Port Gamble Bay Eelgrass (*Zostera marina*) Restoration Monitoring Final Report

Port Gamble S'Klallam Tribe Natural Resources Department
Hans Daubenberger
Emily Bishop, Westward Ecology
Katy Davis
Julianna Sullivan

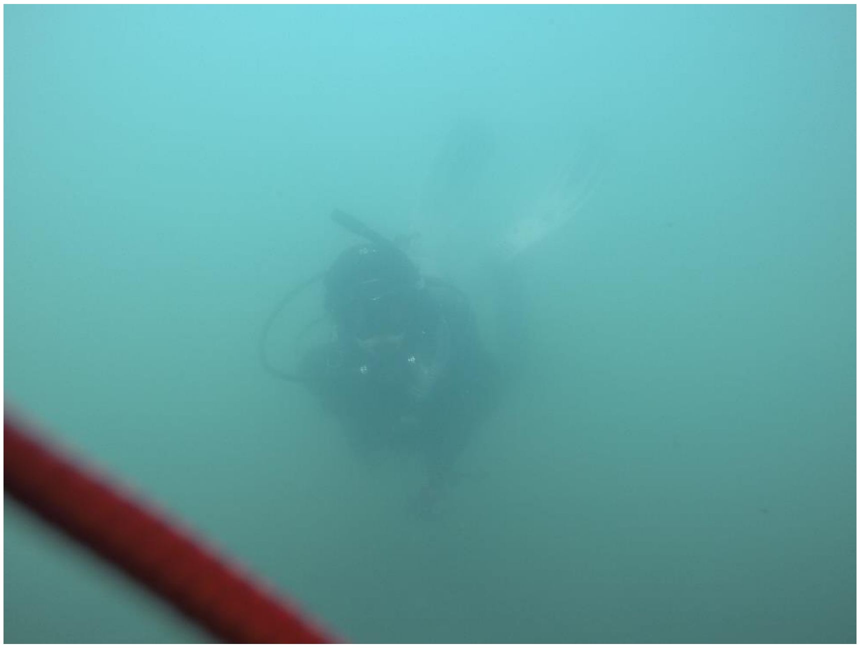

Photo of Katy Davis by Hans Daubenberger
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Background

In April of 2015, the Washington Department of Ecology in collaboration with the Washington Department of Natural Resources and the Pacific Northwest National Laboratory (PNNL), transplanted approximately twenty-four thousand eelgrass *(Zostera marina)* shoots into four plots along the south shore of Port Gamble Bay. The planted plots are located in an area known to have historically supported eelgrass beds, reportedly through the 1950s, according to local residents. Today eelgrass is largely absent from the southern shore of Port Gamble Bay. During the April 2015 event, four restoration plots totaling approximately 2.08 acres were planted with eelgrass from a nearby donor bed. The planting resulted in a checkerboard distribution of newly transplanted shoots. The checkerboard planting design was intended to promote the reestablishment of the largest eelgrass bed size, with the fewest number of transplanted shoots.

Following the April 2015 eelgrass transplanting, PNNL prepared a report titled: Port Gamble Eelgrass Restoration Project Summary PNNL-24432. The report describes the background, goals, methods and recommendations associated with this project. The project monitoring recommendations included in the PNNL report are the subject of this monitoring summary. The Port Gamble S'Klallam Tribe (PGST) strove to follow the annual monitoring recommendation provided by PNNL, however due to budgetary restraints this scope of work only covers one year of monitoring as opposed to the five recommended in the report.

Methods

Water Quality

In February of 2016 PGST located the four restoration sites using a GoPro video drop cam, and subsequently deployed dual Sea-Bird Coastal PAR SB photosynthetically active radiation (PAR) sensors, an Onset HOBO Conductivity Logger U24-002-C, and an Onset HOBO Water Level Logger U20L-02 on April 30, 2016. The PAR sensor system consisted of two sensors suspended on a steel frame, at 0.5m and 1m from the bottom, and was deployed outside of Restoration Plot 3 to avoid the possibility of impacting eelgrass growth at the site. Temperature monitors were placed at each of the four restoration plots, the donor bed, and at a reference eelgrass bed at Hood Head (approximately 7.8km away from the restoration site). Additionally, an Onset HOBO Water Level Logger U20-001-04 was deployed at sea level to record barometric pressure and was used to correct the in-water U20L-02 data.

PGST biologists conducted monthly monitoring at the restoration and reference sites by deploying a YSI EXO2 Sonde and an additional Sea-Bird Coastal PAR sensor at each plot for approximately 5 minutes. The data collected during these sampling events were used to correct the long-term PAR deployment values which were affected by biological growth on the sensor and calibration drift. The longterm PAR sensors and water quality sensors were retrieved for data downloading and cleaning October 12th 2016, after which time PGST decided only one longterm PAR sensor would be needed to provide informative results. A single sensor was re-deployed on October 28th. The PAR sensor memory unexpectedly reached capacity on January 3rd2017, so no data was collected after that time until the sensor was re-deployed on March 10th. The sensor was collected for the final time on June 19th 2017.

Photograph of the dual photosynthetically active radiation (PAR) sensor system first deployed on April 30th 2016 (left) Photograph of the Sonde and PAR sensor deployed monthly (right).

