kelp cover during early summer at Cornet Bay control (median = 100%, IQR = 86.5%) than during late summer (median = 100%, IQR = 0%) (Mann-Whitney U, $p < 0.05$) (Table 5).

Relative Depth Comparisons. When split into relative deep and shallow areas, the benthic elevations (MLLW, ft) at Cornet Bay were found to be slightly though significantly deeper in the control (median = -7.4 ft, IQR = -0.3 ft) than at the dock (median = -5.6 ft, IQR = -0.5 ft) (Mann-Whitney U, $p < 0.05$) (Table 6). This is primarily due to a steep shelf that dropped to approximately -20 ft (MLLW) along the last meter or two on the deep end of each transect. Additionally, there was a significant difference in water depth (MLLW, ft) between the deep and shallow areas for both the control (deep median = -8.0 ft, IQR = 0.4 ft; shallow median = -6.0 ft, IQR 0.3 ft) and the dock (deep median = -6.6 ft, IQR = 0.9; shallow median = -4.8 ft, IQR = 0.4 ft) (Mann-Whitney U, $p < 0.05$) (Table 7).

Control. Cornet Bay control had 71% kelp cover in the deep area during early summer (median = 100%, IQR = 86.2%), ranging from 0-100% cover by transect, which increased significantly to 97.3% cover, ranging from 72.4-100% cover by transect, during late summer (median = 100%, IQR = 0%) (Wilcoxon signed rank, $p < 0.5$) (Figure 25, Tables 1 and 5). There was 59% kelp cover in the shallow area (median = 69.7%, IQR = 88.4%), ranging from 0-100% cover by transect, during early summer which increased significantly to 97.9% cover (median = 100%, IQR = 0%), ranging from 79.3-100% cover by transect, during late summer (Wilcoxon signed rank, $p < 0.5$) (Figure 23, Tables 1 and 5).

Dock. During early summer at Cornet Bay dock, kelp cover was 43.5% in the deep area, ranging from 0-100% cover by transect, which remained consistent into late summer, showing 46.5% cover that also ranged from 0-100% by transect. In the shallow area, there was 20.4% kelp cover that ranged from 0-100% cover by transect during early summer which dropped slightly to 13.3% for late summer, ranging from 0-70.8% cover by transect (Figure 23, Table 1). There were no significant differences in kelp cover between early and late summer for either water depth (Wilcoxon signed rank, $p > 0.05$) (Table 5). However, during both early and late summer, there was significantly more kelp cover in the deep area (early median = 40.3%, IQR = 54.8%; late median = 29.3%, IQR =

53.0%) than in the shallow area (early median = 0%, IQR = 27.2%; late median = 5.3%, IQR = 20.0%) (Wilcoxon signed rank, $p < 0.05$) (Table 8).

Dock perimeter. During early summer, kelp cover at Cornet Bay was 70.5% in the deep area of the dock perimeter, ranging from 26.7-83.9% cover by transect, which increased to 91.7% cover, ranging from 83.3-100% cover by transect, for late summer (Figure 23, Table 1). In the shallow area of the dock perimeter, kelp cover was 40.3%, ranging from 8.7-100% cover by transect for early summer, increasing slightly to 52.5%, ranging from 32.8-70.8% cover by transect, for late summer (Figure 23, Table 1). The dock perimeter showed no significant difference in kelp cover between the deep and shallow areas during early summer, but during late summer there was significantly more kelp cover in the deep area (median = 95.0%, IQR = 16.7%) than in the shallow area (median = 50.0%, IQR = 17.0%) (Mann-Whitney U, $p < 0.05$) (Table 9). There were no significant differences in kelp cover between early and late summer in the dock perimeter for either water depth (Mann-Whitney U, $p > 0.05$) (Table 10).

Dock core. At the dock core, kelp cover was 29.4% in the deep area, ranging from 0-77.8% cover by transect, during early summer which remained consistent showing 32.3% cover, ranging from 0-96.4% by transect, for late summer (Figure 23, Table 1). In the shallow area, kelp cover was 15.5%, ranging from 0-100% cover by transect, during early summer which dropped to 5.9%, ranging from 0-23.5% cover by transect, for late summer (Figure 23, Table 1). For both early and late summer there was significantly more kelp cover in the deep area (early median = 29.3%, IQR = 44.3%; late median = 25.5%, IQR = 31.6%) than in the shallow area (early median = 0%, IQR = 5.9%; late median = 0%, IQR = 8.3%) (Mann-Whitney U, $p < 0.05$) (Table 9). There were no significant differences in kelp cover between early and late summer in the dock perimeter for either water depth (Mann-Whitney U, $p > 0.05$) (Table 10).

During early summer, the dock perimeter had significantly more kelp cover than the dock core in the shallow area (perimeter median = 27.2, IQR = 51.1; core median = 0%, IQR = 5.9%) (Mann-Whitney U, $p < 0.05$) (Table 2). During late summer, however, the dock perimeter had significantly more kelp cover than the dock core in both the deep (perimeter median = 95.0%, IQR = 16.7%; core median = 27.7%, IQR = 34.6%) and shallow areas (perimeter median = 50.0%, IQR = 17.0%; core median = 0%, IQR = 8.3%) (Mann-Whitney U, $p < 0.05$) (Table 2).

Kelp cover was categorized as present or absent by each 1 m^{-2} grid cell and correlated with the water depth of that cell. During early summer, kelp cover showed a strong negative relationship with water depth in the deep area of the control (-0.6664 r_s), and a moderate negative relationship with water depth in the shallow area of the control (-0.5805 r_s) (Spearman rank, $p < 0.05$) (Table 11). At the dock, kelp cover had a moderate correlation with water depth for the total area of the dock (-0.4743 r_s), and a strong negative relationship with water depth for the deep area of the dock (-0.7069 r_s) (Spearman rank, $p < 0.05$) (Table 11). Similarly, kelp cover in the dock core showed a moderate negative relationship with water depth for the total area of the dock core (-0.4404 r_s), as well as with water depth for the deep area of the dock core (-0.5026 r_s) (Spearman rank, $p < 0.05$) (Table 11). No other significant relationships between kelp cover and water depth were found (Spearman rank, $p > 0.05$).

During late summer, there were no significant relationships found between kelp cover and water depth at Cornet Bay control nor Cornet Bay dock perimeter (Spearman rank, $p > 0.05$). However, there was a moderate negative relationship between kelp cover and water depth for the total area of the dock (-0.5348 r_s) (Spearman rank, $p < 0.05$) (Table 11). Similarly, there was a moderate negative relationship between kelp cover and water depth for the total area of the dock core (-0.5113 r_s) (Spearman rank, $p < 0.05$) (Table 11). No other significant relationships were found between kelp cover and water depth at Cornet Bay for early or late summer (Spearman rank, $p > 0.05$).

Camano Island

Total Area Comparisons.

Early summer. Kelp cover for early summer at Camano Island control was 88.1% (Figures 29 and 30, Table 1), ranging from 35.7-100% cover by transect (Figure 31).

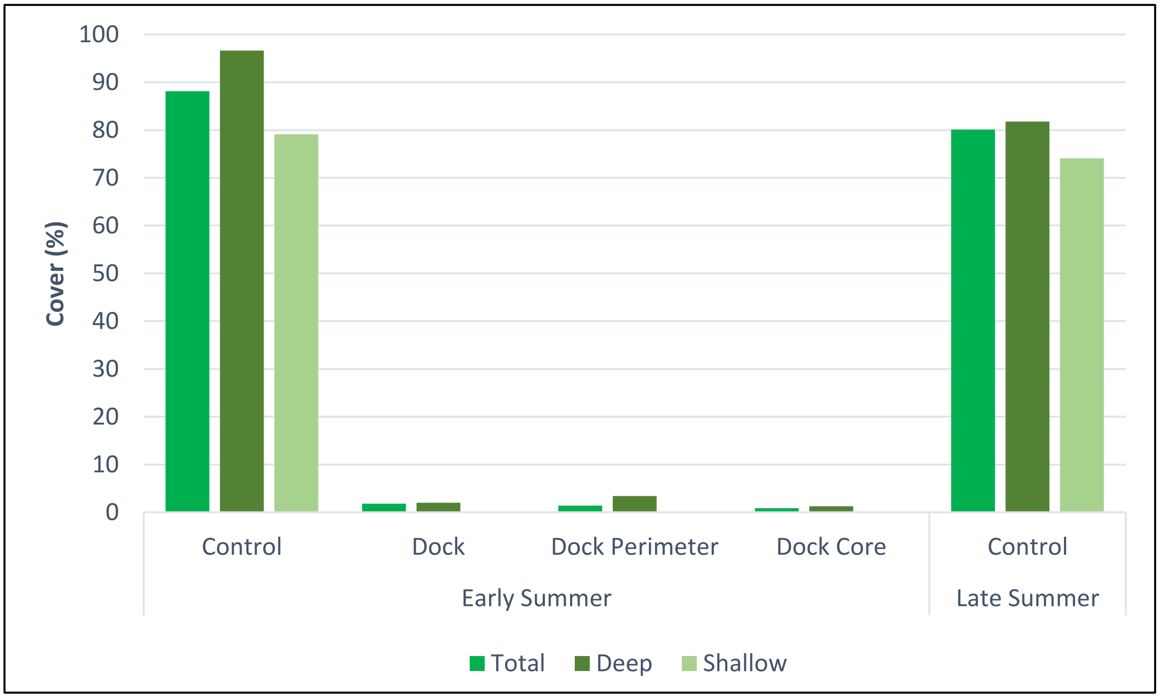


Figure 29. *Kelp cover (%) at Camano Island for total area and relative water depths, early and late summer, 2017.*

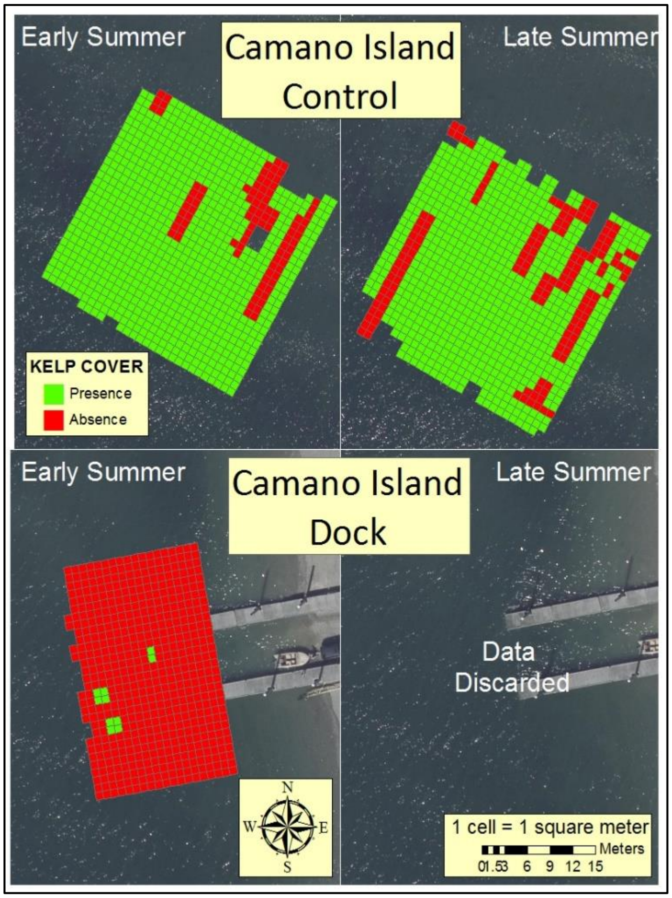


Figure 30. *Kelp cover at Camano Island, early and late summer, 2017.*

Cover was thick with minimal presence of eelgrass or green filamentous algae. Bare patches of sediment made up most of the kelp absence areas. All kelp identifiable by video was sugar kelp. Camano Island dock revealed kelp cover of 1.8% (Figures 29 and 30, Table 1) which ranged from 0-13.6% cover by transect (Figure 31). Much of the dock video showed barren patches of coarse sediment with interspersed eelgrass present in the finer sediment. All kelp identifiable by video at Camano Island dock was sugar kelp with large individual specimens of sugar kelp attached to the floating docks. There was significantly more kelp cover at the control (median = 100%, IQR = 10%) than at the dock (median = 0%, IQR = 0%) (Mann-Whitney U, $p < 0.05$) (Table 3).

At the dock perimeter, kelp cover was 1.4% for early summer which ranged from 0-13.6% cover by transect, while there was 0.9% cover in the core that ranged from 0-11.8% cover by transect (Figures 29 and 32, Table 1). There were no significant differences in kelp cover between dock perimeter and dock core (Mann-Whitney U, $p > 0.05$) (Table 1).

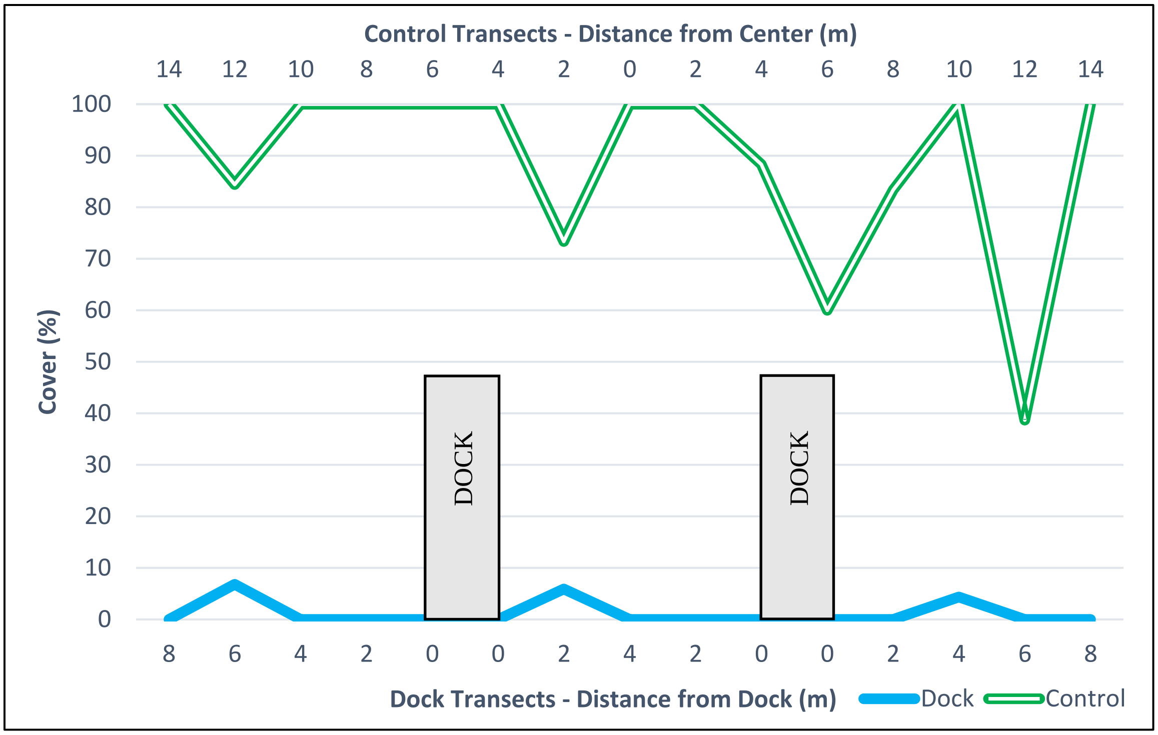


Figure 31. *Kelp cover (%) by transect at Camano Island, early summer, 2017.*

Kelp cover was found to be significantly greater at the control (median = 100%, IQR = 16.4%) than at the dock perimeter (median = 0%, IQR = 0%) and the dock core (median = 0%, IQR = 0%) (Kruskal-Wallis, $p < 0.05$) which were a homogenous group (Comparison of mean ranks, $p < 0.05$) (Table 4).

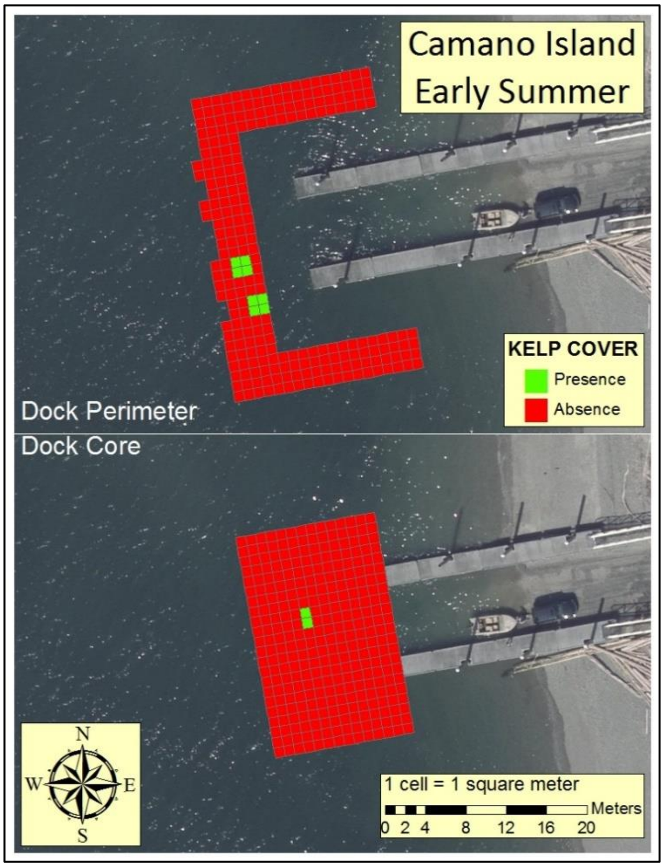


Figure 32. *Kelp cover at Camano Island dock, early summer, 2017.*

Late summer. Kelp cover in the control lowered slightly to 80.1% during late summer (Figures 29 and 30, Table 1), ranging from 33.4-100% cover by transect (Figure 33). All kelp identifiable by video was sugar kelp. Benthic conditions were similar to early summer with thick kelp cover and minimal presence of eelgrass or green filamentous algae. At the dock, however, benthic conditions were drastically different for late summer. There were large amounts of fresh kelp detritus surrounding the entire dock and trapped within the boat ramps extending out into the water which created a thick blanket of kelp near the benthos (Figure 34). It was impossible to distinguish between living, attached kelp and newly detached kelp, hovering near the benthos, which had begun senescence. For this reason, the results from late summer at Camano Island dock, and any associated statistical tests are highly questionable and were discarded.

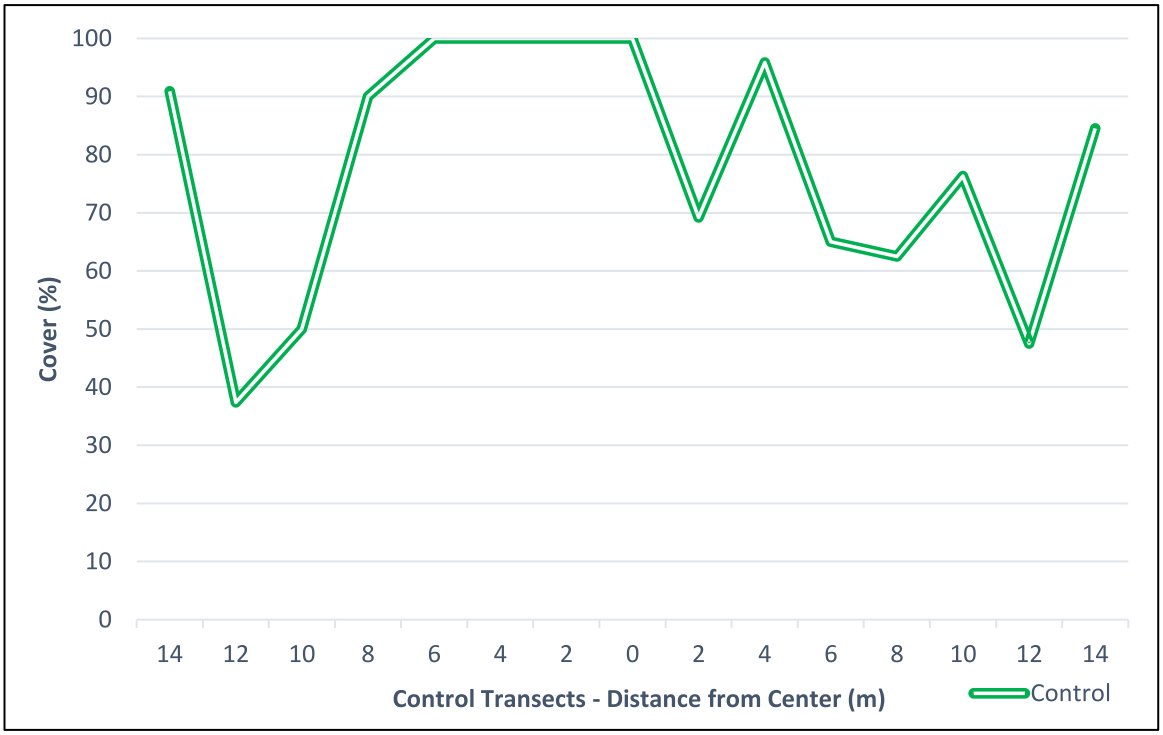


Figure 33. *Kelp cover (%) by transect at Camano Island control, late summer, 2017.*

Relative Depth Comparisons. When split into relative deep and shallow areas, the benthic elevations at Camano Island (MLLW, ft) were found to be significantly deeper, albeit slightly, in the control (median = -6.0 ft, IQR = 1.8 ft) than at the dock (median = -5.0 ft, IQR = 2.6 ft (Mann-Whitney U, $p < 0.05$) (Table 6). Additionally, there was a significant difference in water depth (MLLW, ft) between the deep and shallow areas for both the control (deep median = -7.0 ft, IQR = 0.9 ft; shallow median = -5.9 ft, IQR 0.8 ft) and the dock (deep median = -6.0 ft, IQR = 0.8; shallow median = -4.3 ft, IQR = 0.5 ft) (Mann-Whitney U, $p < 0.05$) (Table 7).

Figure 34. *Thick kelp detritus on the boat ramp at Camano Island dock, late summer, 2017.*

Control. During early summer, Camano Island control had 96.6% kelp cover in the deep area, ranging from 66.7-100% cover by transect, which dropped slightly to 81.8% cover during late summer, ranging from 0-100% cover by transect. There was 79.1% kelp cover in the shallow area, ranging from 10.7-100% cover by transect, that remained consistent through late summer with 74.1% cover, ranging from 25-100% cover by transect (Figure 29, Table 1). During early summer, there was significantly more kelp cover in the deep area (median = 100%, IQR = 0%) than in the shallow area (median = 100%, IQR = 26.3%) (Wilcoxon signed rank, $p < 0.05$) (Table 8).

Dock. During early summer, at Camano Island dock, kelp cover was 2% in the deep area, ranging from 0-11.8% cover by transect, while there was 0% cover in the shallow area (Figure 29, Table 1).

Dock perimeter. Kelp cover during early summer was 3.4% in the deep area of the dock perimeter, ranging from 0-13.6% cover by transect, and 0% in the shallow area (Figure 29, Table 1).

Dock core. At the dock core, kelp cover was 1.3% in the deep area, ranging from 0-11.8% cover by transect, and again 0% in the shallow area for early summer (Figure 29, Table 1). There was no significant difference in kelp cover between deep and shallow areas for the dock perimeter nor the dock core during early summer at Camano Island (Mann-Whitney U, $p > 0.05$) (Table 9). Additionally, there were no significant differences in kelp cover between the dock perimeter and core for either water depth during early summer (Mann-Whitney U, $p > 0.05$) (Table 2).

Kelp cover was again categorized as present or absent by each 1 m^{-2} grid cell and correlated with the water depth of that cell. The only significant correlation between kelp cover and water depth during early summer at Camano Island was a moderate negative relationship found at the dock perimeter (-0.4298 r_s) (Spearman rank, $p < 0.05$) (Table 11).

Biomass

Bowman Bay

Total Area Comparisons.

Early summer. No kelp biomass samples were collected from the initial Bowman Bay control, despite two attempts at each of 30 locations. Correspondingly, this data was discarded along with cover data from the video survey. From the 60 sampling attempts at Bowman Bay dock, there was only one 87.2 g sample collected from the perimeter (Figure 35). The sample was sugar kelp.

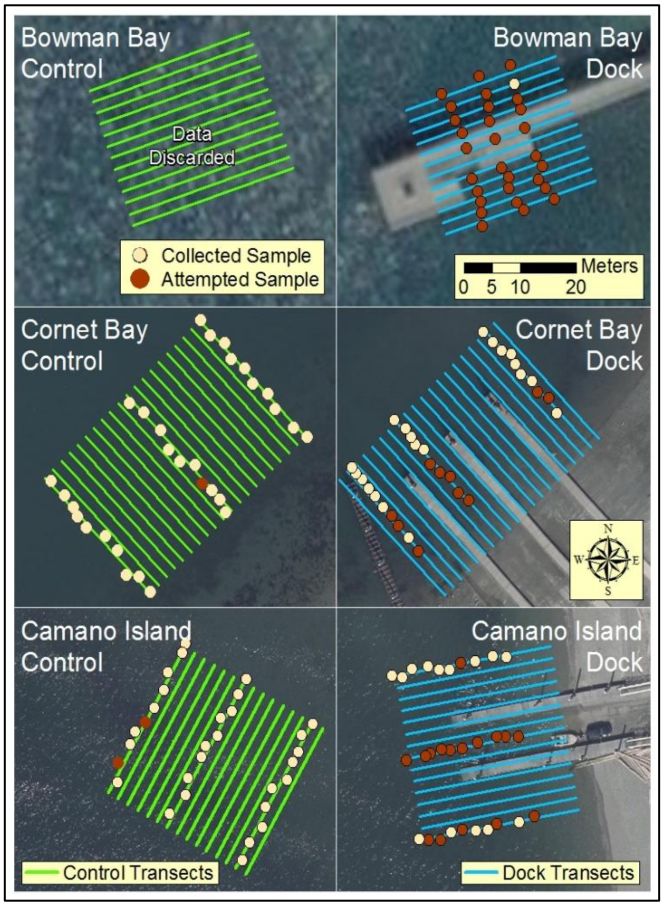


Figure 35. *Biomass sampling locations, early summer, 2017. Note – Bowman Bay control data was discarded.*

Late summer. Of the 30 biomass sampling locations in the second established control, only two failed to retrieve kelp (Figure 36). These samples ranged from 24.2 g to 2.3 kg and were entirely comprised of sugar kelp. Despite two sampling attempts from each of 30 locations at the dock, no samples were collected (Figure 36).

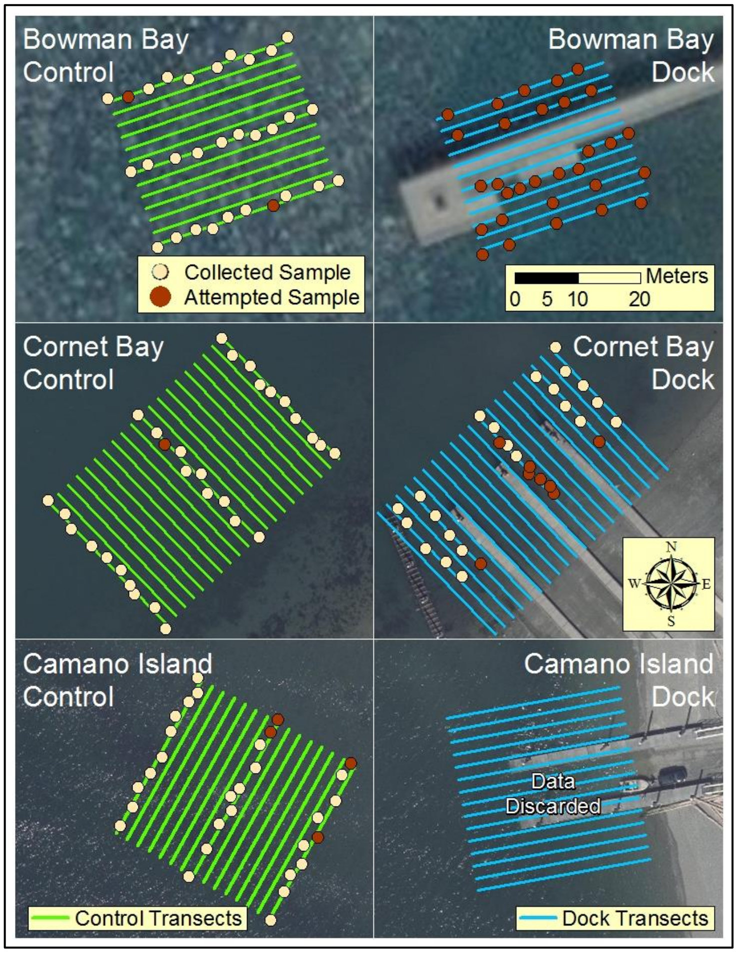


Figure 36. *Biomass sampling locations, late summer, 2017. Note – Camano Island dock data was discarded.*

Relative Depth Comparisons.

Control. During late summer, at Bowman Bay control, there was significantly more kelp biomass found in the deep area (median 1150.4 g, IQR 790.1 g, n = 15), ranging from 0-1.63 kg by sample, than in the shallow area (median 366.2 g, IQR 474.9 g, n = 15), ranging from 0-2.3 kg by sample (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 12).

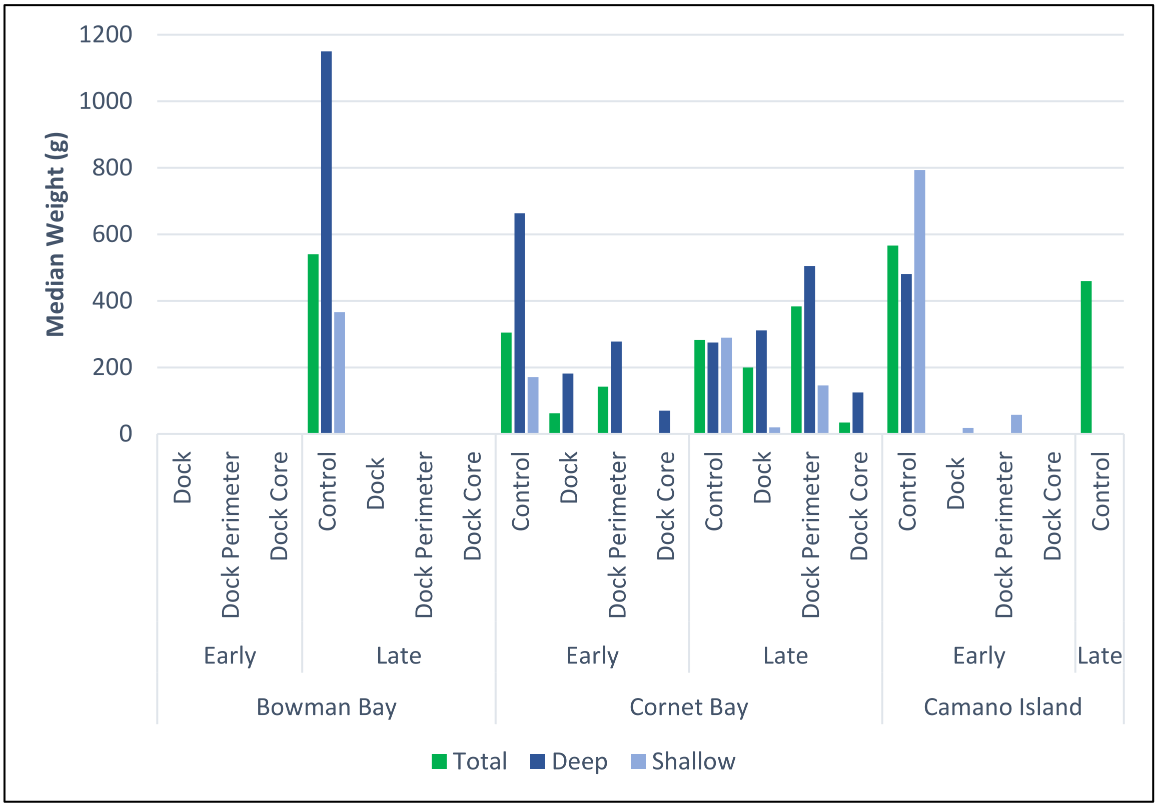


Figure 37. *Median kelp biomass weights (g) for total area and relative water depths by location, early and late summer, 2017.*

Table 12. *Differences in control and dock kelp biomass weight [median (IQR)] between relative water depths, early and late summer, 2017.*

	Control (g)					Dock (g)			
Site	Deep	n	Shallow	n	Site	Deep	n	Shallow	n
Bowman Bay					Bowman Bay				
Early	<Null>	n/a	<Null>	n/a	Early	0 (0)	12	0 (0)	18
Late*	1150.4 (790.1)	15	366.2 (474.9)	15	Late	0 (0)	14	0 (0)	16
Cornet Bay					Cornet Bay				
Early*	663.0 (796.5)	15	170.8 (368.0)	15	Early*	181.6 (365.8)	19	0 (12.9)	11
Late	274.8 (904.8)	15	289.3 (362.9)	15	Late*	311.7 (289.7)	20	0 (100.9)	10
Camano Island					Camano Island				
Early	480.6 (657.5)	13	792.8 (1612.7)	17	Early*	0 (0)	16	17.8 (66.0)	14
Late	756.0 (736.0)	15	288.4 (602.0)	15	Late	<Null>	n/a	<Null>	n/a

* = significant difference (Mann-Whitney U, $p < 0.05$).

Each biomass sample was correlated with the water depth at that sample location. The only significant correlation found between kelp biomass and water depth for either visit to Bowman Bay was a moderate negative relationship for the total area at the control during late summer (-0.4109 r_s) (Spearman rank, $p < 0.05$) (Table 13).

Table 13. *Spearman rank correlations (r_s, $p < 0.05$), late summer, 2017.*

Site	Factor	Area	Bowman Bay Depth	Cornet Bay Depth	Camano Island Depth
Control	Biomass	Total	-0.4109	X	X
Dock	Cover	Total	X	-0.5248	X
	Biomass	Total	X	-0.66	X
	Biomass	Deep	X	-0.512	X
Dock Perimeter	Biomass	Total	X	-0.6593	X
Dock Core	Cover	Total	X	-0.5113	X
	Biomass	Total	X	-0.6288	X

X = no significance.

Kelp Blade Morphometrics. Morphometric measurements from Bowman Bay control revealed an average blade length of 121 cm, and an average blade width of 23.4 cm, from a total of 35 stipes counted from 5 random samples giving an average density of 28 stipes per m^{-2} (Figure 38, Table 14). Because no biomass samples were retrieved from

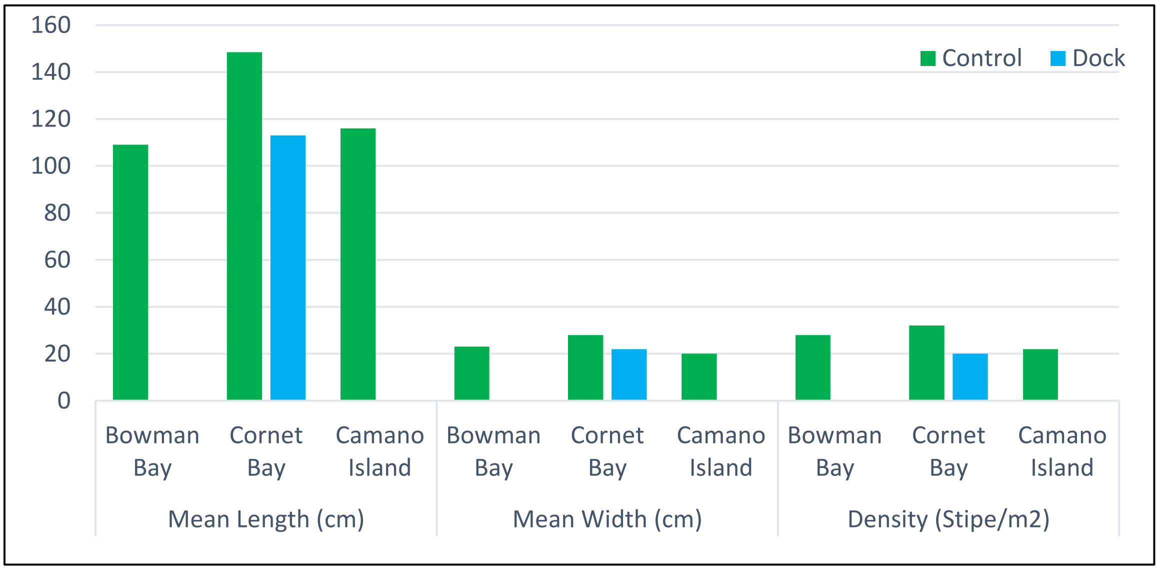


Figure 38. *Mean kelp blade length and width (cm). Density reported as stipe count per m^{-2}.*

any portion of the late summer visit to Bowman Bay dock, morphometric measurements were not recorded.

Table 14. *Differences in kelp blade length and width [Median (IQR)] between control and dock*

	Length (cm)			Width (cm)		Stipe Count		Density (Stipe/m^{-2})	
Site	Control	Dock	Site	Control	Dock	Control	Dock	Control	Dock
Bowman Bay	109.0 (81.0)	<Null>	BB	23.0 (8.5)	<Null>	35	n/a	140	n/a
Cornet Bay*	148.5 (93.0)	113.0 (82.0)	CB*	28.0 (15.5)	22 (10)	40	25	160	100
Camano Island	116.0 (80.0)	n/a	CI	20.0 (8.0)	n/a	27	n/a	108	n/a

** = significant difference (Mann-Whitney U, $p < 0.05$). Stipe count is total number in sample. Density is stipe count per m^{-2}.*

Cornet Bay

Total Area Comparisons.

Early summer. Kelp biomass samples from early summer at Cornet Bay control totaled over 15 kg, ranging from 0-1.9 kg by sample. Only one biomass sampling attempt failed to yield kelp (Figure 35). Because there was nearly no kelp present in the dock core, as noted on-site during video survey, the sampling grid was altered to capture more samples from the perimeter. Total dock biomass was substantially lower, totaling only 5.5 kg, with 33% of sampling locations failing to yield kelp (Figure 35). There was significantly more kelp present in the control (median = 304.4, IQR = 676.2) than at the dock (median = 62.0, IQR = 260.6) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 15). All kelp retrieved from both sites was sugar kelp.

Table 15. *Differences in kelp biomass weight [median (IQR)] between control and dock, early and late summer, 2017.*

	Early Summer (g)					Late Summer (g)			
Site	Control	n	Dock	n	Site	Control	n	Dock	n
Bowman Bay	<Null>	n/a	0 (0)	30	Bowman Bay*	540.3 (934.4)	30	0 (0)	30
Cornet Bay*	304.4 (676.2)	30	62 (260.6)	30	Cornet Bay*	282.1 (614.8)	30	199.6 (368.4)	30
Camano Island*	565.9 (1286.5)	30	0 (39.6)	30	Camano Island	459.1 (685.7)	30	<Null>	n/a

** = significant difference (Mann-Whitney U, p < 0.05).*

Kelp biomass from the dock perimeter totaled approximately 5.2 kg, ranging from 0-856.3g by sample with only 23% of sampling locations failing to yield kelp. Dock core biomass totaled only 282.7 g, ranging from 0 to 99.9 g by sample with 63% of sampling locations failing to yield kelp. There was significantly more kelp biomass in the perimeter (median = 141.9 g, IQR = 351.5) than the core (median = 0 g, IQR = 77.6 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 16).

Table 16. *Differences in kelp biomass weight [median (IQR)] between dock core and perimeter by total area and relative water depths, early and late summer, 2017.*

	Early Summer (g)					Late Summer (g)			
Site	Core	n	Perimeter	n	Site	Core	n	Perimeter	n
Bowman Bay					Bowman Bay				
Total	0 (0)	30	0 (0)	30	Total	0 (0)	30	0 (0)	30
Deep	0 (0)	8	0 (0)	4	Deep	0 (0)	7	0 (0)	7
Shallow	0 (0)	10	0 (0)	8	Shallow	0 (0)	7	0 (0)	9
Cornet Bay					Cornet Bay				
Total*	0 (77.6)	30	141.9 (351.5)	30	Total*	33.9 (196.1)	30	383.7 (307.0)	30
Deep*	70.2 (99.9)	5	277.2 (347.3)	14	Deep*	124.9 (294.7	11	504.8 (261.4	9
Shallow	0 (0)	3	0 (30.8)	8	Shallow*	0 (0)	6	145.4 (175.7)	4
Camano Island					Camano Island				
Total*	0 (0)	30	0 (57.0)	30	Total	<Null>	n/a	<Null>	n/a
Deep	0 (0)	4	0 (4.5)	10	Deep	<Null>	n/a	<Null>	n/a
Shallow*	0 (0)	4	57 (67.3)	12	Shallow	<Null>	n/a	<Null>	n/a

** = significant difference (Mann-Whitney U, p < 0.05).*

There was a significant difference in kelp biomass weight between the control (median = 304.4 g, IQR = 676.2 g), the dock perimeter (median = 141.9 g, IQR = 351.5 g), and the dock core (median 0 g, IQR 77.6 g) (Kruskal-Wallis, $p < 0.05$). Comparison of mean ranks revealed two homogenous groups where the control and core were distinct from each other but not from the perimeter which was similar to both (comparison of mean ranks, $p < 0.05$) (Figure 37, Table 17).

Table 17. *Differences in kelp biomass weight [median (IQR] by location, early and late summer, 2017.*

Site	Control (g)	n	Core (g)	n	Perimeter (g)	n
Early						
Cornet Bay*	304.4 (676.2)^{a}	30	0 (77.6)^{b}	8	141.9 (351.5)^{ab}	22
Camano Island*	565.9 (1286.5)^{a}	30	0 (0)^{b}	8	0 (57.0)^{b}	22
Late						
Bowman Bay*	540.3 (934.4)^{a}	30	0 (0)^{b}	14	0 (0)^{b}	16
Cornet Bay*	282.0 (614.8)^{a}	30	33.9 (196.1)^{b}	17	383.7 (307.0)^{a}	13

** = significant difference (Kruskal-Wallis, p < 0.05). Superscript letters identify homogenous groups (Comparison of mean ranks, p < 0.05).*

Late summer. Kelp biomass at the control to totaled over 17 kg, ranging from 0-39 kg by sample with only 3% of sampling locations failing to yield kelp (Figure 36). The dock biomass samples were substantially lower, totaling only 7.5 kg of kelp, ranging from 0-1 kg by sample with 27% of sampling locations failing to yield kelp (Figure 36). All kelp collected was sugar kelp except for one blade of bull kelp. There was significantly more kelp biomass at the control (median = 281.1 g, IQR = 614.8 g) than at the dock (median = 199.6 g, IQR = 368.4 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 15).

Kelp biomass samples from the dock perimeter totaled 5.6 kg, ranging from 40.1-1001.5 g by sample with all 100% of sampling locations yielding kelp. At the core, biomass totaled 1.9 kg, ranging from 0-357.2 g by sample with 47% of sampling locations yielding no kelp. There was significantly more kelp biomass in the dock perimeter (median = 383.7 g, IQR = 307.0 g) than in the core (median = 33.9 g, IQR = 196.1 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 16).

There was a significant difference in kelp biomass weight between the control (median = 282.0 g, IQR = 614.2 g), the dock perimeter (median = 383.7 g, IQR = 307 g) and the dock core (median = 33.9 g, IQR = 196.1 g) (Kruskal-Wallis, $p < 0.05$). Comparison of mean ranks revealed that the control and perimeter were a homogenous group and were distinct from the core (comparison of mean ranks, $p < 0.05$) (Figure 37, Table 17).

Relative Depth Comparisons.

Control. Biomass from the deep area during early summer at Cornet Bay control totaled 10.2 kg, ranging from 84.2-1877.4 g by sample with 100% of sampling locations yielding kelp. During late summer, biomass totaled 11.4 kg, ranging from 0-3.9 kg by sample with only one of 15 locations failing to yield kelp. In the shallow area of the control, biomass totaled 5.5 kg, ranging from 0-1.5 kg by sample, with only 6% of sampling locations failing to yield kelp during early summer. For late summer, biomass in the shallow area totaled 5.7 kg, ranging from 80.6-1083.2 g by sample with 100% of locations yielding kelp.

During early summer, there was significantly more kelp biomass in the deep area (median = 663.0 g, IQR = 796.5) than in the shallow area (median = 170.8 g, IQR = 368.0 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 12). However, there were no significant differences in kelp biomass between early and late summer for either water depth (Mann-Whitney U, *p* > 0.05) (Figure 37, Table 18).

Table 18. *Differences in control and dock kelp biomass weight [median (IQR)] between early and late summer by total area and relative water depths.*

Site	Control (g)				Site	Dock (g)			
	Early	n	Late	n		Early	n	Late	n
Bowman Bay					Bowman Bay				
Total	<Null>	n/a	540.3 (934.4)	30	Total	0 (0)	30	0 (0)	30
Deep	<Null>	n/a	1150.4 (790.1)	15	Deep	0 (0)	12	0 (0)	14
Shallow	<Null>	n/a	366.2 (454.9)	15	Shallow	0 (0)	18	0 (0)	16
Cornet Bay					Cornet Bay				
Total	304.4 (676.2)	30	282.1 (614.8)	30	Total	62 (260.6)	30	199.6 (368.4)	30
Deep	663.0 (796.5)	15	274.8 (904.8)	15	Deep	181.6 (365.8)	19	311.7 (289.7)	20
Shallow	170.8 (368.0)	15	289.3 (362.9)	15	Shallow	0 (12.9)	11	20.1 (100.9)	10
Camano Island					Camano Island				
Total	565.9 (1286.5)	30	459.1 (685.7)	30	Total	0 (39.6)	30	<Null>	n/a
Deep	480.6 (657.5)	13	756.0 (736.0)	15	Deep	480.6 (657.5)	16	<Null>	n/a
Shallow*	792.8 (1612.7)	17	288.4 (602.0)	15	Shallow	792.8 (1612.7)	14	<Null>	n/a

** = significant difference (Mann-Whitney U, p < 0.05).*

Dock. Kelp biomass in the deep area of the dock from early summer totaled 5.2 kg, ranging from 0-856.3 g by sample with only 10% of sampling locations failing to yield kelp. During late summer, biomass totaled 6.7 kg in the deep area, ranging from 0-1001.5 g by sample with 15% of sampling locations failing to yield kelp. In the shallow area, for early summer, biomass totaled only 280 g, ranging from 0-208.4 g by sample with 73% of sampling locations failing to yield kelp. During late summer, biomass in the shallow area totaled 833.3 g, ranging from 0-397.2 g with half of the sampling locations yielding kelp.

For both visits to Cornet Bay dock, there was significantly more kelp biomass in the deep area (early median = 181.6 g IQR = 365.8 g; late median = 311.7g, IQR = 289.7 g) than the shallow area (early median = 0 g, IQR = 12.9 g; late median = 0 g, IQR = 100.9 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 12). However, there were no significant differences in kelp biomass between early and late summer for either water depth (Mann-Whitney U, $p > 0.05$) (Figure 37, Table 18).

Dock perimeter. During early summer, kelp biomass in the deep area of the dock perimeter totaled 4.9 kg, ranging from 30.9-856.3 g by sample with 100% of sampling locations yielding kelp. For late summer, the deep area of the perimeter again had 4.9 kg of kelp in total, which ranged from 257-1001.5 g by sample, with 100% of sampling locations yielding kelp. For early summer in the shallow area of the dock, kelp biomass totaled 280.0 g, ranging from 0-144.1g by sample which increased to 728.1 g for late summer, ranging from 40.1-397.2 g by sample with 100% of sampling locations yielding kelp.

For both early and late summer, there was significantly more kelp biomass in the deep area (early median = 277.2 g, IQR = 347.3 g; late median = 504.8 g, IQR = 261.4 g) than in the shallow area (early median = 0 g, IQR = 30.8 g; late median = 145.4 g, IQR = 175.7 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 19).

Table 19. *Differences in dock core and perimeter kelp biomass weight [median (IQR)] between relative water depths, early and late summer, 2017.*

	Dock Core (g)					Dock Perimeter (g)			
Site	Deep	n	Shallow	n	Site	Deep	n	Shallow	n
Bowman Bay					Bowman Bay				
Early	0 (0)	8	0 (0)	10	Early	0 (0)	4	0 (0)	8
Late	0 (0)	7	0 (0)	7	Late	0 (0)	7	0 (0)	9
Cornet Bay					Cornet Bay				
Early	70.2 (99.9)	5	0 (0)	3	Early*	277.2 (347.3)	14	0 (30.8)	8
Late*	124.9 (294.7)	11	0 (0)	6	Late*	504.8 (261.4)	9	145.4 (175.7)	4
Camano Island					Camano Island				
Early	0 (0)	4	0 (0)	4	Early*	0 (4.5)	10	57 (67.3)	12
Late	<Null>	n/a	<Null>	n/a	Late	<Null>	n/a	<Null>	n/a

** = significant difference (Mann-Whitney U, $p < 0.05$).*

There was significantly more kelp biomass present in the shallow area of Cornet Bay dock during late summer (median = 145.4 g, IQR = 175.7 g) than there was during early summer (median = 0 g, IQR = 30.8 g) (Mann-Whitney U, $p > 0.05$) (Figure 37, Table 20).

Table 20. *Differences in dock core and perimeter kelp biomass weight [median (IQR)] between early and late summer by relative water depths.*

	Dock Core (g)					Dock Perimeter (g)			
Site	Early	n	Late	n	Site	Early	n	Late	n
Bowman Bay					Bowman Bay				
Deep	0 (0)	8	0 (0)	7	Deep	0 (0)	4	0 (0)	7
Shallow	0 (0)	10	0 (0)	7	Shallow	0 (0)	8	0 (0)	9
Cornet Bay					Cornet Bay				
Deep	70.2 (99.9)	5	124.9 (294.7)	11	Deep	277.2 (347.3)	14	504.8 (261.4)	9
Shallow	0 (0)	3	0 (0)	6	Shallow*	0 (30.8)	8	145.4 (175.7)	4
Camano Island					Camano Island				
Deep	0 (0)	4	<Null>	n/a	Deep	0 (4.5)	12	<Null>	n/a
Shallow	0 (0)	4	<Null>	n/a	Shallow	57 (67.3)	10	<Null>	n/a

** = significant difference (Mann-Whitney U, $p < 0.05$).*

Dock core. During early summer, there was 282.7 g of kelp biomass, ranging from 0-112.6 g by sample, with 60% of sampling locations yielding kelp from the deep area of the dock core. For late summer, the same area yielded 1.8 kg of kelp, ranging from 0-357.2 g by sample, with 81% of sampling locations yielding kelp. In the shallow area of the dock core, for early summer, there was no kelp collected from three attempted sampling locations while in late summer only one sample, weighing 105.2 g was retrieved: 17% of sampling attempts.

At the dock core, there was significantly more kelp in the deep area (median = 124.9 g, IQR = 294.7g) than in the shallow area (median = 0 g, IQR = 0 g) only during late summer (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 19). There were no significant differences in kelp biomass found between early and late summer at Cornet Bay dock core (Mann-Whitney U, $p > 0.05$) (Figure 37, Table 20).

For early summer at Cornet Bay dock, the perimeter had significantly more kelp biomass than the core for the deep area (perimeter median = 277.2 g, IAR = 347.3 g; core median = 70.2 g, IQR = 99.9 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 16). During late summer at Cornet Bay dock, both the deep and shallow areas had significantly more kelp biomass in the perimeter (deep median = 504.8 g, IQR = 261.4 g; shallow median = 145.4 g, IQR = 175.7 g) than in the core (deep median = 124.9 g, IQR = 294.7 g; shallow median = 0 g, IQR = 0 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 16). There was also significantly more kelp biomass found in the shallow area of the dock perimeter during late summer (median = 145.4 g, IQR = 175.7 g) than during early summer (median = 0 g, IQR = 30.8 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 20).

Each biomass sample was correlated with the water depth at that sample location. During early summer, kelp biomass showed a moderate negative correlation with water depth for the total area of the control (-0.4256 r_s) (Spearman rank, $p < 0.05$) (Table 11). At the dock, kelp biomass showed a strong negative correlation with water depth for the total area (-0.6344 r_s) and for the dock perimeter (-0.7069 r_s), while there was a very strong negative correlation between kelp biomass and water depth for the total area of the dock core (-0.8456 r_s) (Spearman rank, $p < 0.05$) (Table 11). During late summer, kelp biomass showed a moderate negative relationship with water depth for the total area of the dock (-0.66 r_s), the deep area of the dock (-0.512 r_s), the total area of the dock perimeter (-0.6593 r_s), and the total area of the dock core (-0.6288 r_s) (Spearman rank, $p < 0.05$) (Table 13).

Kelp Blade Morphometrics. The average length of kelp blades collected from Cornet Bay control was 140.6 cm with an average blade width of 29.5 cm from 40 stipes counted from 5 samples making the average density 32 stipes per m^{-2}. The average length of kelp blades collected from Cornet Bay dock was 117.4 cm with an average width of 22.9 cm with a total of 25 stipes counted from 5 samples making the average density 20 stipes per m^{-2}. Kelp blades were significantly longer and wider at Cornet Bay control (length median = 148.5 cm, IQR = 93.0 cm; width median = 28.0 cm, IQR = 15.5 cm) than at Cornet Bay dock (length median = 113.0 cm, IQR = 82.0 cm; width median = 22.0 cm, IQR = 10.0 cm) (Mann-Whitney U, $p < 0.05$) (Figure 38, Table 14).

Camano Island

Total Area Comparisons.

Early summer. Kelp was abundant at Camano Island control totaling 24.8 kg, ranging from 0-2.6 kg by sample, with only 7% of sampling locations not yielding any kelp (Figure 35). Many of the samples were multiple stipes attached to a single large cobble. All kelp collected was sugar kelp. Biomass samples from Camano Island dock totaled 661.7 g, ranging from 0-144.1 g by sample, with only 33% of sampling locations yielding kelp (Figure 35). Because there was nearly no kelp present at the dock, as noted in the video survey, the biomass sampling grid was altered to include more samples from the perimeter where more kelp was present. However, there was still significantly more kelp biomass at the control (median = 565.9 g, IQR = 1,286.5 g) than at the dock (median = 0 g, IQR = 39.6 g) (Mann-Whitney U, $p < 0.05$) (Figure 35, Table 15).

All kelp sampled during early summer was retrieved from the dock perimeter: 661.7 g in total, ranging from 0-144.1 g by sample, from 45% of the sampling locations (Figure 35). No kelp was sampled from the dock core despite 16 attempts, in total, from eight sampling locations.

Late summer. Kelp biomass totaled 17.1 kg at the control, ranging from 0-1,575.1 g by sample, with only 13% failing to yield kelp (Figure 36). All sampled kelp was sugar kelp in thick coverage with several stipes commonly attached to a single cobble. At the dock, from 30 sampling locations, the kelp was often single, loose, and obviously senesced blades. As explained in the late summer Camano Island kelp cover results section, the large amount of kelp detritus made biomass results from Camano Island dock highly suspect as well and, as such, were discarded.

Relative Depth Comparisons.

Control. Kelp biomass during early summer from the deep area of the control totaled 6.9 kg, ranging from 0-1480.5 g by sample, with only 15% of sampling locations failing to yield kelp. During late summer, biomass totaled 11.0 kg in the deep area, ranging from 185.4-1575.1 g by sample with kelp being collected from 100% of sampling locations.

During early summer, biomass in the shallow area totaled 17.9 kg, ranging from 47.5-2600.6 g by sample, with kelp being retrieved from 100% of sampling locations, while a total of 6.1 kg biomass was sampled during late summer, ranging from 0-1494.7 g by sample, with 27% of sampling locations failing to yield kelp. There were no significant differences in kelp biomass between deep and shallow areas for either visit to Camano Island control (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 12). However, there was significantly more kelp biomass in the shallow area during early summer (median = 792.8 g, IQR = 1612.7 g) than late summer (median = 288.4 g, IQR = 602.0 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 18).

Dock. At the deep area of the dock, during early summer, kelp biomass totaled 132.0 g, ranging from 0-72.9 g by sample, with only 19% of sampling locations yielding kelp. In the shallow area, biomass totaled 529.7 g, ranging from 0-144.1 g by sample with half of the sampling locations failing to yield kelp. For early summer, at Camano Island dock, there was significantly less kelp biomass in the deep area (median = 0 g, IQR = 0

g) than in the shallow area (median = 17.8 g, IQR = 66.0 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 12).

Dock perimeter. At the deep area of the dock perimeter, during early summer, kelp biomass totaled 132.0 g, ranging from 0-72.9 g by sample with 75% of sampling locations failing to yield kelp. In the shallow area, biomass totaled 529.7 g, ranging from 0-144.1 g by sample with only 30% of sampling locations failing to yield kelp. For early summer there was significantly less kelp biomass in the deep area (median = 0 g, IQR = 4.5 g) than in the shallow area (median = 57 g, IQR = 67.3 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 9).

Dock core. No kelp biomass samples were collected from the dock core during early summer from four sampling locations in the deep, and four in the shallow areas. There was significantly more kelp biomass, during early summer, at the shallow area of the dock perimeter (median = 57.0 g, IQR = 67.3 g) than at the shallow area of the dock core (median = 0 g, IQR = 0 g) (Mann-Whitney U, $p < 0.05$) (Figure 37, Table 16).

Each biomass sample was correlated with the water depth at that sample location. The only significant correlation found between kelp biomass and water depth at Camano Island for either visit was a moderate negative relationship with the total area of the dock perimeter during early summer (-0.4298 r_s) (Spearman rank, $p < 0.05$) (Table 11).

Kelp Blade Morphometrics. The average blade length of kelp sampled from Camano Island control was 128.1 cm with an average blade width of 21.2 cm from 27 stipes counted from 5 samples making the average density 22 stipes per m^2 (Figure 38, Table 14). Morphometric measurements were taken during the late summer visit to all sites and, as such, all measurements from Camano Island dock were discarded due to the overabundant detritus as a result of senescing kelp.

Dry-weight to Wet-weight Kelp Carbon Content Ratio

During late summer, five random biomass samples were retained from each control and dock site for calculating a dry-weight to wet-weight carbon content ratio. These samples were weighed, dried for 24 hr at 60 °C, and then reweighed. No samples were retrieved from Bowman Bay dock resulting in 25 samples being used to calculate the averaged dry-weight to wet-weight kelp carbon content ratio. The averaged ratio from all samples combined was 0.14:1.

Total kelp biomass weight per m^{-2} was calculated for all dock (12.2 g/m^{-2} on average) and control sites (87.5 g/m^{-2} on average) which was then multiplied by the total area of each site. These total weights were then averaged by control and dock sites, resulting in an aggregated kelp biomass weight for the total area examined for all sites combined. Similarly, kelp cover was averaged for all control (17.0%) and dock sites (84.5%), respectively. This results in an estimated average of 79.9% less kelp cover at docks in the Sound than comparable sites nearby without docks.

Light Attenuation

Bowman Bay

Early Summer. Synchronous PAR readings on all sensors began July 11th, 2017, at 18:40 and were logged every 2 min until 18:10 on July 12th, 2017 totaling 16.8 hr of readings during daylight. The tide during this time approximately ranged from 5.5 ft to

14.1 ft above the benthic sensors. Because no kelp was found in the control, PAR data, like kelp cover and biomass data, was discarded. Full incoming PAR above water totaled 59.32 mol m^{-2} during daylight, with benthic sensors around the dock recording between 4.8% (north core) and 26.6% (east perimeter) of this total while the sensor floating 1 m from surface beneath the dock recorded only 2.8% of total incoming PAR (Figure 39, Table 21).

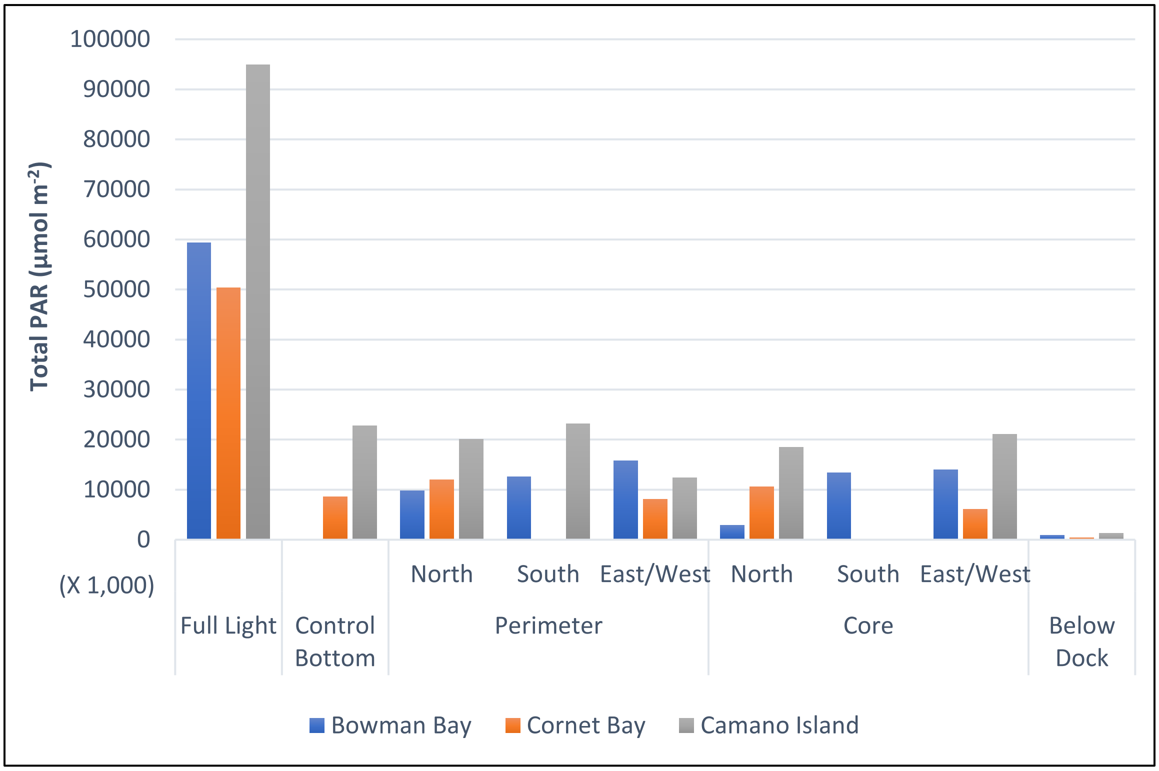


Figure 39. *Total PAR (µmol m^{-2}) by location as recorded over synchronous time periods varying by study site, early summer, 2017.*

Table 21. *PAR sensor depths (MLLW, ft), average PAR per hr (µmol m^{-2} hr^{-1}), percentage of total PAR recorded above water, and light extinction coefficient (ft^{-1}) by location and cardinal direction in relation to dock, early and late summer, 2017.*

			Core (2.5 m from dock)			Perimeter (7.5 m from dock)			
Site – Early	Hr/ Sun Angle	Under Dock	N	S	E/W	N	S	E/W	Control Bottom
Bowman Bay	16.8 / 63°								
Depth		n/a	-10.9	-10.1	-9.0	-10.8	-9.7	-8.1	n/a
PAR/hr		98,280	169,226	793,832	829,589	582,804	748,267	940,394	n/a
% of Total		2.8	4.8	22.5	23.5	16.5	21.2	26.6	n/a
Coefficient		0.66	0.32	0.19	0.23	0.20	0.20	0.23	n/a
Cornet Bay	25 / 61°								
Depth		n/a	-5.9	<Null>	-7.8	-4.6	<Null>	-8.1	-9.4
PAR/hr		21,476	235,559	<Null>	148,794	287,094	<Null>	176,741	293,010
% of Total		0.7	11.7	<Null>	7.4	14.25	<Null>	8.8	14.54
Coefficient		1.65	0.24	<Null>	0.23	0.28	<Null>	0.20	0.15
Camano Island	28.5 / 58°								
Depth		n/a	-4.9	<Null>	-6.7	-5.7	-5.4	-8.0	-4.96
PAR/hr		45,996	650,031	<Null>	741,147	704,287	812,675	435,114	797,555
% of Total		1.4	19.5	<Null>	22.2	21.1	24.4	13.1	23.9
Coefficient		1.65	0.29	<Null>	0.21	0.24	0.23	0.23	0.25
Site – Late									
Bowman Bay	24.5 / 53°								
Depth		n/a	-11.2	-10.1	-9.0	-10.9	-9.7	-8.2	-9.2
PAR/hr		68,160	74,844	183,932	217,274	96,050	239,512	228,223	305,726
% of Total		3.1	3.4	8.3	9.8	4.3	10.8	10.3	13.8
Coefficient		0.99	0.28	0.24	0.25	0.27	0.23	0.26	0.21
Cornet Bay	26 / 48°								
Depth		n/a	-5.6	-5.7	-7	-5.4	-5.4	-7.7	-6.7
PAR/hr		11,278	122,870	138,025	99,922	146,954	243,000	102,129	211,042
% of Total		-0.9	10.1	11.3	8.2	12.0	19.9	8.4	17.3
Coefficient		1.4	0.28	0.26	0.25	0.26	0.20	0.24	0.19
Camano Island	21 / 43°								
Depth		n/a	-5.5	-5.9	-6.7	-5.7	-5.4	-8.0	-6.0
PAR/hr		24,058	276,777	224,244	218,709	338,165	258,904	162,201	328,687
% of Total		1.2	14.4	11.6	11.4	17.6	13.4	8.4	17.1
Coefficient		1.34	0.22	0.23	0.20	0.18	0.23	0.22	0.18

Hr column is total hr of PAR readings for each site. Sun angle is reported at solar noon.

As expected, the highest PAR readings recorded by benthic sensors was when the tide was at the lowest combined with when the sun was at its highest position, i.e. lower low water coinciding with solar noon (Figure 40). However, the converse was not decidedly true. Instead, the lowest PAR readings were generally recorded when the tide was switching from high slack into ebb or from low slack into flood, regardless of the sun angle (Figure 40).

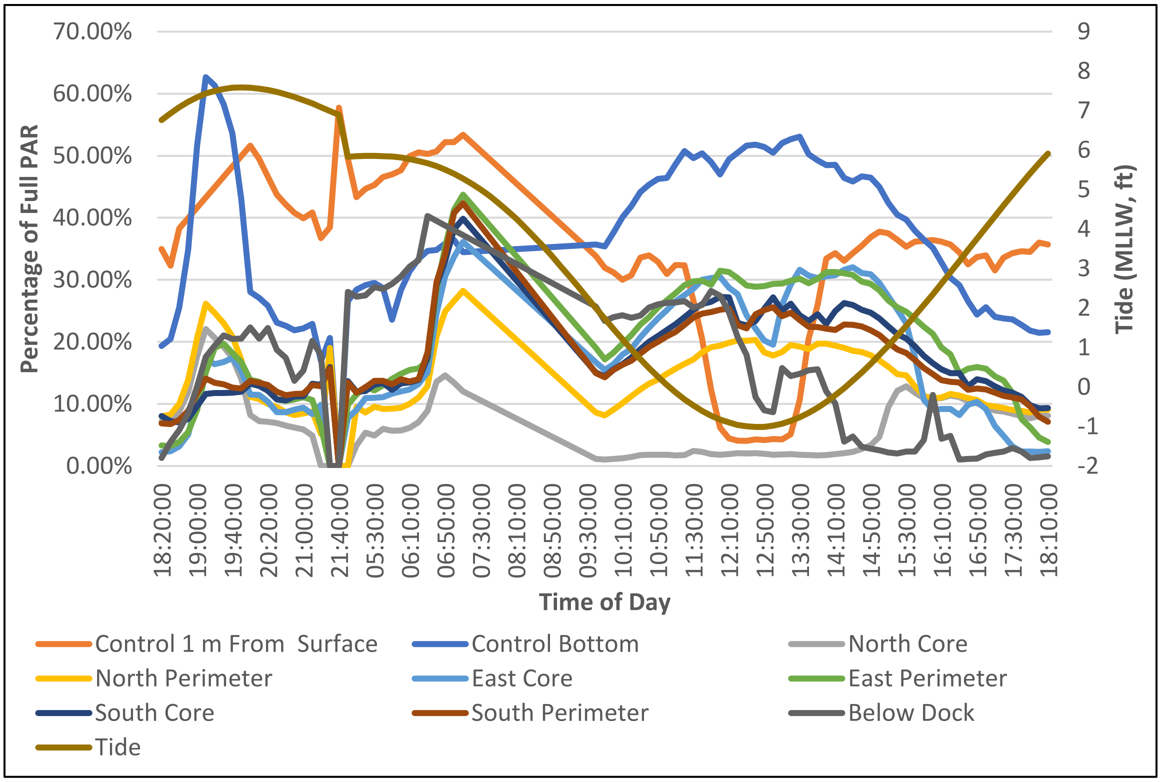


Figure 40. *Submerged PAR sensor readings (% of full PAR above water) and tide level (MLLW, ft) at Bowman Bay, early summer, 2017.*

Extinction coefficients ranged from a minimum 0.19 ft^{-1} in the south core to a maximum of 0.32 ft^{-1} in the north core for the benthic sensors while the sensor floating 1 m from surface beneath the dock had an extinction coefficient of 0.66 ft^{-1} (Figure 41, Table 21). Extinction coefficients calculated from benthic sensors followed a similar but opposite trend as PAR readings. In general, they were the highest at ebb tide, steadily decreased through ebb and were at the lowest during low slack tide when they again began to increase through flood tide (Figure 42).

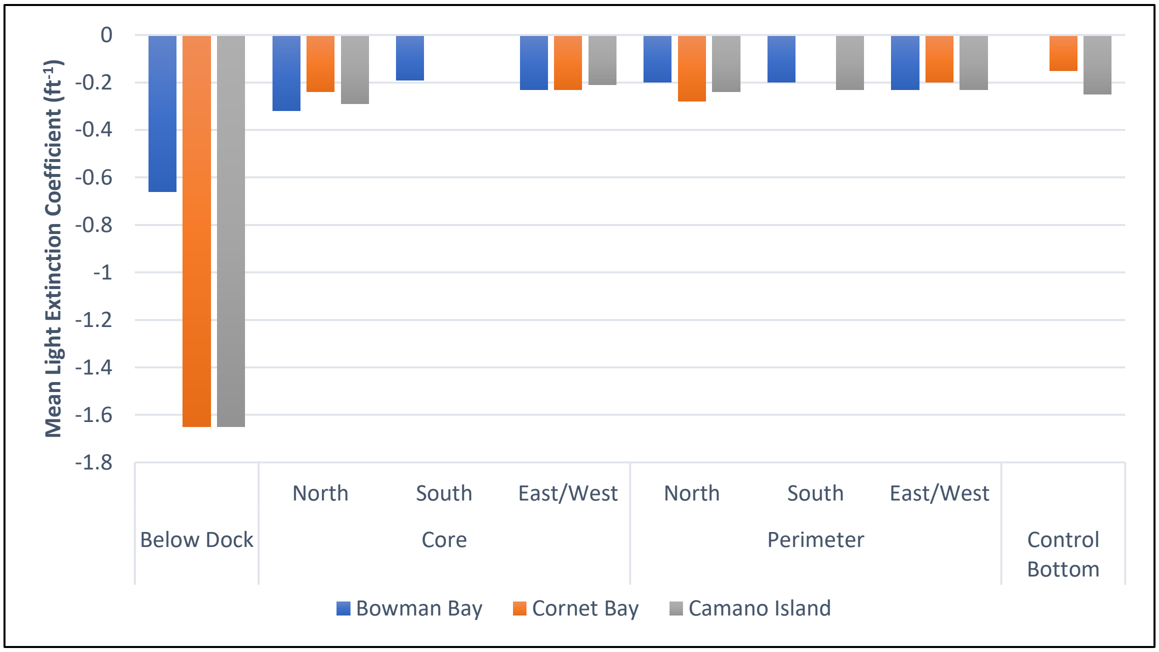


Figure 41. *Mean light extinction coefficients (ft^{-1}) by location, early summer, 2017.*

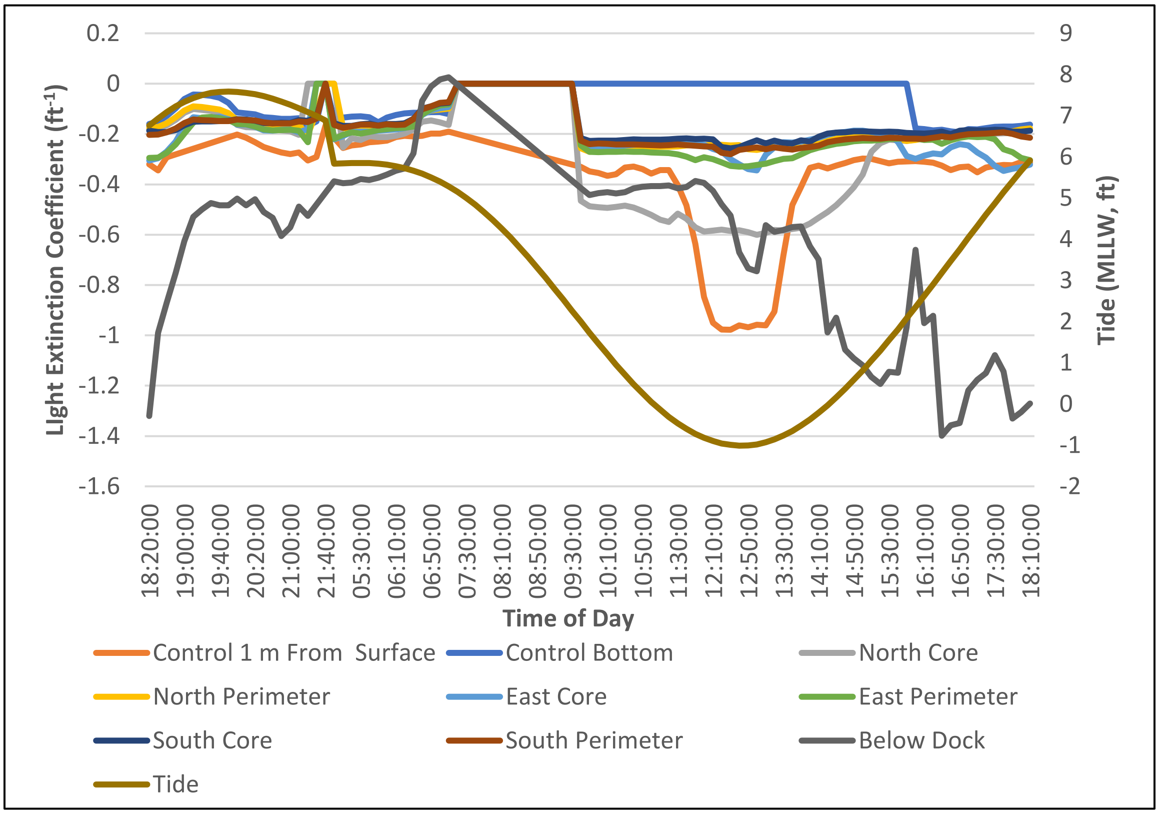


Figure 42. *Light extinction coefficients (ft^{-1}) and tide level (MLLW, ft) at Bowman Bay, early summer, 2017.*

There was significantly more PAR recorded by benthic sensors in 10 min intervals in the dock perimeter than in the dock core for the north (perimeter mean = 174.6 µmol m^{-2} s^{-1}, STD =166.0 µmol m^{-2} s^{-1}; core mean = 52.2 µmol m^{-2} s^{-1}, STD = 60.3 µmol m^{-2} s^{-1}) and east sensors (perimeter mean = 279.0 µmol m^{-2} s^{-1}, STD = 273.5 µmol m^{-2} s^{-1}; core mean = 246.7 µmol m^{-2} s^{-1}, STD = 265.8 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 39, Table 22). However, there was significantly more PAR recorded by the benthic sensors in the dock core than in the dock perimeter for the south sensors (core mean = 236.2 µmol m^{-2} s^{-1}, STD = 225.2 µmol m^{-2} s^{-1}; perimeter mean = 221.3 µmol m^{-2} s^{-1}, STD = 210.9 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 39, Table 22).

Table 22. *Differences between core and perimeter PAR readings (µmol m^{-2} s^{-1}) [mean (STD)] at 10-min intervals by aspect of dock, early and late summer, 2017.*

	North			South			East/West	
Site – Early	Core	Perimeter	Site	Core	Perimeter	Site	Core	Perimeter
Bowman Bay*	52.2 (60.3)	174.6 (166.0)	BB*	236.2 (225.2)	221.3 (210.9)	BB*	246.7 (265.8)	279.0 (273.5)
Cornet Bay*	67.3 (93.1)	83.1 (107.9)	CB	<Null>	<Null>	CB*	43.1 (53.4)	52.1 (68.5)
Camano Island*	178.5 (240.1)	193.4 (245.7)	CI	<Null>	223.1 (294.8)	CI*	203.5 (283.0)	119.5 (214.6)
Site – Late								
Bowman Bay*	21.1 (23.4)	27.2 (31.5)	BB*	51.7 (70.1)	67.4 (86.2)	BB*	61.0 (78.1)	64.1 (78.7)
Cornet Bay*	33.9 (37.6)	40.6 (38.3)	CB*	38.1 (36.7)	67.1 (65.5)	CB	27.6 (27.6)	28.2 (27.6)
Camano Island*	75.7 (97.1)	92.5 (112.6)	CI*	61.3 (76.3)	70.8 (90.1)	CI*	60.0 (73.8)	44.4 (55.7)

** = significant difference (paired t test, p < 0.05).*

Additionally, there was significantly more PAR recorded by the south sensors than the north sensors for both the dock perimeter (south mean = 207.4 µmol m^{-2} s^{-1}, STD = 199.5 µmol m^{-2} s^{-1}; north mean = 161.6 µmol m^{-2} s^{-1}, STD = 157.7 µmol m^{-2} s^{-1}) and the dock core (south mean = 220.1 µmol m^{-2} s^{-1}, STD = 213.5 µmol m^{-2} s^{-1}; north mean = 46.9 µmol m^{-2} s^{-1}, STD = 57.5 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 39, Table 23).

Table 23. *Differences in dock core and perimeter PAR readings (µmol m^{-2} s^{-1}) [mean (STD)] at 10 min intervals between north and south sides of the dock, early and late summer, 2017.*

	Core (2.5 m from dock)			Perimeter (7.5 m from dock)	
Site - Early	North	South	Site - Early	North	South
Bowman Bay*	46.9 (57.5)	220.1 (213.5)	Bowman Bay*	161.6 (157.7)	207.4 (199.5)
Cornet Bay	113.6 (158.3)	<Null>	Cornet Bay	129.0 (163.5)	<Null>
Camano Island	178.5 (240.0)	<Null>	Camano Island*	193.4 (245.7)	223.1 (294.8)
Site - Late			Site - Late		
Bowman Bay*	26.6 (22.4)	50.1 (68.9)	Bowman Bay*	26.2 (31.1)	65.2 (84.8)
Cornet Bay*	33.3 (37.6)	37.4 (36.7)	Cornet Bay*	39.8 (37.3)	65.8 (65.5)
Camano Island*	75.7 (97.0)	61.3 (76.4)	Camano Island*	92.5 (112.6)	70.8 (90.1)

** = significant difference (paired t test, $p < 0.05$).*

Differences between extinction coefficients revealed varied results as compared to PAR readings. On the south side of the dock, the perimeter had slightly but significantly greater light extinction than the dock core (perimeter mean = 0.20 ft^{-1}, STD = 0.05 ft^{-1}; core mean = 0.19 ft^{-1}, STD = 0.04 ft^{-1}), but the north side showed the opposite with the core having significantly greater light extinction than the perimeter (core mean = 0.32 ft^{-1}, STD = 0.18 ft^{-1}; perimeter mean = 0.20 ft^{-1}, STD = 0.05 ft^{-1}) (paired t test, $p < 0.05$) (Figure 42, Table 24). The north side of the dock had significantly greater light extinction than the south side of the dock for the core only (north mean = 0.32 ft^{-1}, STD = 0.18 ft^{-1}; south mean = 0.19 ft^{-1}, STD = 0.04 ft^{-1}) (paired t test, $p < 0.05$) (Figure 42, Table 25).

Table 24. *Differences between core and perimeter light extinction coefficients (ft^{-1}) [mean (STD)] by aspect of dock, early and late summer, 2017.*

	North			South			East/West	
Site – Early	Core	Perimeter	Site	Core	Perimeter	Site	Core	Perimeter
Bowman Bay*	0.32 (0.18)	0.20 (0.05)	BB*	0.19 (0.04)	0.20 (0.05)	BB	0.23 (0.06)	0.23 (0.06)
Cornet Bay*	0.24 (0.10)	0.28 (0.19)	CB	<Null>	<Null>	CB*	0.23 (0.07)	0.20 (0.05)
Camano Island*	0.29 (0.13)	0.24 (0.07)	CI	<Null>	0.23 (0.07)	CI*	0.21 (0.04)	0.23 (0.06)
Site – Late								
Bowman Bay	0.28 (0.11)	0.27 (0.13)	BB*	0.24 (0.08)	0.23 (0.08)	BB*	0.25 (0.07)	0.26 (0.07)
Cornet Bay*	0.28 (0.12)	0.26 (0.09)	CB*	0.26 (0.07)	0.20 (0.05)	CB*	0.25 (0.07)	0.24 (0.05)
Camano Island*	0.22 (0.03)	0.18 (0.03)	CI	0.23 (0.05)	0.23 (0.05)	CI*	0.20 (0.03)	0.22 (0.05)

** = significant difference (paired t test, $p < 0.05$).*

Table 25. *Differences in dock core and perimeter light extinction coefficients (ft^{-1}) [mean (STD)] between north and south sides of the dock, early and late summer, 2017.*

	Core (2.5 m from dock)			Perimeter (7.5 m from dock)	
Site - Early	North	South	Site - Early	North	South
Bowman Bay*	0.32 (0.18)	0.19 (0.04)	Bowman Bay	0.20 (0.05)	0.19 (0.05)
Cornet Bay	0.24 (0.10)	<Null>	Cornet Bay	0.28 (0.19)	<Null>
Camano Island	0.30 (0.12)	<Null>	Camano Island	0.24 (0.07)	0.23 (0.07)
Site – Late			Site – Late		
Bowman Bay*	0.28 (0.11)	0.24 (0.08)	Bowman Bay*	0.27 (0.13)	0.23 (0.08)
Cornet Bay*	0.28 (0.12)	0.26 (0.07)	Cornet Bay*	0.26 (0.09)	0.20 (0.05)
Camano Island	0.22 (0.03)	0.23 (0.04)	Camano Island*	0.18 (0.03)	0.23 (0.05)

** = significant difference (paired t test, $p < 0.05$).*

Late Summer. Synchronous PAR readings on all sensors began August 22nd, 2017, at 16:10 and were logged every 2 min until 11:40 on August 24th, 2017 totaling 24.5 hr of readings during daylight. The tide during this time frame approximately ranged from 8.1 ft to 15.9 ft above the benthic sensors. Full incoming PAR above water totaled

54.20 mol m^{-2} during daylight with benthic sensors at the dock recording between 3.4% (north core) and 10.8% (south perimeter) of this total while the benthic control sensor recorded 13.8% of total PAR above water (Figure 43, Table 21). The sensor floating beneath the dock at 1 m from surface recorded only 3.1% of total incoming PAR. Similar to early summer at Bowman Bay, the highest PAR readings recorded by benthic sensors was when the tide was at the lowest combined with when the sun was at its highest (Appendix A). In general, all benthic sensors recorded very low percentages of comparable full incoming PAR. The PAR readings declined steadily through flood tide and were at a minimum just before high slack tide when there was a slight peak in most of the sensor's readings (Appendix A).

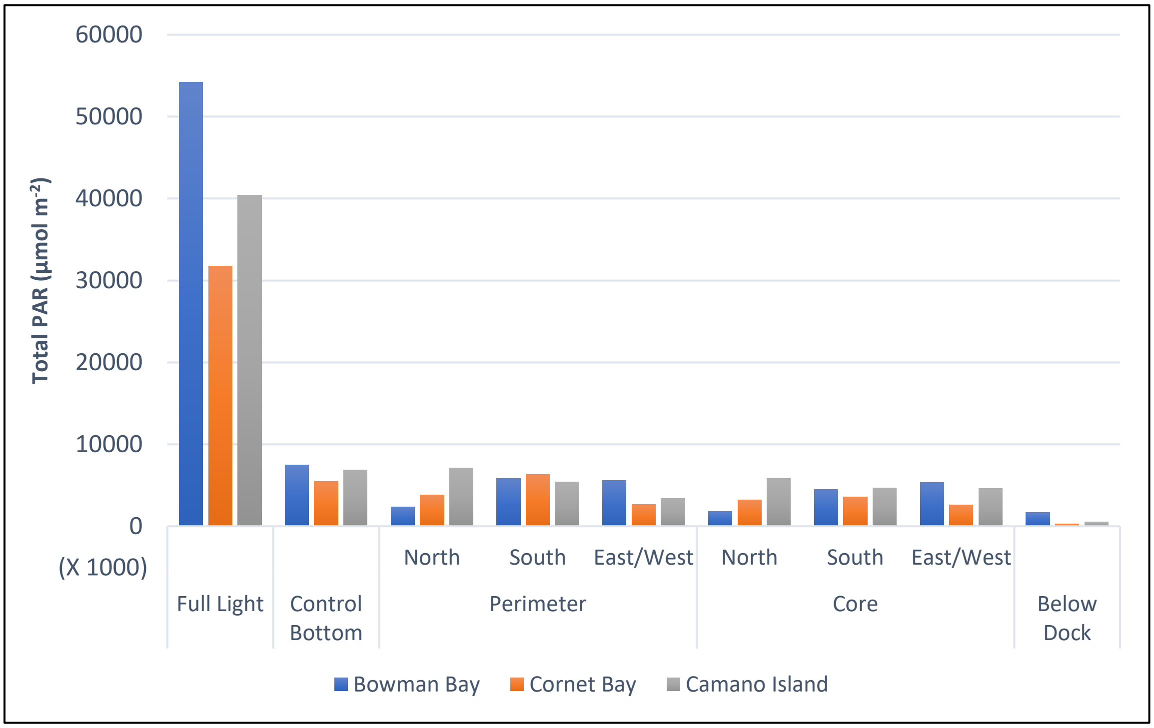


Figure 43. *Total PAR (µmol m^{-2}) by location as recorded over synchronous time periods varying by study site, late summer, 2017.*

The extinction coefficient for the benthic control sensor was 0.21 ft^{-1} while the benthic sensors around the dock ranged from a minimum of 0.23 ft^{-1} in the south perimeter to a maximum of 0.28 ft^{-1} in the north core (Figure 44, Table 21). The sensor floating 1 m from surface beneath the dock had an extinction coefficient of 0.99 ft^{-1} (Figure 44, Table 21). Extinction coefficients followed a nearly identical pattern as early summer calculations with minimums observed at low slack tide, increases throughout flood tide, maximums at high slack tide, and decreases throughout ebb tide (Appendix B).

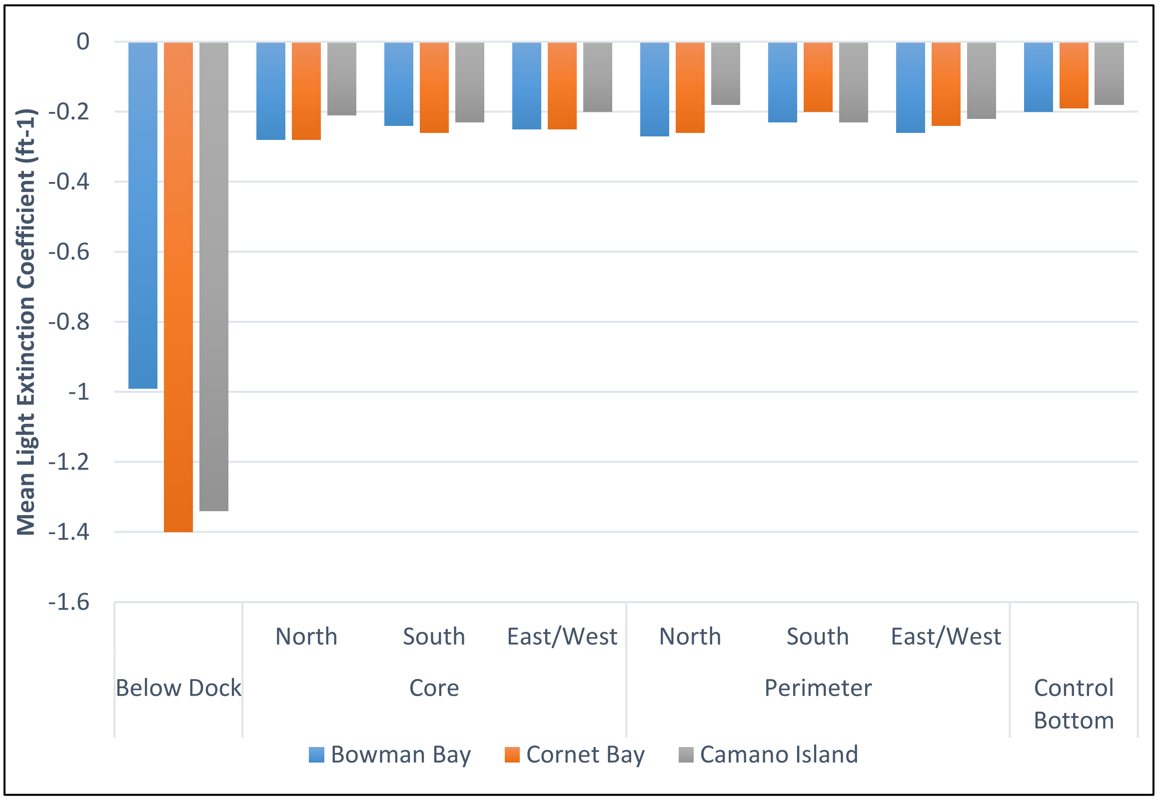


Figure 44. *Mean light extinction coefficients (ft^{-1}) by location, late summer, 2017.*

The benthic PAR sensor at the control (mean = 85.0 µmol m^{-2} s^{-1}, STD = 94.0 µmol m^{-2} s^{-1}) recorded significantly more PAR than the north (mean = 27.5 µmol m^{-2} s^{-1}, STD = 31.5 µmol m^{-2} s^{-1}), south (mean = 67.4 µmol m^{-2} s^{-1}, STD = 86.2 µmol m^{-2} s^{-1}) and east perimeter sensors (mean = 64.1 µmol m^{-2} s^{-1}, STD = 78.7 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 44, Table 26).

Table 26. *Differences in PAR sensor readings (µmol m^{-2} s^{-1}) [mean (STD)] at 10 min intervals between control bottom sensor and each dock perimeter sensor.*

Site – Early	Control Bottom	North Perimeter	Site	Control Bottom	South Perimeter	Site	Control Bottom	East/West Perimeter
Cornet Bay*	84.5 (111.1)	83.1 (107.9)	CB	84.5 (111.1)	<Null>	CB*	84.5 (111.1)	52.1 (68.5)
Camano Island*	219.0 (283.0)	193.4 (245.7)	CI	219.0 (283.0)	223.1 (294.8)	CI*	219.0 (283.0)	119.5 (214.6)
Site – Late								
Bowman Bay*	85.0 (94.0)	27.2 (31.5)	BB*	85.0 (94.0)	67.4 (86.2)	BB*	85.0 (94.0)	64.1 (78.7)
Cornet Bay*	58.2 (59.0)	40.6 (38.3)	CB*	58.2 (59.0)	67.1 (65.5)	CB*	58.2 (59.0)	28.2 (27.6)
Camano Island*	90.0 (112.5)	92.5 (112.6)	CI*	90.0 (112.5)	70.8 (90.1)	CI*	90.0 (112.5)	44.4 (55.7)

** = significant difference (paired t test, $p < 0.05$).*

There was significantly more PAR recorded by benthic sensors in the dock perimeter than in the dock core for the north (perimeter mean = 27.2 µmol m^{-2} s^{-1}, STD = 31.5 µmol m^{-2} s^{-1}; core mean = 21.1 µmol m^{-2} s^{-1}, STD = 23.4 µmol m^{-2} s^{-1}), south (perimeter mean = 67.4 µmol m^{-2} s^{-1}, STD = 86.2 µmol m^{-2} s^{-1}; core mean = 51.7 µmol m^{-2} s^{-1}, STD = 70.1 µmol m^{-2} s^{-1}), and east sensors (perimeter mean = 64.1 µmol m^{-2} s^{-1}, STD = 78.7 µmol m^{-2} s^{-1}; core mean = 61.0 µmol m^{-2} s^{-1}, STD = 78.1 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 44, Table 22). Additionally, there was significantly more PAR recorded by the south sensors than the north sensors for both the dock perimeter (south mean = 65.2 µmol m^{-2} s^{-1}, STD = 84.8 µmol m^{-2} s^{-1}; north mean = 26.2 µmol m^{-2} s^{-1}, STD = 31.1 µmol m^{-2} s^{-1}) and the dock core (south mean = 50.1 µmol m^{-2} s^{-1}, STD = 68.9 µmol m^{-2} s^{-1}; north mean = 26.6 µmol m^{-2} s^{-1}, STD = 22.4 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 44, Table 23).

There was significantly less light extinction at the control (mean = 0.21 ft^{-1}, STD = 0.07 ft^{-1}) than all three perimeter sensors around the dock (north mean = 0.27 ft^{-1}, STD = 0.13 ft^{-1}; south mean = 0.23 ft^{-1}, STD = 0.08 ft^{-1}; east mean = 0.26 ft^{-1}, STD = 0.07 ft^{-1}) (paired t test, $p < 0.05$) (Figure 44, Table 27).

Table 27. *Differences in light extinction coefficients (ft^{-1}) [mean (STD)] between control bottom sensor and each dock perimeter sensor.*

Site – Early	Control Bottom	North Perimeter	Site	Control Bottom	South Perimeter	Site	Control Bottom	East/West Perimeter
Cornet Bay*	0.15 (0.03)	0.28 (0.19)	CB	0.15 (0.03)	<Null>	CB*	0.15 (0.03)	0.20 (0.05)
Camano Island	0.25 (0.08)	0.24 (0.07)	CI*	0.25 (0.08)	0.23 (0.07)	CI*	0.25 (0.08)	0.23 (0.06)
Site – Late								
Bowman Bay*	0.21 (0.07)	0.27 (0.13)	BB*	0.21 (0.07)	0.23 (0.08)	BB*	0.21 (0.07)	0.26 (0.07)
Cornet Bay*	0.19 (0.04)	0.26 (0.09)	CB*	0.19 (0.04)	0.20 (0.05)	CB*	0.19 (0.04)	0.24 (0.05)
Camano Island	0.18 (0.02)	0.18 (0.03)	CI*	0.18 (0.02)	0.23 (0.05)	CI*	0.18 (0.02)	0.22 (0.05)

** = significant difference (paired t test, p < 0.05)*

At the dock, the south core had significantly greater light extinction (mean = 0.24 ft^{-1}, STD = 0.08 ft^{-1}) than the south perimeter (mean = 0.23 ft^{-1}, STD = 0.13 ft^{-1}), while the east perimeter had significantly greater light extinction (mean = 0.26 ft^{-1}, STD = 0.07 ft^{-1}) than the east core (mean = 0.25 ft^{-1}, STD = 0.07 ft^{-1}) (paired t test, $p < 0.05$) (Figure 44, Table 24). Additionally, the north sensors had significantly greater light extinction than the south sensors for both the core (north mean = 0.28 ft^{-1}, STD = 0.11 ft^{-1}; south mean = 0.24 ft^{-1}, STD = 0.08 ft^{-1}) and the perimeter (north mean = 0.27 ft^{-1}, STD = 0.013 ft^{-1}; south mean = 0.23 ft^{-1}, STD = 0.08 ft^{-1} (paired t test, $p < 0.05$) (Figure 44, Table 25).

Cornet Bay

Early Summer. Synchronous PAR readings on all sensors began July 24th, 2017, at 18:10 and were logged every 2 min until 11:10 on July 26th, 2017 totaling 25 hr of readings during daylight. The tide during this time frame ranged approximately from 3.8 ft to 16.7 ft above the benthic sensors. Full incoming PAR above water totaled 50.35 mol m^{-2} during daylight hours, with benthic sensors around the dock recording between 7.4% (west core) and 14.3% (north perimeter) of this total while the benthic control sensor recorded 14.5% of total PAR above water (Figure 39, Table 21). The sensor floating beneath the dock at 1 m from surface recorded only 0.7% of total incoming PAR. The highest PAR readings recorded by benthic sensors was when the tide was at the lowest combined with when the sun was at its highest (Appendix C). There was a lower peak in readings during high slack tide when they again decreased slightly as ebb tide began, increased throughout ebb tide to the maximum readings at low slack tide, and again decreased throughout flood tide (Appendix C).

The extinction coefficient for the benthic control sensor was 0.15 ft^{-1} while the benthic sensors around the dock ranged from a minimum of 0.20 ft^{-1} in the west perimeter to a maximum of 0.28 ft^{-1} in the north perimeter (Figure 41, Table 21). The sensor floating 1 m from surface beneath the dock had an extinction coefficient of 1.65 ft^{-1} (Figure 41, Table 21). Extinction coefficients calculated from benthic sensors again followed a similar but opposite trend as PAR readings. They were the highest as the tide was switching from high slack into ebb tide, steadily decreased through ebb and were at the lowest during low slack tide when they again began to increase through flood tide

(Appendix D). There fewer but still some anomalous patterns in extinction coefficients calculated from the floating sensors as seen in Appendix D.

The benthic PAR sensor at the control (mean = 84.5 µmol m^{-2} s^{-1}, STD = 111.1 µmol m^{-2} s^{-1}) recorded significantly more PAR in 10 min intervals than the north perimeter (mean = 83.1 µmol m^{-2} s^{-1}, STD = 107.9 µmol m^{-2} s^{-1}) and west perimeter sensors (mean = 52.1 µmol m^{-2} s^{-1}, STD = 68.5 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 38, Table 26). The south perimeter sensor experienced a seal failure and the unit was destroyed resulting in no readings for this time frame. Similarly, the south core sensor failed to record at all, so no data was logged. However, there was significantly more PAR recorded in the perimeter than in the core for both the north sensors (perimeter mean = 83.1 µmol m^{-2} s^{-1}, STD = 107.9 µmol m^{-2} s^{-1}; core mean = 67.3 µmol m^{-2} s^{-1}, STD = 93.1 µmol m^{-2} s^{-1}), and the west sensors (perimeter mean = 52.1 µmol m^{-2} s^{-1}, STD = 68.5 µmol m^{-2} s^{-1}; core mean = 43.1 µmol m^{-2} s^{-1}, STD = 53.4 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 39, Table 22).

There was significantly less light extinction at the control (mean = 0.15 ft^{-1}, STD = 0.03 ft^{-1}) than both perimeter sensors at the dock (north mean = 0.28 ft^{-1}, STD = 0.19 ft^{-1}; west mean = 0.20 ft^{-1}, STD = 0.05 ft^{-1}) (paired t test, $p < 0.05$) (Figure 41, Table 27).

At the dock, the north perimeter had significantly greater light extinction (mean = 0.28 ft^{-1}, STD = 0.19 ft^{-1}) than the north core (mean = 0.24 ft^{-1}, STD = 0.10 ft^{-1}), while the west core had significantly greater light extinction (mean = 0.23 ft^{-1}, STD = 0.07 ft^{-1}) than the west perimeter (mean = 0.20 ft^{-1}, STD = 0.05 ft^{-1}) (paired t test, $p < 0.05$) (Figure 41, Table 24).

Late Summer. Synchronous PAR readings on all sensors began September 5th, 2017, at 13:50 and were logged every 2 min until 12:30 on September 7th, 2017 totaling 26 hr of readings during daylight. The tide during this time frame ranged approximately from 5.1 ft to 14.8 ft above the benthic sensors. Full incoming PAR above water totaled 19.06 mol m^{-2} during daylight hours with benthic sensors around the dock reading between 8.2% (west core) and 19.9% (south perimeter) of this total while the benthic control sensor read 17.3% of total PAR above water (Figure 43, Table 21). The sensor floating beneath the dock at 1 m from surface recorded only 0.9% of total incoming PAR. Late summer PAR readings by benthic sensors followed quite consistent patterns throughout their measurements. In general, there was a low peak in readings in the middle of flood tide, then a decrease throughout flood to a minimum at high slack tide followed by another peak in the middle of ebb tide and an increase throughout ebb to the maximum readings at low slack tide (Appendix E).

The extinction coefficient for the benthic control sensor was 0.19 ft^{-1} while the benthic sensors at the dock ranged from a low of 0.20 ft^{-1} in the south perimeter to a high of 0.45 ft^{-1} in the north core and the sensor floating 1 m from surface beneath the dock had an extinction coefficient of 1.40 ft^{-1} (Figure 44, Table 21). Extinction coefficients calculated from benthic sensors followed a nearly identical but opposite trend as PAR readings. They were the highest at high slack tide and decreased steadily through ebb reaching a minimum during low slack tide when they again began to increase through flood tide (Appendix F).

The benthic PAR sensor at the control (mean = 58.2 µmol m^{-2} s^{-1}, STD = 59.0 µmol m^{-2} s^{-1}) recorded significantly more PAR than the north (mean = 40.6 µmol m^{-2} s^{-1}, STD = 38.5 µmol m^{-2} s^{-1}) and east perimeter sensors (mean = 28.2 µmol m^{-2} s^{-1}, STD = 27.6 µmol m^{-2} s^{-1}), but significantly less than the south perimeter sensor (mean = 67.1 µmol m^{-2} s^{-1}, STD = 65.5 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 26).

There was significantly more PAR recorded by benthic sensors in the dock perimeter than in the dock core for the north (perimeter mean = 40.6 µmol m^{-2} s^{-1}, STD = 38.3 µmol m^{-2} s^{-1}; core mean = 33.9 µmol m^{-2} s^{-1}, STD = 37.6 µmol m^{-2} s^{-1}) and south areas (perimeter mean = 67.1 µmol m^{-2} s^{-1}, STD = 65.5 µmol m^{-2} s^{-1}; core mean = 38.1µmol m^{-2} s^{-1}, STD = 36.7 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 22). Additionally, there was significantly more PAR recorded by the south sensors than the north sensors for both the dock perimeter (south mean = 65.8 µmol m^{-2} s^{-1}, STD = 65.5 µmol m^{-2} s^{-1}; north mean = 39.8 µmol m^{-2} s^{-1}, STD = 37.3 µmol m^{-2} s^{-1}) and the dock core (south mean = 37.4 µmol m^{-2} s^{-1}, STD = 36.7 µmol m^{-2} s^{-1}; north mean = 33.3 µmol m^{-2} s^{-1}, STD = 37.6 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 23).

Light extinction was significantly less at the control (mean = 0.19 ft^{-1}, STD = 0.04 ft^{-1}) than all three perimeter sensors at the dock (north mean = 0.26 ft^{-1}, STD = 0.09 ft^{-1}; south mean = 0.20 ft^{-1}, STD = 0.05 ft^{-1}; west mean = 0.24 ft^{-1}, STD = 0.07 ft^{-1}) (paired t test, $p < 0.05$) (Figure 44, Table 27).

At the dock, the core had significantly greater light extinction than the perimeter for all aspects of the dock (north core mean = 0.28 ft^{-1}, STD = 0.12 ft^{-1}; north perimeter mean = 0.26 ft^{-1}, STD = 0.09 ft^{-1}; south core mean = 0.26 ft^{-1}, STD = 0.07 ft^{-1}; south perimeter mean = 0.20 ft^{-1}, STD = 0.05 ft^{-1}; west core mean = 0.25 ft^{-1}, STD = 0.07 ft^{-1};

west perimeter mean = 0.24 ft^{-1}, STD = 0.05 ft^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 24).

Additionally, the north area had significantly greater light extinction than the south area for both the core and perimeter (north core mean = 0.28 ft^{-1}, STD = 0.12 ft^{-1}; south core mean = 0.26 ft^{-1}, STD = 0.07 ft^{-1}; north perimeter mean = 0.26 ft^{-1}, STD = 0.09 ft^{-1}; south perimeter mean = 0.20 ft^{-1}, STD = 0.05 ft^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 25).

Camano Island

Early Summer. Synchronous PAR readings on all sensors began August 7th, 2017, at 15:10 and were logged every 2 min until 13:00 on August 9th, 2017 totaling 28.5 hr of readings during daylight. The tide during this time frame ranged approximately from 3.1 ft to 15.8 ft above the benthic sensors. Full incoming PAR above water totaled 94.96 mol m^{-2} with benthic sensors at the dock recording between 13.1% (west perimeter) and 24.4% (south perimeter) of this total while the benthic control sensor recorded 23.9% of total PAR above water (Figure 39, Table 21). The sensor beneath the dock floating at 1 m from surface recorded only 1.4% of total incoming PAR. The highest PAR readings recorded by benthic sensors was when the tide was at the lowest combined with when the sun was at its highest (Appendix G). The readings were the lowest during high slack tide, then steadily increased throughout ebb tide to the maximum readings at low slack tide, and again decreased throughout flood tide (Appendix G). Data from the south core sensor was corrupted during transfer and lost.

The extinction coefficient for the benthic control sensor was 0.25 ft^{-1} while the benthic sensors around the dock ranged from a minimum of 0.21 ft^{-1} in the west core to a maximum of 0.29 ft^{-1} in the north core (Figure 41, Table 21). The sensor floating 1 m from surface beneath the dock had an extinction coefficient of 1.65 ft^{-1} (Figure 40, Table 21). Extinction coefficients calculated from benthic sensors followed a nearly identical but opposite trend as PAR readings. They were the highest at high slack tide and decreased steadily through ebb reaching a minimum during low slack tide when they again began to increase through flood tide (Appendix H).

The benthic PAR sensor at the control (mean = 219.0 µmol m^{-2} s^{-1}, STD = 283.0 µmol m^{-2} s^{-1}) recorded significantly more PAR than the north sensor (mean = 193.4 µmol m^{-2} s^{-1}, STD = 245.7 µmol m^{-2} s^{-1}) and west perimeter sensor (mean = 119.5 µmol m^{-2} s^{-1}, STD = 214.6 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 39, Table 26). There was significantly more PAR recorded in the north perimeter (mean = 193.4 µmol m^{-2} s^{-1}, STD = 245.7 µmol m^{-2} s^{-1}) than in the north core (mean = 178.5 µmol m^{-2} s^{-1}, STD = 240.1 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 39, Table 22). However, the west core sensor (mean = 203.5 µmol m^{-2} s^{-1}, STD = 283.0 µmol m^{-2} s^{-1}) recorded significantly more PAR than the west perimeter sensor (mean = 119.5 µmol m^{-2} s^{-1}, STD = 214.6 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 39, Table 22).

Surprisingly, light extinction coefficients were significantly greater at the control (mean = 0.25 ft^{-1}, STD = 0.08 ft^{-1}) than the south and west perimeter sensors at the dock (south mean = 0.23 ft^{-1}, STD = 0.07 ft^{-1}; west mean = 0.23 ft^{-1}, STD = 0.06 ft^{-1}) (paired t test, $p < 0.05$) (Figure 41, Table 27).

At the dock, the north core had significantly greater light extinction (mean = 0.29 ft^{-1}, STD = 0.13 ft^{-1}) than the north perimeter (mean = 0.24 ft^{-1}, STD = 0.07 ft^{-1}), while the west perimeter had significantly greater light extinction than the west core (west perimeter mean = 0.23 ft^{-1}, STD = 0.06 ft^{-1}; west core mean = 0.21 ft^{-1}, STD = 0.04 ft^{-1}) (paired t test, $p < 0.05$) (Figure 41, Table 24).

Late Summer. Synchronous PAR readings on all sensors began September 19th, 2017, at 14:10 and were logged every 2 min until 9:20 on September 20th, 2017 totaling 21 hr of readings during daylight. The tide during this time frame ranged approximately from 5.0 ft to 16.2 ft above the benthic sensors. Full incoming PAR above water totaled 24.26 mol m^{-2} during daylight with benthic dock sensors recording between 8.4% (west perimeter) and 17.6% (north perimeter) of this total while the benthic control sensor recorded 17.1% of total PAR above water (Figure 43, Table 21). The sensor beneath the dock floating at 1 m from surface recorded only 1.2% of total incoming PAR. Patterns in late summer PAR readings were nearly identical to early summer readings at Camano Island. The highest PAR readings recorded by benthic sensors was again when the tide was at the lowest combined with when the sun was at its highest (Appendix I). The readings were the lowest during high slack tide, then steadily increased throughout ebb tide to the maximum readings at low slack tide, and again decreased throughout flood tide (Appendix I).

The extinction coefficient for the benthic control sensor was 0.18 ft^{-1} while the benthic sensors around the dock ranged from a minimum of 0.18 ft^{-1} in the north perimeter to a maximum of 0.23 ft^{-1} in the south core and south perimeter (Figure 44, Table 21). The sensor floating 1 m from surface beneath the dock had an extinction coefficient of 1.34 ft^{-1} (Figure 44, Table 21). Extinction coefficients calculated from benthic sensors again followed a nearly identical but opposite trend as PAR readings. They were the highest at high slack tide and decreased steadily through ebb reaching a minimum during low slack tide when they again began to increase through flood tide (Appendix J).

The benthic PAR sensor at the control (mean = 90.0 µmol m^{-2} s^{-1}, STD = 112.5 µmol m^{-2} s^{-1}) recorded significantly more PAR than the south perimeter sensor (mean = 70.8 µmol m^{-2} s^{-1}, STD = 90.1 µmol m^{-2} s^{-1}) and the west perimeter sensor (mean = 44.4 µmol m^{-2} s^{-1}, STD = 55.7 µmol m^{-2} s^{-1}) but significantly less than the north perimeter sensor (mean = 92.5 µmol m^{-2} s^{-1}, STD = 112.6 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 26).

There was significantly more PAR recorded in the dock perimeter than in the dock core for the north side (perimeter mean = 92.5 µmol m^{-2} s^{-1}, STD = 112.6 µmol m^{-2} s^{-1}; core mean = 75.7 µmol m^{-2} s^{-1}, STD = 97.1 µmol m^{-2} s^{-1}) and the south side (perimeter mean = 70.8 µmol m^{-2} s^{-1}, STD = 90.1 µmol m^{-2} s^{-1}; core mean = 61.3 µmol m^{-2} s^{-1}, STD = 76.3 µmol m^{-2} s^{-1}), but significantly less on the west side (perimeter mean = 44.4 µmol m^{-2} s^{-1}, STD = 55.7 µmol m^{-2} s^{-1}; core mean = 61.0 µmol m^{-2} s^{-1}, STD = 78.1 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 22). Additionally, there was significantly more PAR recorded by the north sensors than the south sensors in both the dock perimeter (north mean = 92.5 µmol m^{-2} s^{-1}, STD = 112.6 µmol m^{-2} s^{-1}; south mean = 70.8 µmol m^{-2} s^{-1}, STD = 90.1 µmol m^{-2} s^{-1}) and the dock core (north mean = 75.7 µmol m^{-2} s^{-1}, STD = 97.0 µmol m^{-2} s^{-1}; south mean = 61.3 µmol m^{-2} s^{-1}, STD = 76.4 µmol m^{-2} s^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 23).

Light extinction was significantly less at the control (mean = 0.18 ft^{-1}, STD = 0.02 ft^{-1}) than the south and west perimeter sensors at the dock (south mean = 0.23 ft^{-1}, STD = 0.05 ft^{-1}; west mean = 0.23 ft^{-1}, STD = 0.06 ft^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 27). At the dock, the core had significantly greater light extinction than the perimeter for the north side (core mean = 0.22 ft^{-1}, STD = 0.03 ft^{-1}; perimeter mean = 0.18 ft^{-1}, STD = 0.03 ft^{-1}) but significantly less light extinction for the west side (core mean = 0.20 ft^{-1}, STD = 0.03 ft^{-1}; perimeter mean = 0.22 ft^{-1}, STD = 0.05 ft^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 24). Additionally, the south side had significantly greater light extinction than the north side of the dock perimeter (south mean = 0.23 ft^{-1}, STD = 0.05 ft^{-1}; north mean = 0.18 ft^{-1}, STD = 0.03 ft^{-1}) (paired t test, $p < 0.05$) (Figure 43, Table 25).

Substrate

Bowman Bay

Substrate analysis in Bowman Bay control showed a range of organic content from 0.5-4.6%, by sample, while the dock ranged from 0.5-2.0%, by sample (Figure 45). There was significantly more organic content in the substrate at the dock (median = 1.0%, IQR = 0.5%) than at the control (median = 0.7%, IQR = 0.1%) (Mann-Whitney U, p, < 0.05) (Figure 45, Table 28).

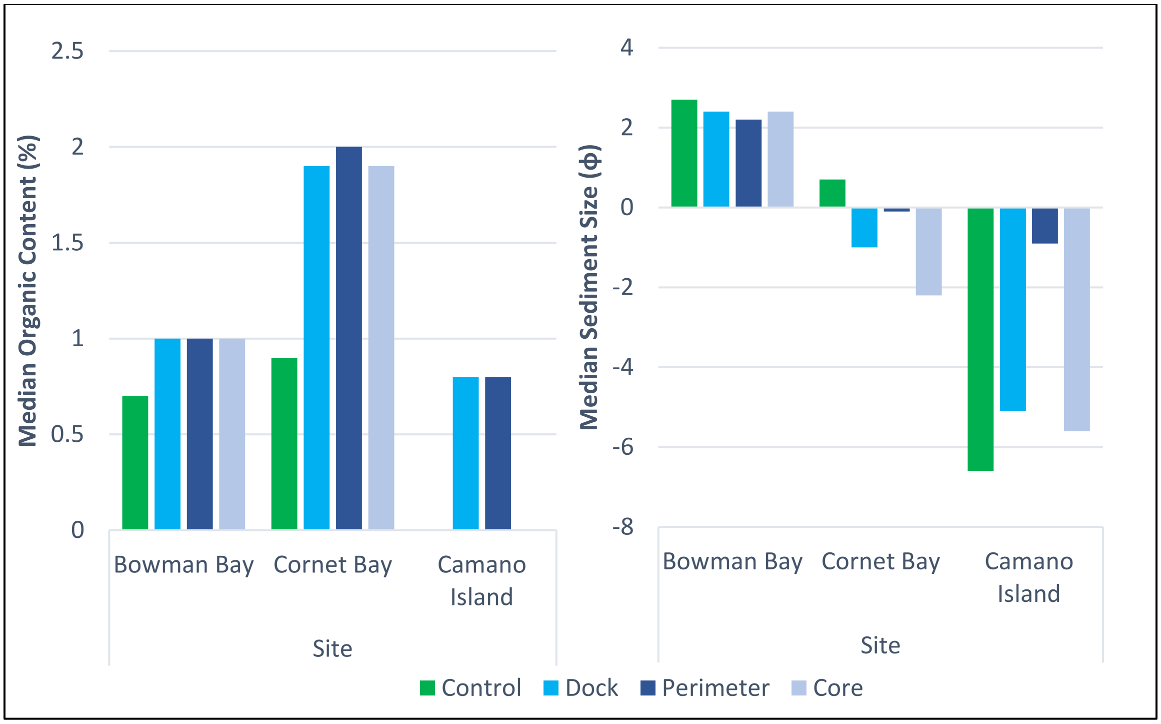


Figure 45. *Substrate characteristics by site.*

Table 28. *Differences in sediment characteristics [median (IQR)] between control and dock sites.*

	Organic Content (%)					Sediment Size (ф)			
Site	Control	n	Dock	n	Site	Control	n	Dock	n
Bowman Bay*	0.7 (0.1)	9	1.0 (0.5)	16	Bowman Bay*	2.67 (0.20)	9	2.40 (0.28)	16
Cornet Bay	0.9 (0.2)	9	1.9 (1.5)	18	Cornet Bay*	0.72 (0.60)	9	-1.00 (2.56)	18
Camano Island	<Null>	9	0.8 (0.1)	15	Camano Island*	-6.64 (0.74)	6	-5.07 (5.40)	15

** = significant difference (Mann-Whitney U, $p < 0.05$).*

Mean sediment sizes were consistent at the control, ranging from 2.37 to 2.67 φ, by sample, all of which fall in the fine sand category on the Wentworth Scale. Results from the dock were quite different with mean sediment sizes ranging from 0.25 to 2.53 φ, falling on the coarse, medium, and fine sand categories of the Wentworth Scale. The control had significantly smaller sediment sizes than the dock (control median = 2.67 φ, IQR = 0.20 φ; dock median = 2.40 φ, IQR = 0.28 φ) (Mann-Whitney U, *p*, < 0.05) (Figure 45, Table 28).

There was no significant difference in organic content nor sediment size between Bowman Bay dock core and Bowman Bay dock perimeter (Mann-Whitney U, p, < 0.05) (Figure 45, Table 29).

Table 29. *Differences in sediment characteristics [median (IQR)] between dock core and perimeter by site.*

	Organic Content (%)					Sediment Size (ϕ)			
Site	Core	n	Perimeter	n	Site	Core	n	Perimeter	n
Bowman Bay	1.0 (0.5)	9	1.0 (0.7)	7	BB	2.44 (0.2)	9	2.2 (1.2)	7
Cornet Bay	1.9 (1.5)	10	2.0 (1.3)	8	CB*	-2.23 (2.24)	10	-0.09 (1.29)	8
Camano Island	<Null>	7	0.8 (0.1)	8	CI*	-5.62 (0.17)	7	-0.91 (5.92)	8

* = significant difference (Mann-Whitney U, $p < 0.05$).

A Spearman's correlation was run for a 2 m buffer around each sediment sampling location at Bowman Bay to assess the relationship between sediment characteristics and water depth, kelp cover, and kelp biomass, but no significant relationships were found (Spearman rank, $p > 0.05$).

Cornet Bay

Substrate analysis from Cornet Bay control showed a range of organic content from 0.5-3.1%, by sample while the dock ranged from 0.5% to 3.6% by sample. Control sediment sizes ranged from 0.23 to 1.03 φ in the control samples, which mainly fell in the coarse sand category of the Wentworth Scale with only one sample falling in the medium sand category. Cornet Bay dock sediment sizes were much coarser, ranging from 0.43 to -3.96 φ, covering categories on the Wentworth Scale from coarse sand to medium pebbles. The dock had significantly larger sediment sizes than the control (dock median = -1.00 φ, IQR = 2.56 φ; control median = 0.72 φ, IQR = 0.60 φ) (Mann-Whitney U, p, < 0.05) (Figure 45, Table 28). Additionally, sediment sizes in the dock core were coarser than the dock perimeter (core median = -2.23 φ, IQR = 2.24 φ; perimeter median = -0.09 φ, IQR = 1.29 φ) (Mann-Whitney U, *p*, < 0.05) (Figure 45, Table 29).

A Spearman's correlation was run for a 2 m buffer around each sediment sampling location at Cornet Bay to assess the relationship between sediment characteristics and water depth, kelp cover, and kelp biomass, but no significant relationships were found (Spearman rank, *p* > 0.05).

Camano Island

Organic content was not analyzed from Camano Island control as only cobbles were retrieved from all nine sampling locations. At the dock, however, organic content ranged from 0.7-1.0%, by sample. Sediment sizes were quite coarse in the control with means ranging from -5.23 to -7.36 φ. This equates to the very coarse pebbles category to the cobbles category on the Wentworth Scale. At Camano Island dock, the sediment samples were finer overall, but showed a much larger range, with means ranging from 0.53 to -6.03 φ. This range covers the coarse sand category to the cobbles category on the Wentworth scale. The control had significantly larger sediment sizes than the dock (control median = -6.64 φ, IQR = 0.74 φ; dock median = -5.07 φ, IQR = 5.40 φ) (Mann-Whitney U, *p*, < 0.05) (Figure 45, Table 28). Additionally, the dock core had larger sediment sizes than the dock perimeter (core median = -5.62 φ, IQR = 0.17 φ; perimeter median = -0.91 φ, IQR = 5.92 φ) (Mann-Whitney U, *p*, < 0.05) (Figure 45, Table 29).

A Spearman's correlation was run for a 2 m buffer around each sediment sampling location at Camano Island to assess the relationship between sediment characteristics and water depth, kelp cover, and kelp biomass, but no significant relationships were found (Spearman rank, $p > 0.05$).

Fish Use

Bowman Bay

Early Summer. Fish use video monitoring from the early summer visit to Bowman Bay control was discarded due to no kelp being found in the video-georeferenced survey. Video from the dock, however, was captured by two cameras with synchronous coverage from 17:13 to 19:07 on July 12th, 2017, when the tide was in the middle of flood. Thirteen fish were counted at this deployment from still images taken at 2 min intervals from the video (median = 0, IQR = 0) (Figure 46, Table 30). Nearly all fish species counted were juvenile shiner perch (*Cymatogaster aggregate*).

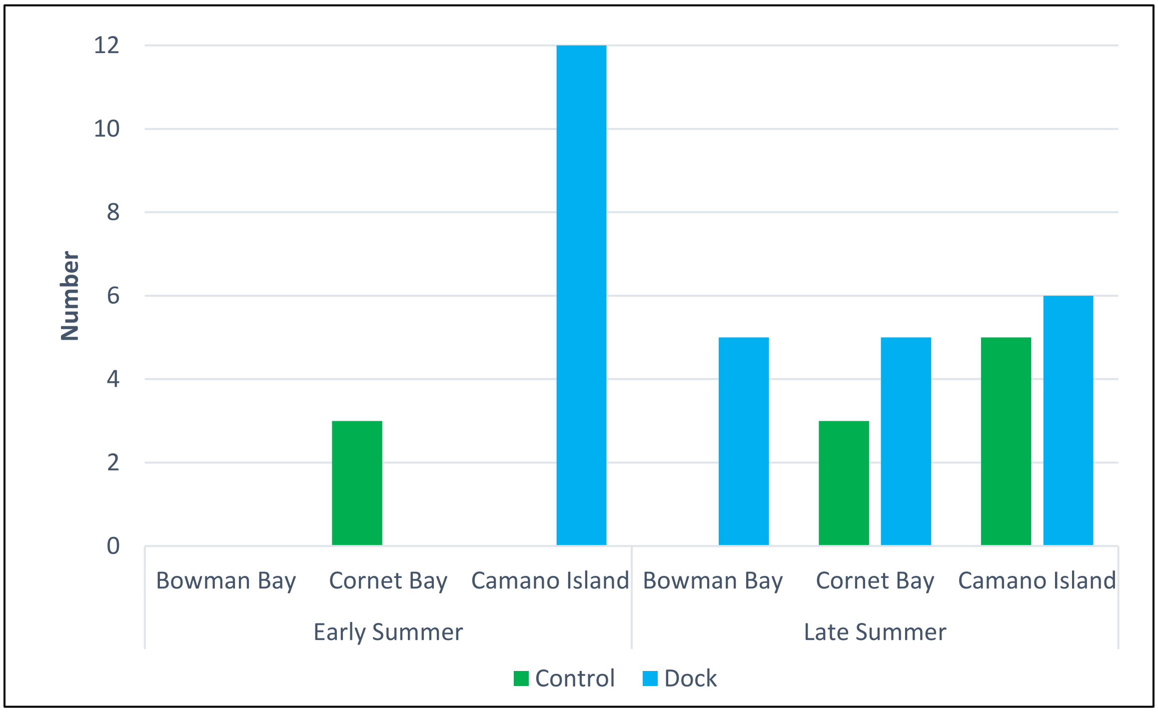


Figure 46. *Number of fish (median) present at 2 min intervals by site, early and late summer, 2017.*

Table 30. *Differences in fish counts [median (IQR)] at 2 min intervals between control and dock sites for early and late summer, 2017.*

	Fish Counts		Control			Dock		
Site – Early	Control	Dock	Tide Range	Duration	PAR	Tide Range	Duration	PAR
Bowman Bay	<Null>	0 (0)	n/a	n/a	n/a	4.4 – 7	1:54	2.0
Cornet Bay*	3 (6)	0 (0)	9.0 – 11.1	2:06	5.8	9.9 – 11.0	1:50	2.3
Camano Island	0 (0)	12 (11)	-0.6 – 0.8	2:14	93.8	9.6 – 11.2	2:04	4.6
Site – Late	Control	Dock	Tide	Time	PAR	Tide	Time	PAR
Bowman Bay*	0 (0.5)	5 (8)	7.3 – 7.5	1:48	6.3	5.2 – 7.6	1:54	4.7
Cornet Bay*	3 (5)	5 (5)	5.5 – 9.3	2:04	4.1	3.8 – 9.0	2:30	3.1
Camano Island*	5 (5.5)	6 (8)	10.5 – 11.1	2:18	3.0	11.2 – 10.1	2:20	1.1

** = significant difference (Mann-Whitney U, $p < 0.05$). Tide range (MLLW, ft) is during video recording. Duration is synchronous video recording length in hr. PAR (μmol m^{-2} s^{-1}) is averaged at 2 min intervals for duration of synchronous video recording.*

Of the 25 Squidpops deployed at the dock, none were missing any bait 1 hr after deployment and only two pieces of bait were missing 24 hr after deployment (Table 31).

Table 31. *Number of Squidpops (n = 25) missing bait after 24 hr.*

	Early Summer		Late Summer	
	Control	Dock	Control	Dock
Bowman Bay	n/a	2	4	1
Cornet Bay	3	1	8	4
Camano Island	4	5	5	13

Late Summer. Fish use video from late summer at Bowman Bay control was captured by four cameras with synchronous coverage from 17:10 to 18:58 on August 22nd, 2017, when the tide was at higher high water for the day. Thirty fish were counted, in total, from still images taken every 2 min from the video. Video from the dock was captured by four cameras with synchronous coverage running from 15:42 to 17:35 on August 22nd, 2017, when the tide was nearing the end of flood. Three hundred and eleven fish were counted from still images taken at 2 min intervals from the video. Nearly all fish species counted from both sites were juvenile shiner perch.

There were significantly more fish present at the dock than at the control (dock mean = 5, IQR = 8; control mean = 0, IQR = 0.5) (Mann-Whitney U, $p < 0.05$) (Figure 46, Table 30). Additionally, there were significantly more fish present at the dock during late summer than early summer (late mean = 5, IQR = 8; early mean = 0, IQR = 0) (Mann-Whitney U, $p < 0.05$) (Figure 46, Table 32).

Table 32. *Differences in fish counts [median (IQR)] at 2 min intervals between early and late summer, 2017.*

	Fish Counts		Early			Late		
Site – Control	Early	Late	Tide	Time	PAR	Tide	Time	PAR
Bowman Bay	<Null>	0 (0.5)	n/a	n/a	n/a	7.3 – 7.5	1:48	6.3
Cornet Bay	3 (6)	3 (5)	9.0 – 11.1	2:06	5.8	5.5 – 9.3	2:04	4.1
Camano Island*	0 (0)	5 (5.5)	-0.6 – 0.8	2:14	93.8	10.5 – 11.1	2:18	3.0
Site – Dock	Early	Late	Tide	Time	PAR	Tide	Time	PAR
Bowman Bay*	0 (0)	5 (8)	4.4 – 7	1:54	2.0	5.2 – 7.6	1:54	4.7
Cornet Bay*	0 (0)	5 (5)	9.9 – 11.0	1:50	2.3	3.8 – 9.0	2:30	3.1
Camano Island*	12 (11)	6 (8)	9.6 – 11.2	2:04	4.6	11.2 – 10.1	2:20	1.1

** = significant difference (Mann-Whitney U, $p < 0.05$). Tide range (MLLW, ft) is during synchronous video recording. Duration is synchronous video recording length. PAR (µmol m^{-2} s^{-1}) is averaged at 2 min intervals for duration of synchronous video recording.*

For late summer at Bowman Bay, no bait was missing from the Squidpops 1 hr after deployment for neither the control nor the dock but after 24 hr, 4 pieces of squid were missing from the control and 1 piece of squid was missing from the dock (Table 31).

Cornet Bay

Early Summer. Fish use video from the control was captured by two cameras with synchronous coverage from 17:46 to 19:52 on July 24th, 2017, when the tide ranged from the end of flood into higher high water for the day. Two hundred and sixty-nine fish were counted in total from still images taken every 2 min from the video. Video from the dock was captured by two cameras with synchronous coverage from 18:17 to 20:05 on July 24th, 2017, when the tide was at higher-high water for the day. Twenty-two fish were counted from images taken at 2 min intervals from the video. Nearly all fish species counted from both sites were juvenile shiner perch.

There were significantly more fish present at the control than at the dock (control mean = 3, IQR = 6; dock mean = 0, IQR = 0) Mann-Whitney U, $p < 0.05$) (Figure 46, Table 30).

No bait was missing from any Squidpop at the control nor the dock 1 hr after deployment. Twenty-four hr after deployment, however, 3 pieces of squid were missing from the control, while 1 piece of squid was missing from the dock (Table 31).

Late Summer. Fish use video from the control was captured by four cameras with synchronous coverage from 14:58 to 17:01 on September 5th, 2017, when the tide ranged from mid-flood to almost peak higher-high water. Two hundred and fifty-two fish were counted from still images taken at 2 min intervals from the video. Fish-use video from the dock was captured by four cameras with synchronous coverage from 14:14 to 16:43 on September 5th, 2017, when the tide was at the peak of flood. Four hundred and sixtyseven fish were counted from 2 min intervals during late summer at Cornet Bay dock. Nearly all fish species counted from both the control and dock were shiner perch.

There were significantly more fish present at the dock than at the control (dock mean = 5, IQR = 5; control mean = 3, IQR = 5) (Mann-Whitney U, $p < 0.05$) (Figure 46, Table 30). Additionally, there were significantly more fish present at the dock during late summer than early summer (late mean = 5, IQR = 5; early mean = 0, IQR = 0) (Mann-Whitney U, $p < 0.05$) (Figure 46, Table 32).

During late summer at Cornet Bay, no bait was missing from the Squidpops 1 hr after deployment at neither the control nor the dock. However, 24 hr after deployment, 8 pieces were missing from the control and 4 pieces were missing from the dock (Table 31).

Camano Island

Early Summer. Fish use video from the control was captured by four cameras with synchronous coverage from 10:48 to 12:15 on August 7th, 2017, when the tide ranged from lower-low water into late flood. Forty-two fish were counted in total from still images taken every 2 min from the video. Fish use video from the dock was captured by four cameras with synchronous coverage from 16:50 to 18:04 on August 7th, 2017, when the tide centered on higher high water for the day. Five hundred and seventeen fish were counted during this deployment from still images taken every 2 min from the video. The lengthy difference in deployment times between the control and the dock was due to a mechanical failure of the research boat. Nearly all fish species counted at both sites were shiner perch.

During early summer at Camano Island, no bait was missing from the Squidpops 1 hr after deployment from neither the control nor the dock. However, 24 hr after deployment 4 pieces of squid were missing from the control and 5 pieces of squid were missing from the dock (Table 31).

Late Summer. Fish use video at the control was captured by four cameras with synchronous coverage from 15:06 to 17:10 pm on September 18th, 2017, when the tide ranged from higher-high water into the first portion of ebb. Two hundred and fifty-three fish were counted from still images taken every 2 min from the video. Fish use video at the dock was captured by four cameras with synchronous coverage from 16:19 to 18:39 on September 18th, 2017, when the tide ranged from the peak of flood into the first stages of ebb. Five-hundred and ninety-nine fish were counted from still images taken every 2 min from the video. Nearly all fish species from the control and dock were shiner perch.

There were significantly more fish present at the dock than at the control (dock mean = 6, IQR = 8; control mean = 5, IQR = 5.5) (Mann-Whitney U, $p < 0.05$) (Figure 46, Table 30). Additionally, there were significantly more fish present during late summer than early summer at the control (late mean = 5, IQR = 5.5; early mean = 6, IQR = 8) but there were significantly more fish present during early summer than late summer at the dock (early mean = 12, IQR = 11; late mean = 6, IQR = 8) (Mann-Whitney U, $p < 0.05$) (Figure 46, Table 32).

During late summer at Camano Island, no bait was missing from the Squidpops 1 hr after deployment. However, 24 hr after deployment 5 pieces of squid were missing from the control and 11 pieces were missing from the dock (Table 31).

CHAPTER 6

DISCUSSION AND CONCLUSIONS

Kelp Cover

Kelp coverage was nearly non-existent around most of the docks (1.3 – 39.9%). In fact, of all the docks, kelp cover was only markedly present at Cornet Bay (39.8 – 39.9%). However, kelp was abundant across all controls without exception (62.3 – 97.6%). Indeed, in every instance, kelp cover by transect was found to be significantly higher at the controls than at the docks (dock medians = 0 – 20.4%; control medians = 96.2 - 100%) (Tables 33 and 34). These significant differences in subtidal kelp coverage between docks and paired controls across all sites, and for both study visits, imply that docks are reducing subtidal kelp distribution as suggested by NOAA (Kelty and Bliven, 2003).

Table 33. *Differences in variables measured by site, early summer, 2017.*

Early Summer	Control	Docks	Dock Perimeter	Dock Core
Kelp Cover				
Bowman Bay	Null	Null	ND	ND
Cornet Bay	H	L	H	L
Camano Island	H	L	ND	ND
Overall	SH	SL	V	V
Kelp Biomass				
Bowman Bay	Null	Null	ND	ND
Cornet Bay	H	L	H	L
Camano Island	H	L	H	L
Overall	SH	SL	MH	ML
Available PAR				
Bowman Bay	Null	Null	V	V
Cornet Bay	H	L	H	L
Camano Island	H	L	V	V
Overall	SH	SL	V	V
Extinction Coefficient				
Bowman Bay	Null	Null	H	L
Cornet Bay	L	H	V	V
Camano Island	H	L	V	V
Overall	V	V	V	V

H = significantly higher, L = significantly lower, V = varied results, SH = strongly higher (all sites higher), SL = strongly lower (all sites lower), MH = moderately higher (2 out of 3 sites higher), ML = moderately lower (2 out of 3 sites lower), ND = no difference.

Table 34. *Differences in variables measured by site, late summer, 2017.*

Late Summer	Control	Docks	Dock	
			Perimeter	Core
Kelp Cover				
Bowman Bay	H	L	ND	ND
Cornet Bay	H	L	H	L
Camano Island	Null	Null	Null	Null
Overall	SH	SL	V	V
Kelp Biomass				
Bowman Bay	H	L	H	L
Cornet Bay	H	L	H	L
Camano Island	Null	Null	Null	Null
Overall	SH	SL	SH	SL
Available PAR				
Bowman Bay	H	L	H	L
Cornet Bay	V	V	H	L
Camano Island	ND	ND	V	V
Overall	V	V	MH	ML
Extinction Coefficient				
Bowman Bay	L	H	V	V
Cornet Bay	L	H	V	V
Camano Island	V	V	V	V
Overall	ML	MH	V	V
Percent Organics				
Bowman Bay	L	H	ND	ND
Cornet Bay	ND	ND	ND	ND
Camano Island	Null	Null	Null	Null
Overall	V	V	ND	ND
Sediment Size				
Bowman Bay	L	H	ND	ND
Cornet Bay	L	H	L	H
Camano Island	H	L	L	H
Overall	ML	MH	ML	MH

H = significantly higher, L = significantly lower, V = varied results, SH = strongly higher (all sites higher), SL = strongly lower (all sites lower), MH = moderately higher (2 out of 3 sites higher), ML = moderately lower (2 out of 3 sites lower), ND = no difference.

Further evidence of dock impact to subtidal kelp is seen in the core and perimeter analysis. When kelp was present in both, the dock perimeter had significantly higher cover by transect than the dock core (core medians = 0 – 9.9%; perimeter medians = 0 – 81.7%) (Tables 33 and 34). This effect is best observed at Cornet Bay for both study visits; as distance from the dock increases, so does the quantity of kelp present (dock core median = 3.4% early summer, 9.9% late summer; dock perimeter median = 51.1% early summer, 81.7% late summer). The lack of a similar decline in kelp cover from perimeter to core for both visits to Bowman Bay and the early summer visit to Camano Island were due to there being essentially no kelp present in either area. This nearly total absence of kelp may be attributed to the higher wave energy found at Camano Island as some *Laminaria* species are known to be less productive in such wave climates (Leigh et al., 1987). At Bowman Bay, the near total lack of kelp around the dock may have been due to overall greater water depths (median = -10.3 ft, MLLW) or perhaps the greater width of the dock (effectively 7 m after including the large pier adjacent to the floating dock as opposed 2 m of each individual dock at Cornet Bay and Camano Island).

The statistically significant increase of kelp cover between sampling visits at Cornet Bay control (62.3 – 97.6%) was not observed at Cornet Bay dock which remained quite consistent overall (39.8 – 39.9%) as well as in the core (21.9 – 19.1%) and perimeter (43.1 – 46.5%) (Mann-Whitney U, $p < 0.05$). This observation of significant kelp growth occurring in the control but not at the dock additionally suggests that docks are impeding kelp distribution as suggested by Thom, Williams, and Diefenderfer (2005), and MacDuffee (2014). Further evidence of this observation is supplied by kelp cover in the control being significantly independent from the dock altogether (half of the observations), or similar to the dock perimeter but still independent from the dock core (Kruskal-Wallis, $p < 0.05$) (Table 4).

Water Depth

When kelp was markedly present at the dock (Cornet Bay only), the deep areas had significantly more presence than the shallow areas (deep medians = 33.3 – 40.3%; shallow medians = 0 – 5.3%) for both dock core (deep median = 27.5 – 33.3%; shallow median = 0%) and the dock perimeter (deep median = 69.3 – 95%; shallow median = 27.2 – 50%) (Mann-Whitney U, $p < 0.05$). However, there was no significant difference in kelp cover between the deep and shallow areas of any control site except for early summer at Camano Island. Because the water depths between relative deep and shallow areas at each site were significantly different from one another, yet the control sites showed a significant difference in cover between relative depths in only one case, it would seem that a factor other than water depth is controlling kelp distribution and productivity.

The control sites were significantly deeper than the dock sites at Cornet Bay and Camano Island (Table 6), so it would seem that they should have less kelp present, as available PAR is the limiting factor to kelp growth when water temperatures are adequate (Steneck et al., 2002). However, the deeper controls had significantly more kelp than the paired docks in every case and water temperatures at all of the sites were nearly identical as measured by the thermometer integrated into the Aqua-Vu camera system. It is possible that potentially greater turbidity in the shallow areas prevented kelp recruitment by increasing light extinction or by sediment burial of the gametophytes, or that higher light levels found in shallower waters prevents gametophyte growth (Mumford, 2007). Or, perhaps wave energy or propeller wash in the shallower areas prevented kelp recruitment in the first place by never allowing the gametophytes to settle and latch on to the substrate (Leigh et al., 1987). However, the lack of kelp in the shallower areas cannot be attributed to any of these factors alone because the area with the least kelp cover by transect in this study was by far the shallow area of the dock cores (medians = 0 – 1.5%) yet the shallow area of the dock perimeters, at equal depths, revealed significantly more kelp presence (medians = 0 – 50%). This observation further supports the evidence in this study that it is the docks that are negatively impacting kelp distribution as suggested by Schlenger et al. (2011).

Water depths of each 1 m^{-2} grid cell were aggregated across all sites based on kelp presence or absence of that cell. Across all sites, water depths where kelp was found to be both present and absent were nearly identical (Table 35) (Mann-Whitney U, $p > 0.05$). This fact additionally shows that it is not water depth that is causing significant reductions in kelp distribution near the docks. Furthermore, although water depths were comparable between control and dock for late summer at Bowman Bay (control depth = -10.0 ft MLLW; dock depth = -10.3 ft MLLW), kelp was plentiful in the control (94.3%) yet nearly absent from the dock where substrate was even more suitable for kelp recruitment (Mumford, 2007).

Table 35. *Differences in environmental controls [median (IQR)] between areas where kelp was present or absent across all sites.*

Environmental Control	Presence	Absence
Depth (MLLW, ft)	-6.77 (2.69)	-6.79 (3.42)
Light Extinction (ft^{-1})*	0.21 (0.06)	0.23 (0.04)
Sediment Organics (%)	0.91 (1.79)	0.88 (0.82)
Sediment Size (ϕ)	0.25 (4.28)	0.25 (6.76)

** = significant difference (Mann-Whitney U, p < 0.05).*

Other than many moderate to very strong negative correlations at Cornet Bay between kelp cover and water depth (r_s = -0.4404 to -0.7069), there was only one significant correlation at all other sites which was a moderately positive correlation (r_s = 0.433) at Bowman Bay dock during early summer (Spearman rank, $p < 0.05$) (Tables 11 and 13). The positive correlation at Bowman Bay is anomalous and likely due to the minimal amount of kelp present there. The many negative correlations at Cornet Bay, however, could be due, in part, to the nearly 2 ft difference in water depths between the control and dock (control median depth = -7.4 ft MLLW, dock median depth = -5.6 ft MLLW). Seventy-five percent of the total correlations between kelp cover and water depth at Cornet Bay were found at the dock. The only correlations between kelp cover and water depth found in the control were when Cornet Bay transects were split into relative water depths. Because these correlations were revealed for only relative water depths in the control, but at the dock, differences were observed for the total area as well as the dock core, it gives weight to the notion that docks are impeding kelp growth in water depths equal to where abundant kelp was found in the controls.

Biomass

In every instance, for both early and late summer, biomass was found to be significantly higher at the controls (medians = 282.1 - 565.9 g) than at the paired docks (medians = 0 – 199.6 g) (Tables 15, 33, and 34). This corroborates the findings of the video survey, showing that where more kelp was present, the biomass weight was indeed higher as well. Additionally, the dock perimeters (medians = 0 – 383.7 g) showed significantly higher kelp biomass than the dock cores (medians = 0 – 33.9 g) where the shading effect of the docks is greater (Tables 16, 33, and 34) (MacDuffee, 2014; Schlenger et al., 2011). This observation further corroborates the findings of the video survey that as the distance from the docks increases, so does the quantity of kelp present. Furthermore, the greater biomass in the dock perimeters, indicating healthier and more productive kelp growth (Best et al., 2001; Brady-Campbell, Campbell, and Harlin, 1984), shows that as distance from the docks increases kelp quality increases along with kelp quantity. To further support this observation, comparisons in morphometric measurements at Cornet Bay revealed significantly smaller and fewer kelp specimens at the dock (median lengths = 113.0 cm, median widths = 22.0 cm) than its paired control (median length = 148.5 cm, median width = 28.0 cm) (Table 14). This analysis again suggests that docks negatively impact kelp productivity as the controls had healthier and more vigorous kelp growth than the docks.

Kelp biomass frequently had a moderate to strong negative correlation with water depth (r_s = -0.41 to -0.84) (Spearman rank, $p < 0.05$) (Tables 11 and 13). This correlation again suggests that as less light is available, subtidal kelp are less productive, furthering the notion that shading by overwater structures is detrimental to kelp productivity (Boyer, 2013; MacDuffee, 2014).

Not including over 5,000 private docks in the Sound, as of 2016 there were 4,702 docks and piers on state-owned aquatic lands alone (WDNR, 2001). When including an 8 m buffer around each structure, these docks total 50,054,970.0 m^{-2}, or 1,149.1 acres. Extrapolating the ratio of median kelp presence/absence differences between docks and paired controls in this study to all the docks on state-owned aquatic lands in the Sound results in approximately 977 acres of kelp habitat being lost due to docks. Then applying the ratio of median kelp biomass to median kelp cover, this 977 acres equates to 796 tons of wet-weight kelp biomass, or 111 tons of dry-weight kelp biomass being absent from areas where it would likely thrive were the docks not there. This is a substantial loss of habitat for the many species that rely on kelp beds for shelter, foraging, nursery, or food (Gelfenbaum et al., 2006; Mumford, 2007).

Light Attenuation

Available PAR was significantly higher at each control (means = 58.2 – 219.0 $\mu mol\ m^{-2}\ s^{-1}$) than all aspects of the paired docks (means = 27.2 – 223.1 $\mu mol\ m^{-2}\ s^{-1}$) with the exception of the north perimeter of Camano Island (mean = 92.5 $\mu mol\ m^{-2}\ s^{-1}$)

and the south perimeter of Cornet Bay (mean = 67.1 µmol m^{-2} s^{-1}) during late summer (Tables 26, 33, and 34). These exceptions were significant, but only slightly, and were anomalies in an otherwise very consistent trend suggesting that docks are blocking PAR in amounts enough to impede kelp growth (Boyer, 2013; Thom, Williams, and Diefenderfer, 2005). These anomalies were likely the result of intermittent biofouling caused by stronger currents mobilizing the thick and abundant kelp blades enough to temporarily shade the benthic control sensor, resulting in less PAR being recorded.

Due to the mostly western orientation of every dock in this study, more shading was expected on their northern sides. This was confirmed by PAR and light extinction analysis showing the sensors on the north side of the dock recording less PAR and, correspondingly, more light extinction than the sensors on the south side of the docks for both the core (north PAR medians = 26.6 – 178.5 µmol m^{-2} s^{-1}, north extinction medians = 0.22 – 0.32 ft^{-1}; south PAR medians = 37.4 – 220.1 µmol m^{-2} s^{-1}, south extinction medians = 0.19 – 0.26 ft^{-1}) and perimeter areas (north PAR medians = 26.2 – 193.4 µmol m^{-2} s^{-1}, north extinction medians = 0.18 – 0.28 ft^{-1}; south PAR medians = 65.2 – 223.1 µmol m^{-2} s^{-1}, south extinction medians = 0.19 – 0.23 ft^{-1}) (Tables 23 and 25). This was true in every case except Camano Island which was anomalous as previously mentioned. The shading effect of the docks is further evidenced on the north side of each dock where the dock perimeters (means = 27.1 – 193.4 µmol m^{-2} s^{-1}) recorded significantly more PAR than the dock cores (means = 21.1 – 178.5 µmol m^{-2} s^{-1}) in every instance, showing that the effect of the docks shadow decreases as distance from the dock increases (Tables 22, 33, and 34).

These results show that docks block significant amounts of PAR from reaching the benthos where kelp need adequate PAR to recruit and grow (Boyer, 2013; Kelty and Bliven, 2003; Mumford, 2007). Differences in kelp presence and biomass between the paired sites may have been affected by different PAR maximums and minimums at each location which may require further investigation. However, this research seems to confirm that light extinction is indeed a primary limiting factor to kelp growth as suggested by Steneck et al. (2002), Bearham, Vanderklift, and Gunson (2013) and others. Furthermore, these results seem to confirm Bearham, Vanderklift, and Gunson's (2013) conclusion that light intensity (and water temperature) best explains patterns of growth and productivity in subtidal kelp. This research additionally confirms NOAA's assertion that overwater structures are a threat to benthic kelp habitats caused by light extinction and shading (Kelty and Bliven, 2003).

Some studies have shown that different types of grating, instead of solid decking boards, reduce the shading effects of docks (Logan, Davis, and Ford, 2015). However, although grating allows more light through, there is evidence that even docks with grating of up to 70% open space still block significant amounts of PAR from reaching the benthos (Gabriel and Donoghue, 2018). Gabriel and Donoghue (2018) found that grid (70% open space) or slotted (42% open space) decking transmitted only 5 – 13% more PAR than solid decking boards even during the summer when sun angles are the highest. Additionally, they discovered that only the open water control sites in their study received enough PAR to sustain eelgrass growth (Gabriel and Donoghue, 2018). Even the 70% open space grid decking transmitted only approximately 20% of PAR found in the open water controls (Gabriel and Donoghue, 2018). This result was found at only 88 cm below water surface (Gabriel and Donoghue, 2018) which is consistent with measurements in this study and is insufficient to mitigate the shading effects of overwater structures at depths where subtidal kelp grow.

Substrate

Overall, the percent of organics in the substrate varied across all sites combined (0.7 – 1.9%) while sediment size was only moderately larger at the docks (2.40 to -5.07 φ), than at the controls (2.67 to -6.64 φ) as well as in the cores (2.44 to -5.62 φ) when compared to the perimeters (2.2 to -0.91 φ) (Tables 28, 29, and 34). This suggests that particle size and organic content has little effect on kelp presence in this study as differences between docks and controls varied by site or were insignificant. This is further evidenced by the lack of a significant correlation between sediment percent organic content and sediment size with any other variables (Spearman rank, $p > 0.05$). It is likely that percent organic content has little influence on kelp recruitment as kelp holdfasts attach to coarse substrate on top of the benthos rather than burrowing into it like roots (Mumford, 2007).

A 2 m buffer was applied to each sediment sampling point at each site. If kelp cover within the buffer was greater than 50%, kelp was considered present, if it was less than 50%, it was considered absent. When all sites were combined, sediment organics and sediment size showed no significant difference where kelp was found to be present or absent (Mann-Whitney U, $p < 0.05$) (Table 35).

The varied results of substrate particle size analysis in this study revealed that, in some cases, kelp was significantly more abundant at control sites with finer-grained substrate than at dock sites where the substrate is larger and likely more suitable for kelp recruitment (Table 28). This further suggests that the shading effects of docks have a negative effect on kelp that outweighs this known preference for coarser substrate (Mumford, 2007). Further implicating the docks shading effects, many large specimens of sugar kelp were found anchored near the water surface to the unshaded portions of the floating docks at both Cornet Bay and Camano Island, but not in the shaded substrates below. Propeller wash from boats at the docks as well as boat trailers potentially passing the concrete boat ramps and traveling directly onto the benthos may be additional stressors affecting the substrate. Substrate was mostly larger beneath and around the docks which may indicate that increased water motion is dispersing the finer particles. This may be caused by concentrated wave action from refraction around the docks or potentially by propeller wash if it consistently reached the benthos. If propeller wash or increased wave action is affecting the substrate, there may have been enough water motion to prevent kelp recruitment by dispersing the gametophytes or enough sediment mixing and settling to bury them. However, these potential stressors were not investigated in this research and require further inquiry to determine if they are significant.

Fish Use

Statistical analysis of fish counts revealed that significantly more fish were present at the docks than at the controls for the early summer visit to Camano Island and the late summer visits to Bowman Bay, Cornet Bay, and Camano Island, however, there were significantly more fish present at the control than at the dock for the late summer visit to Cornet Bay (Mann-Whitney U, $p < 0.05$) (Table 30). Because fish presence significantly varied at all study areas but was not consistent at which site, dock or control, had greater presence, it may not be affected by the docks. More likely, there were uninvestigated variables present in the fish monitoring methods such as wave climate, varying tidal effects, differences in light availability, or feeding patterns that were not revealed within the short video time frame. Further studies could be conducted to focus on longer-term fish use differences between docks and paired controls to understand behavioral patterns of fish in kelp beds to support Siddon, Siddon, and Stekoll (2008) and Hamilton and Konar's (2004) findings that fish presence is directly proportional to kelp density.

Protocol

With a rising human population around the Puget Sound and more HPA permit requests being filed each year, it is imperative that subtidal kelp habitats can be quickly and effectively surveyed prior to permit approval. This survey protocol can drastically reduce HPA permit appeals for proposed overwater structures in the Puget Sound by fulfilling WDNR and WDFW's legal obligations to survey potential dock construction sites. This protocol effectively surveys large areas in an efficient manner by using minimal time and human-power. As remote sensing techniques are highly inconclusive in subtidal kelp study (Vahtmäe et al., 2006) and dive surveys are expensive and dangerous (Werdell and Roesler, 2003), the protocol developed for this research offers a viable and affordable alternative. In total, the subtidal kelp survey rig cost approximately $500 to build and is highly transportable even in small vehicles. Additionally, the platform is adaptable and could be mounted to a kayak for more maneuverability in high current areas or for researchers with impaired leg maneuverability or swimming ability.

The survey rig developed for this project efficiently surveyed potential dock footprints and the 25 ft buffer in approximately 45 min or less with increasing efficiency on subsequent deployments. The green lasers on the recording array were effective for scaling imagery but could be improved by using a higher wattage for greater visibility in post-processing the live feed. Similarly, using a single camera for live feed and recording would improve minor discrepancies in live field of view versus recorded video. The 2 m transects established for this research were sufficiently precise for survey, accommodating drift, tidal current, and GPS accuracy.

Kelp coverage and biomass were significantly lower within the 25 ft buffer established under WAC 220-660 for minimum new construction dock distance from existing kelp beds than in paired controls at all sites. This suggests that the buffer distance may need to be increased to fully negate potential impacts from new dock construction to established kelp beds. However, impact is negligible after 6 m with the dock perimeter often statistically resembling the control more than the dock core.

With the floating research platform’s construction, it was impossible to record directly beneath the overwater structure. It is suggested that a camera on a pull-line or an underwater ROV be used for this purpose if it is deemed necessary. However, no kelp was observed directly beneath any of the docks in this research by drop camera nor visual inspection by snorkeling on either visit to each site. Due to the significant kelp growth at Cornet Bay control between the early and late summer visits and the incredible amount of detritus trapped at Camano Island dock during the late summer survey, it is recommended that kelp surveys in this area be timed for August.

The lasso biomass sampler was effective when the transects were walked or the boat was double anchored. However, it should be constructed out of a more rigid material like lightweight, metal conduit for biomass sampling by boat at depths greater than 2 m. Additionally, density measurements should be confirmed by scuba-diving quadrat surveys to calibrate lasso biomass sampler estimates per m^{-2}.

Lastly, the Squidpops would have proved ineffective at determining fish use in this environment without supplementary video recording. From every video at every site, there were many fish observed nibbling on the bait but not removing it completely. As such, fish presence would have been greatly underestimated by following the official Squidpop protocol with no video monitoring and it is suggested that a smaller diameter circle of bait is used in future studies. In this study, it was initially intended for cameras to be left recording for the duration of the experiment. However, with the cameras set on the lowest possible image quality and framerate, this was still not possible due to battery life. As changing batteries in the middle of the experiment would have interfered with fish presence, using intervalometers was attempted at the first deployment to activate the cameras every 20 min, record for 2 min, then deactivate and repeat this cycle. However, the intervalometers failed in the field by only recording one 2 min log then never reactivating. As such, the fish use monitoring cameras were left recording instead and recording times were reduced. Properly functioning intervalometers could provide a better synopsis of fish use in studies designed specifically for such purposes.

Summary

Overall, this research confirms the hypothesis that shading by overwater structures negatively impacts the productivity and distribution of subtidal kelp: a photosynthetic organism. Data were created for which future studies can expand upon by establishing known levels of PAR, sediment size, percent sediment organics, and water depths in which subtidal kelp are found. This can likely be extrapolated for all areas in the sound with comparable inputs. Baseline subtidal kelp densities for control areas and dock areas, distribution maps, and estimated productivity from morphometric measurements and biomass sampling in this research can all be used in ongoing investigations. Additionally, light availability differences within varied depths were recorded and extinction coefficients created for all study sites in this research. Substrate was analyzed, and fish use differences were recorded between sites. GIS shapefiles created for all recorded data can be used to conduct change over time analyses of these three areas and can be used to develop predictive models for potential dock impacts to other subtidal kelp populations. Most importantly, the subtidal kelp survey protocol developed for this research is effective, affordable, easily replicable, and adaptable to be implemented in various fields of benthic research.

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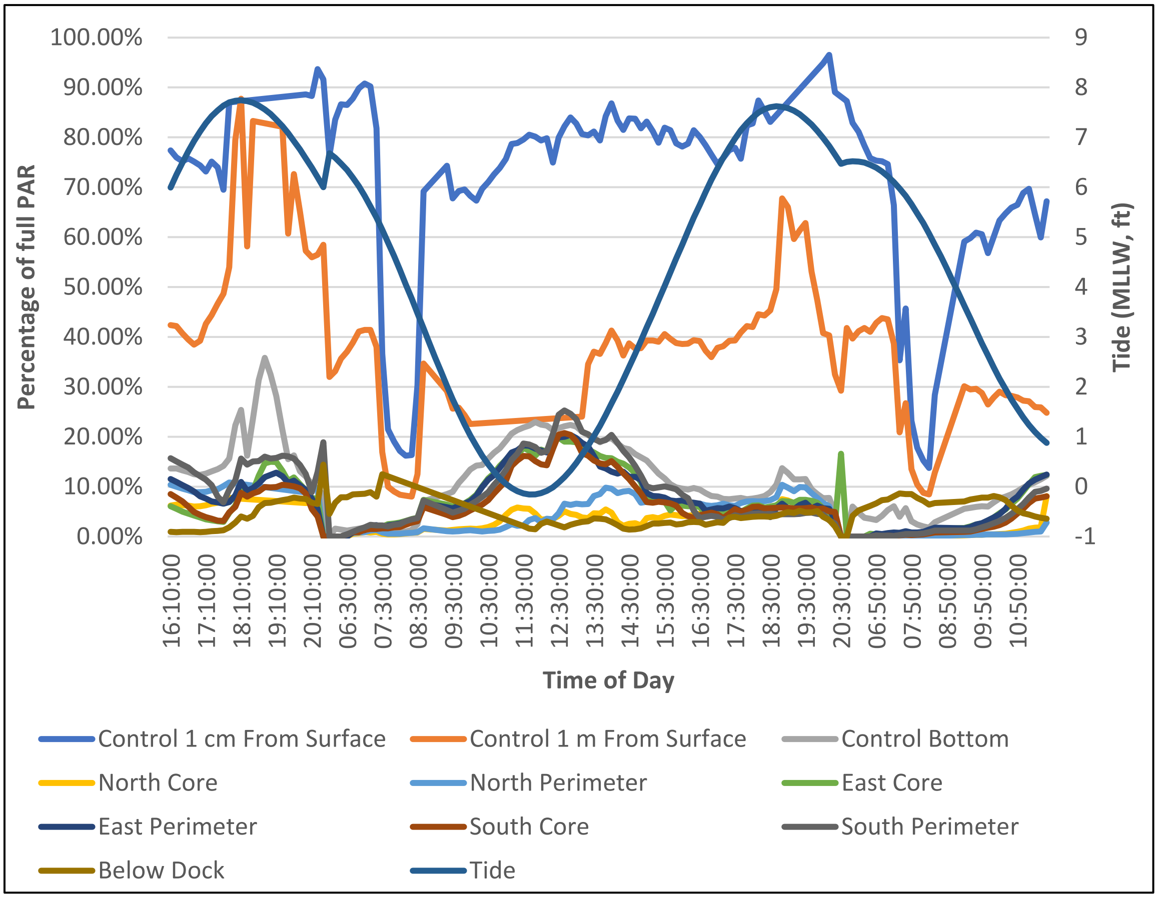
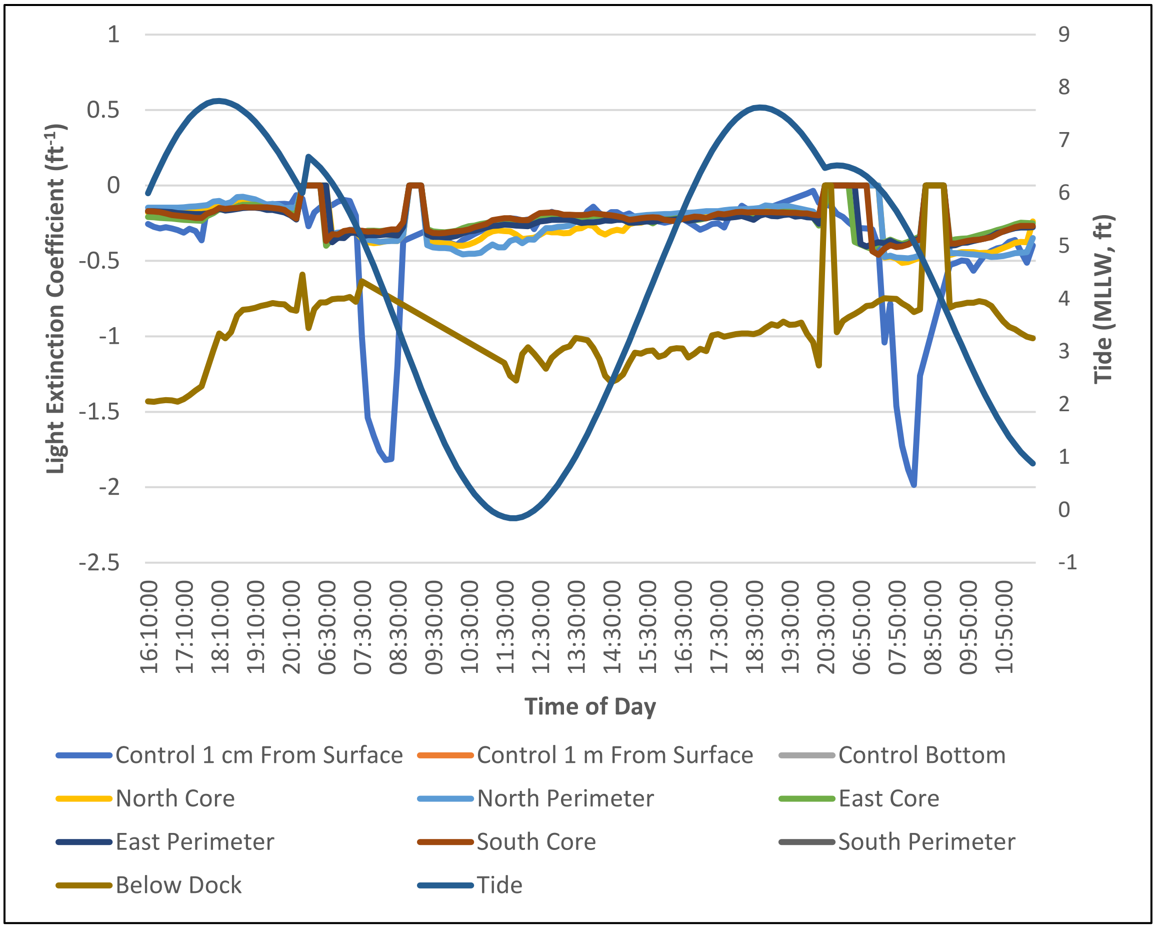
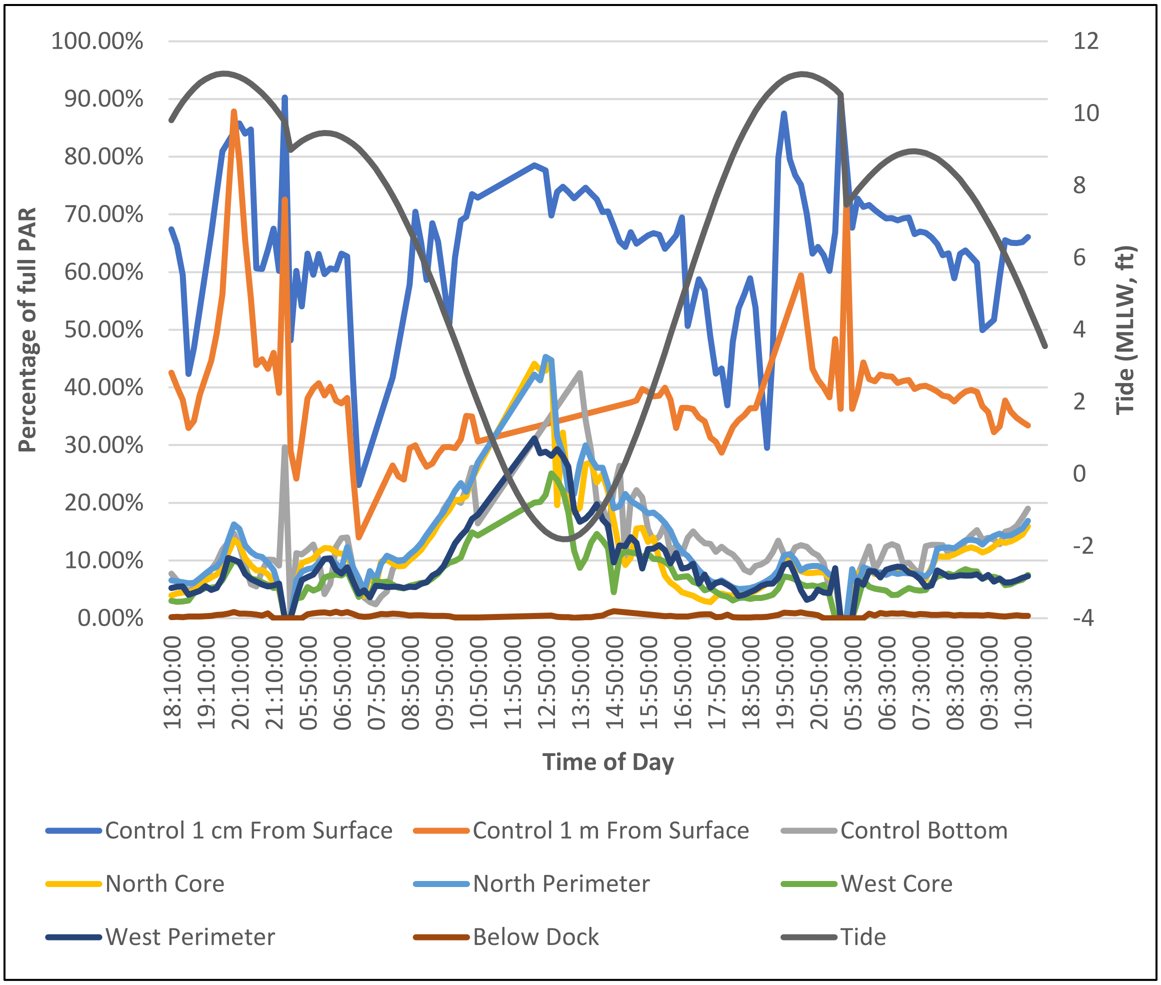
APPENDIXES



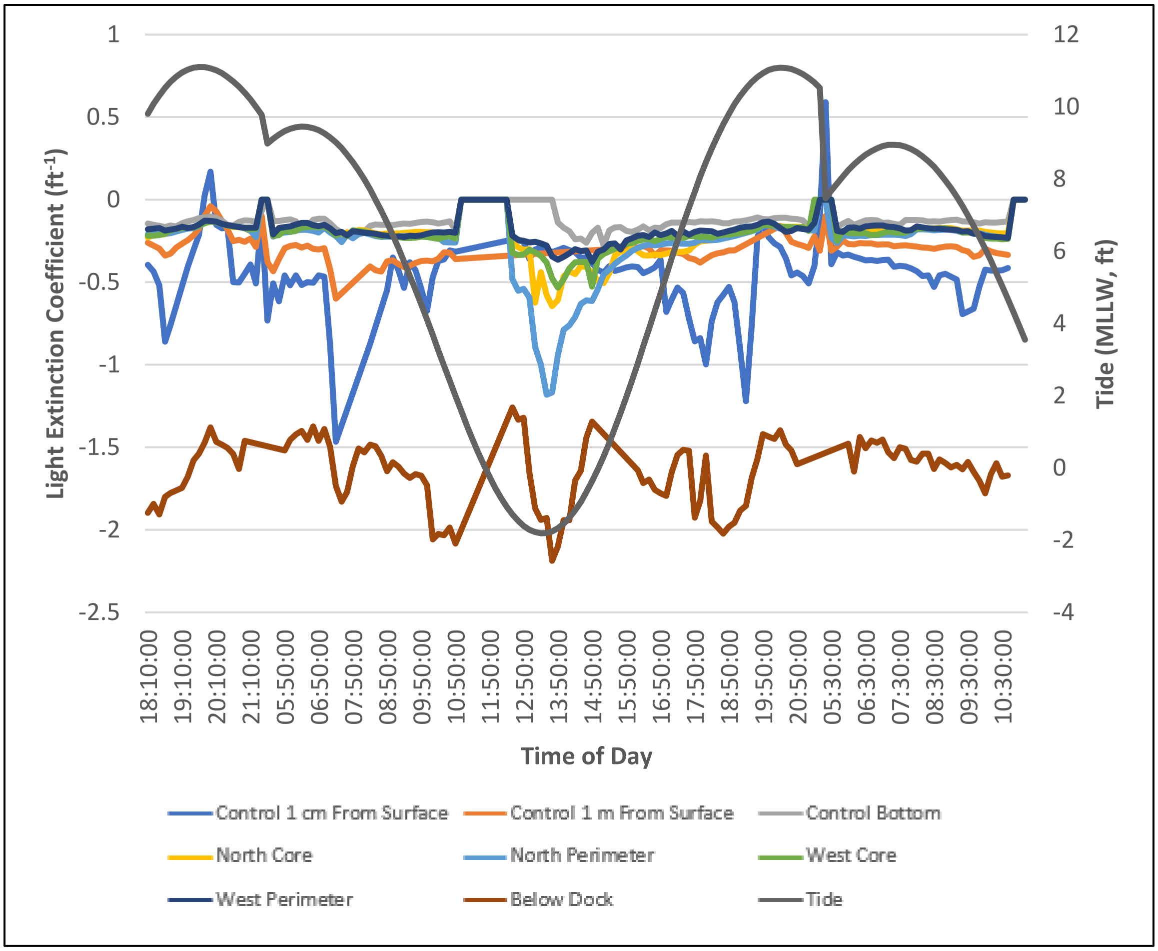
Appendix A. *Submerged PAR sensor readings (% of full PAR above water) and tide level (MLLW, ft) at Bowman Bay, late summer, 2017.*



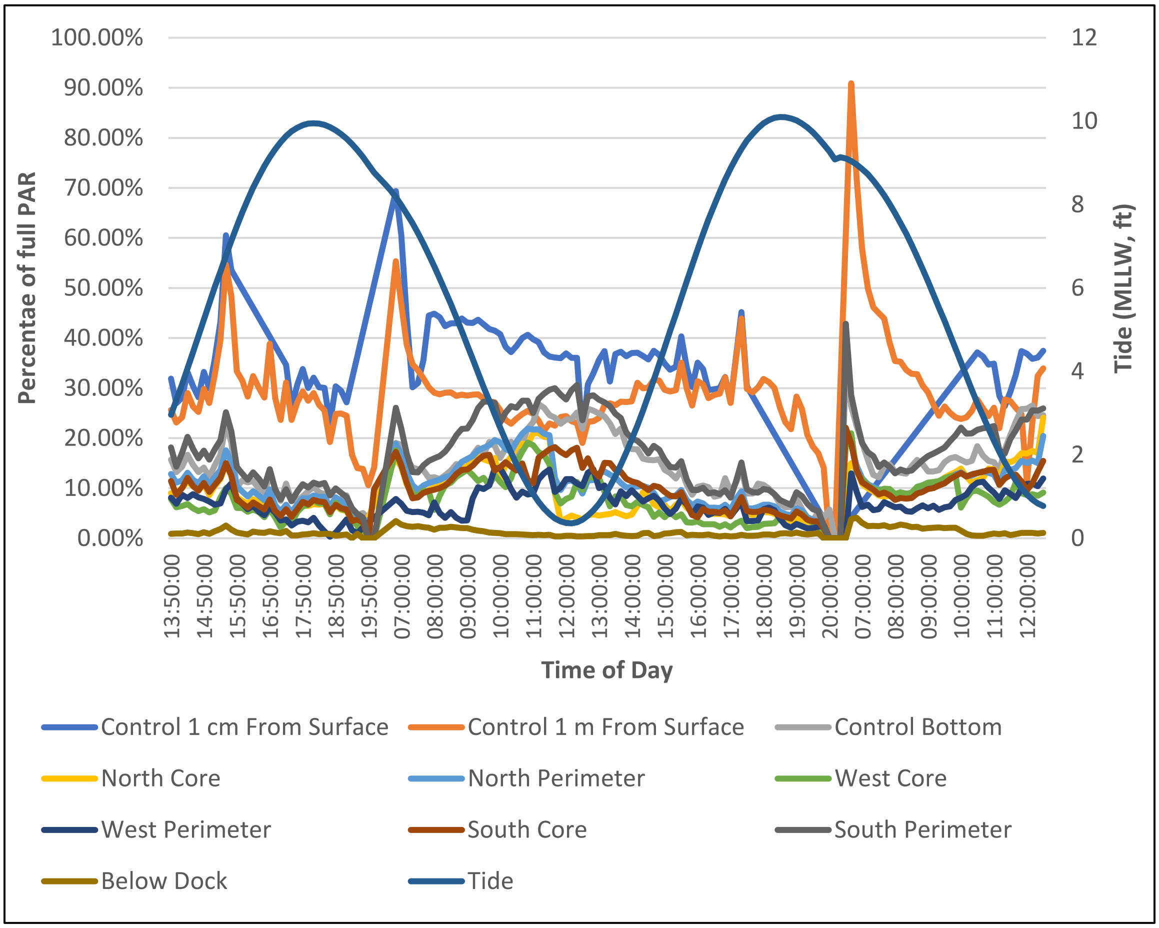
Appendix B. *Light extinction coefficients (ft^{-1}) and tide level (MLLW, ft) at Bowman Bay, late summer, 2017.*



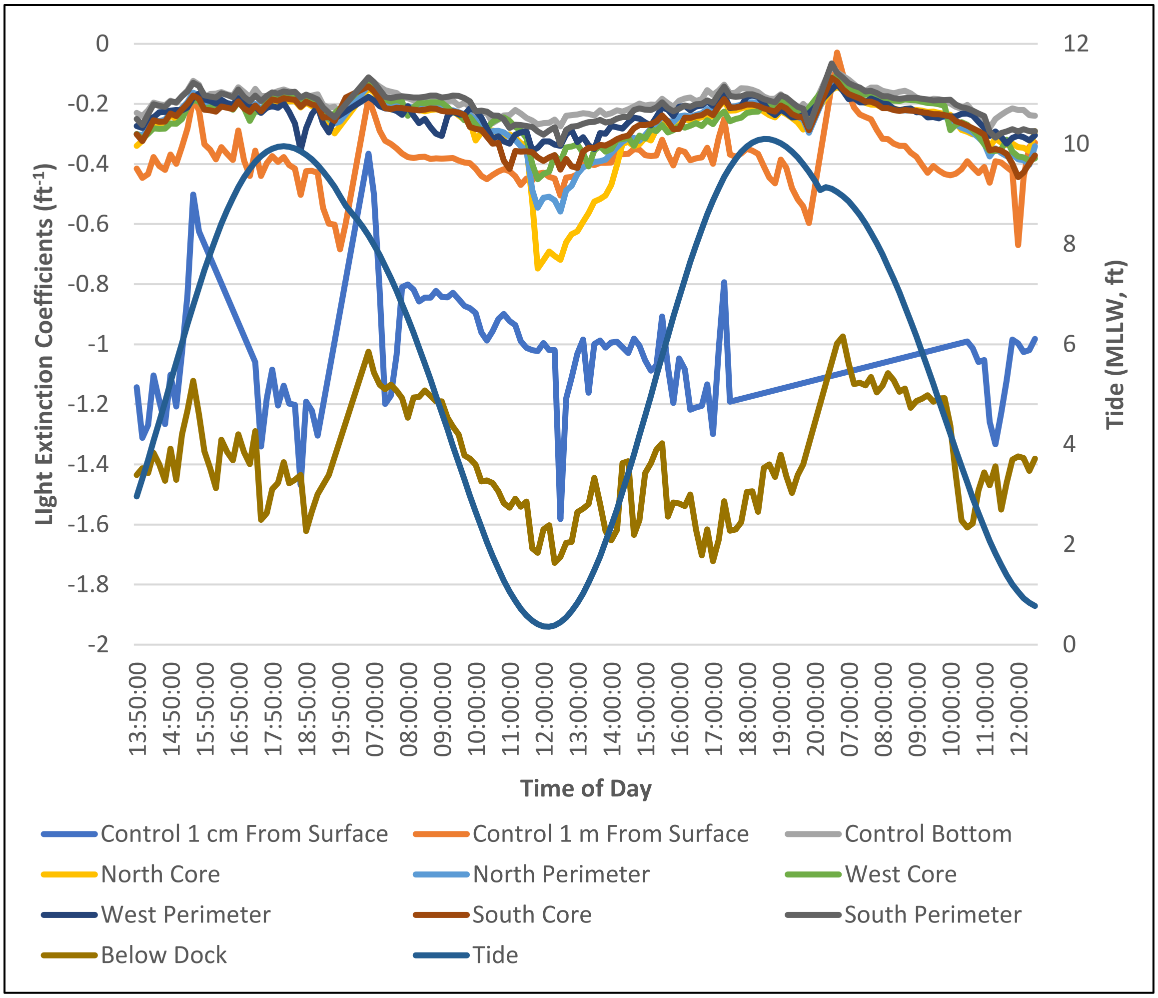
Appendix C. *Submerged PAR sensor readings (% of full PAR above water) and tide level (MLLW, ft) at Cornet Bay, early summer, 2017.*



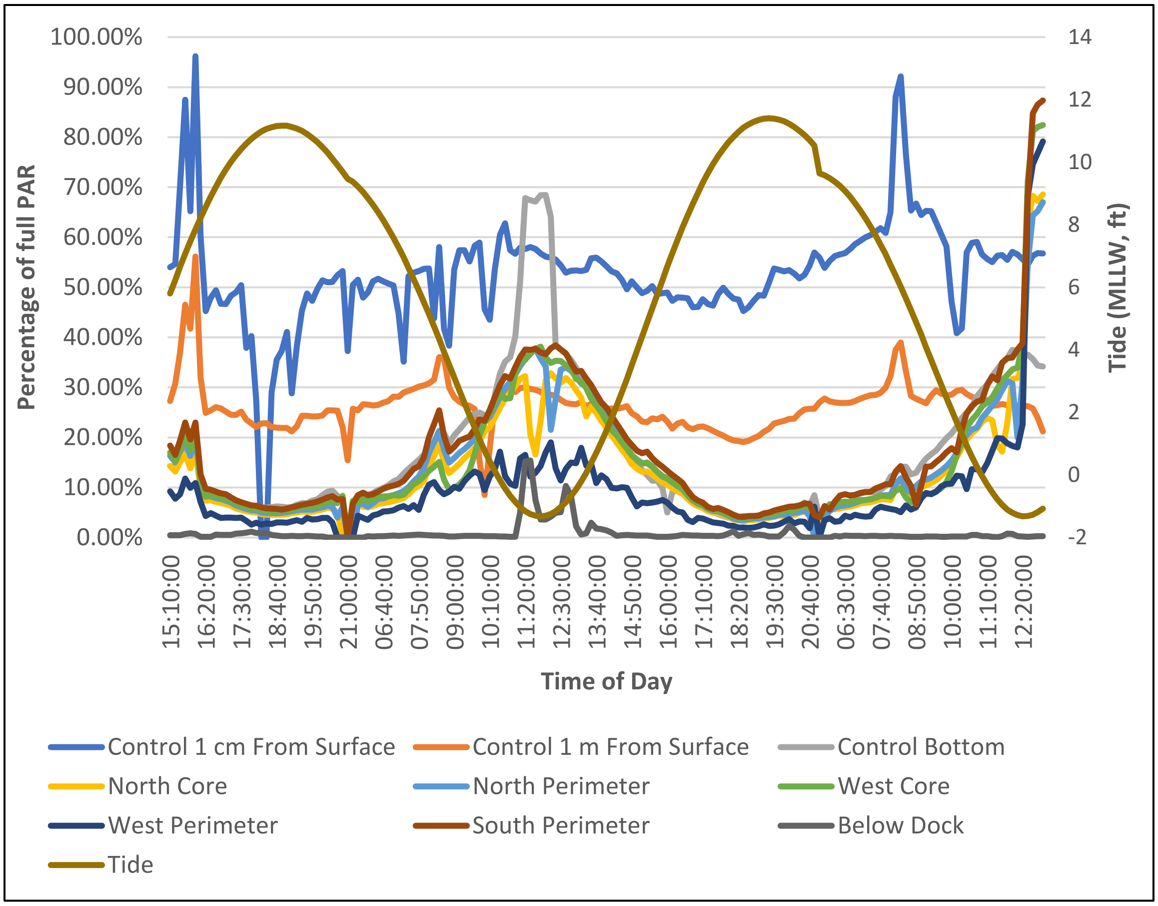
Appendix D. *Light extinction coefficients (ft^{-1}) and tide level (MLLW, ft) at Cornet Bay, early summer, 2017.*



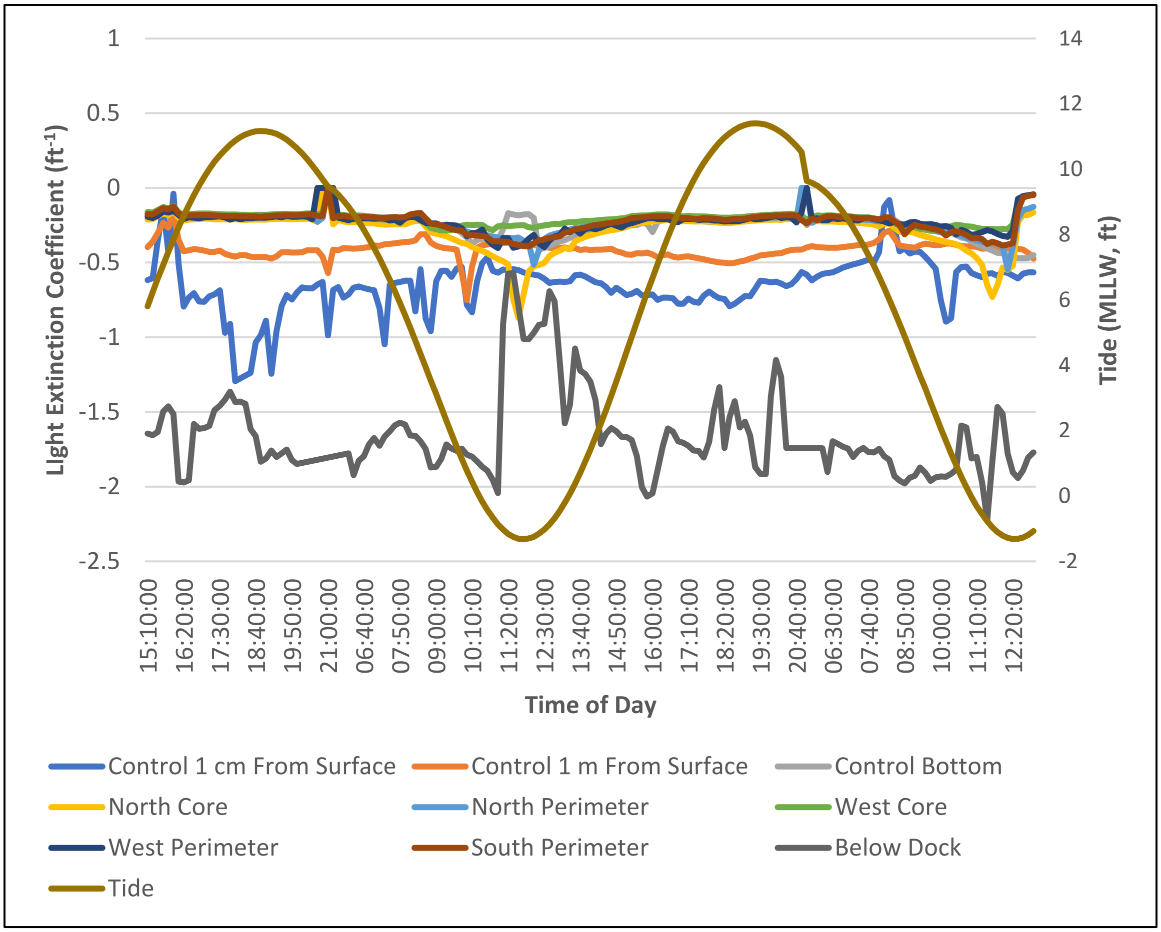
Appendix E. *Submerged PAR sensor readings (% of full PAR above water) and tide level (MLLW, ft) at Cornet Bay, late summer, 2017.*



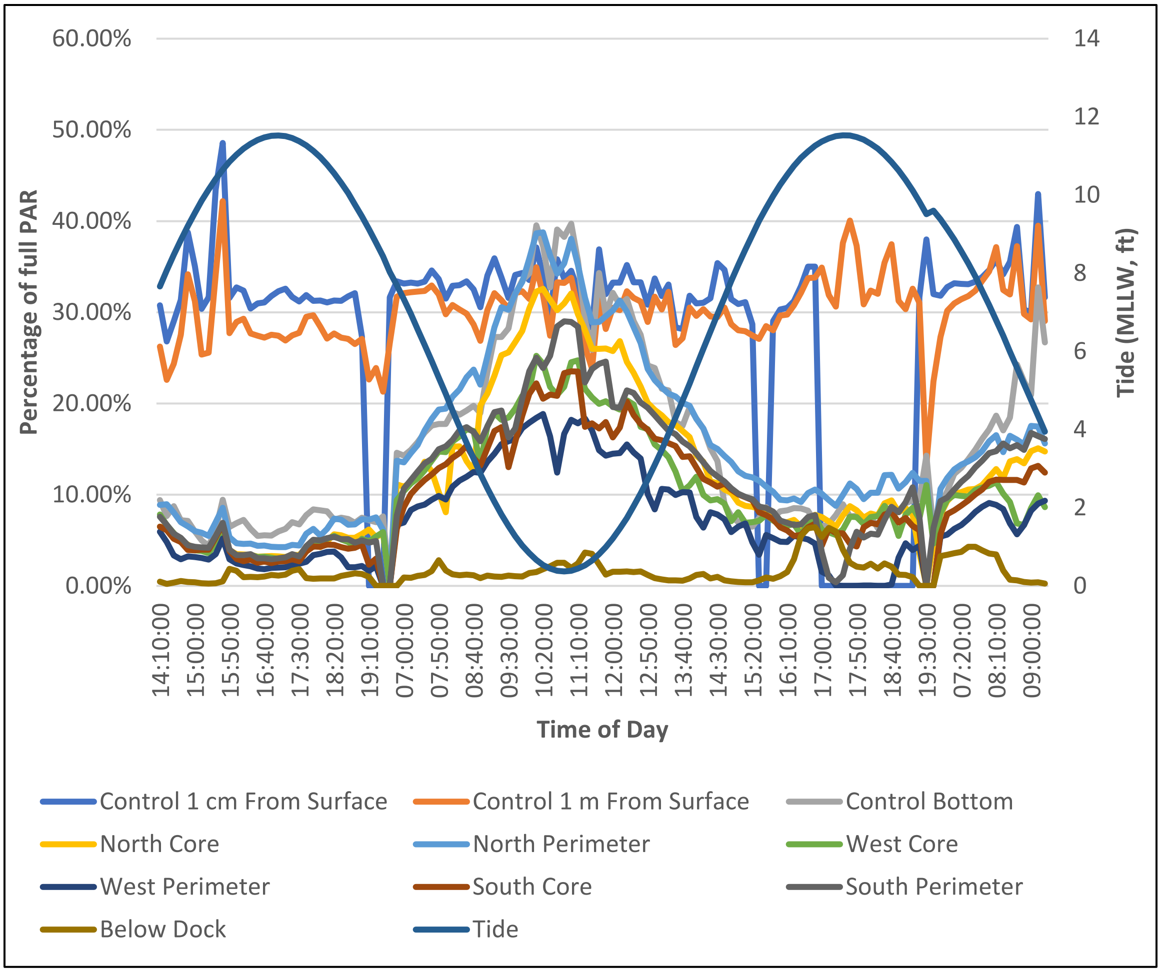
Appendix F. *Light extinction coefficients (ft^{-1}) and tide level (MLLW, ft) at Cornet Bay, late summer, 2017.*



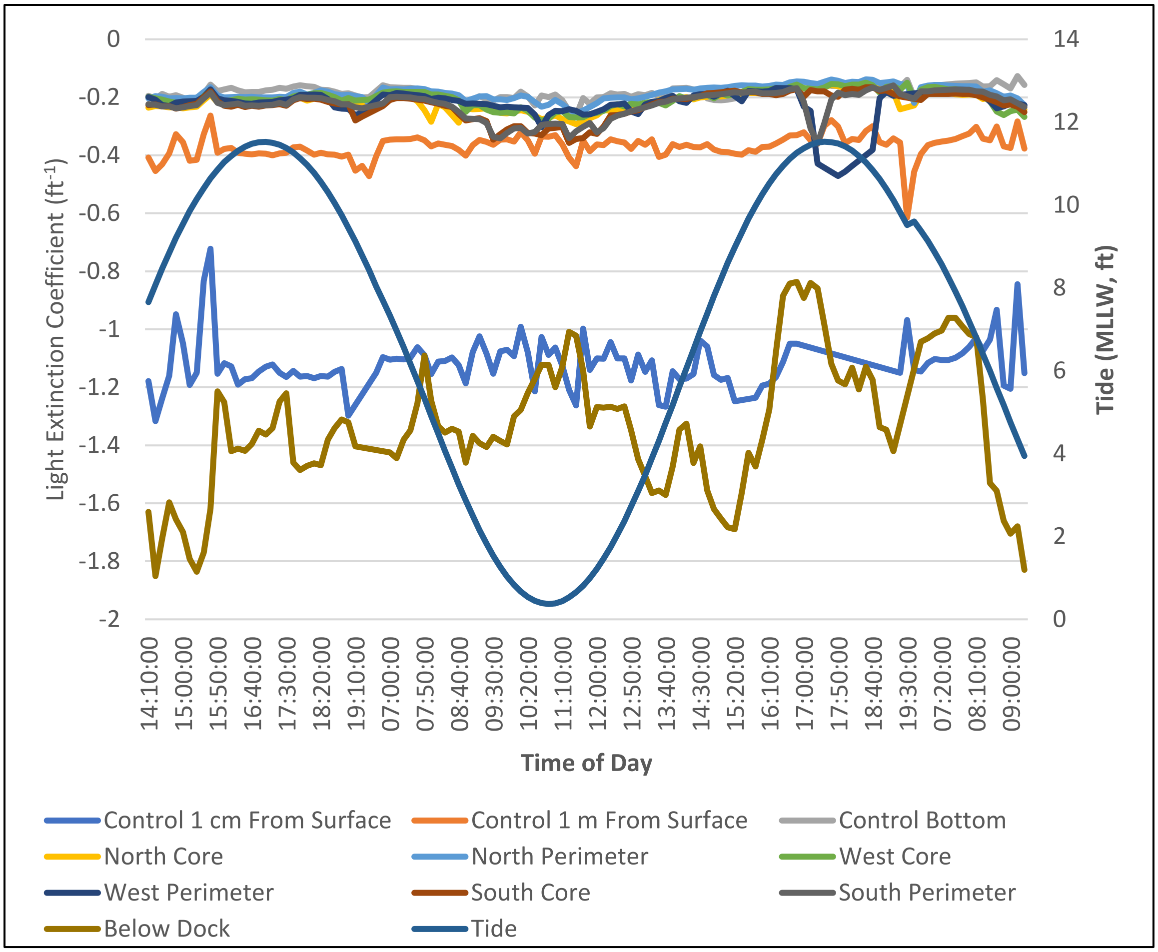
Appendix G. *Submerged PAR sensor readings (% of full PAR above water) and tide level (MLLW, ft) at Camano Island, early summer, 2017.*



Appendix H. *Light extinction coefficients (ft^{-1}) and tide level (MLLW, ft) at Camano Island, early summer, 2017.*



Appendix I. *Submerged PAR sensor readings (% of full PAR above water) and tide level (MLLW, ft) at Camano Island, late summer, 2017.*



Appendix J. *Light extinction coefficients (ft^{-1}) and tide level (MLLW, ft) at Camano Island, late summer, 2017.*