Longterm PAR values were corrected by plot based on the data generated during monthly deployments of the additional PAR sensor. The longterm PAR value[1] taken at the same time and date as the monthly deployment was subtracted from the monthly deployment PAR value[2], producing a correction value for each plot. The correction value was added to each of the longterm PAR values for the corresponding month. When a monthly PAR deployment didn't occur, the conversion values from the preceding and following months were averaged. The November conversion values were used to correct the December longterm data because no monthly deployment occurred in December and longterm PAR values were not collected in January.

Quantitative surveys

Two surveys were conducted via SCUBA during July 18-21st, 2016. PGST constructed a grid made of line the size of a restoration plot, and divers clipped this grid to the helical screw anchors left in place after the restoration planting. Divers used brightly colored markers on the grid to identify the pre-determined places to lay down a 1m^2 quadrat as a boundary in which to quantify eelgrass blades present (Figure 1). This process was used at restoration plots 1 and 4.

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[1] The longterm PAR sensor collected a set of six values at 15 minute intervals. The longterm PAR value referenced here is the average of those six measurements.

[2] The monthly deployment PAR sensor collected six measurements at 30 second intervals. The monthly deployment value is the average of measurements taken during a five minute deployment.

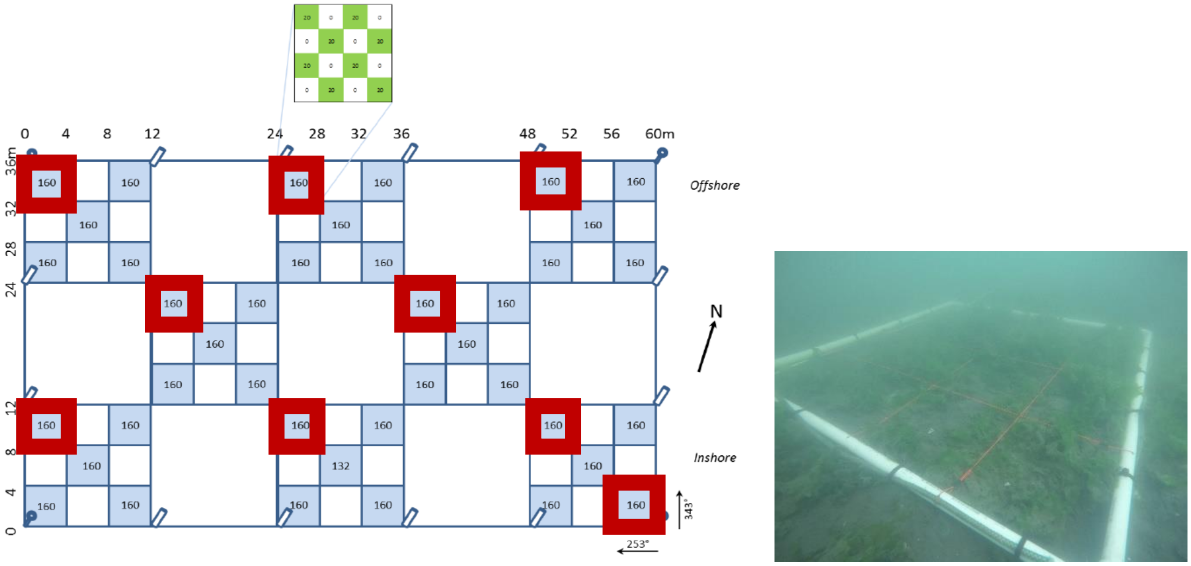


Figure 1. Example planting schematic for eelgrass restoration plots. Shaded squares indicated areas where eelgrass was planted; PGST counted eelgrass shoots within the red outlined areas.

Divers were concerned, because of the low apparent eelgrass survival, that the pre-determined sampling stations may have missed potential survival, so methods were changed for the second dive survey. Restoration plots 2 and 3 were surveyed by dropping a weight at the center of the plot and using an attached meter tape to swim in concentric circles for divers to visually inspect the entire restoration plot area. To confirm that eelgrass which may have exhibited latent development was accounted for, PGST biologists conducted additional snorkel surveys by swimming in concentric circles and randomized transects in restoration plots 1, 3, and 4 in June 2017.

Results

No live eelgrass has been observed in any of the four restoration plots since the 2015 planting event. Dive surveys, drop cams, and the June 2017 snorkel survey found no remaining eelgrass. Several planting staples from the restoration were recovered by PGST biologists during the snorkel and dive surveys. Monthly water quality deployments showed that restoration sites were slightly warmer, fresher, and more turbid than the reference and donor sites and exhibited higher chlorophyll levels across all months except June 2017 (Appendix A). The restoration plots experienced higher water quality variability (Appendix B), which was to be expected given the restoration plots are at the head of a bay while the donor and reference sites are in more exposed areas.

PAR values at the reference sites were higher than values at the restoration sites July through September 2016 (Figure 2). Additionally, corrected values from the bottom longterm PAR sensor show light levels dipped below the minimum required light level for eelgrass in March, April, and May of 2017, a critical time for growth (Figure 2, Thom et al. 2008). This was true for all restoration plots as well as the two reference sites. An alternate analysis of the PAR data can be found in Appendix C.

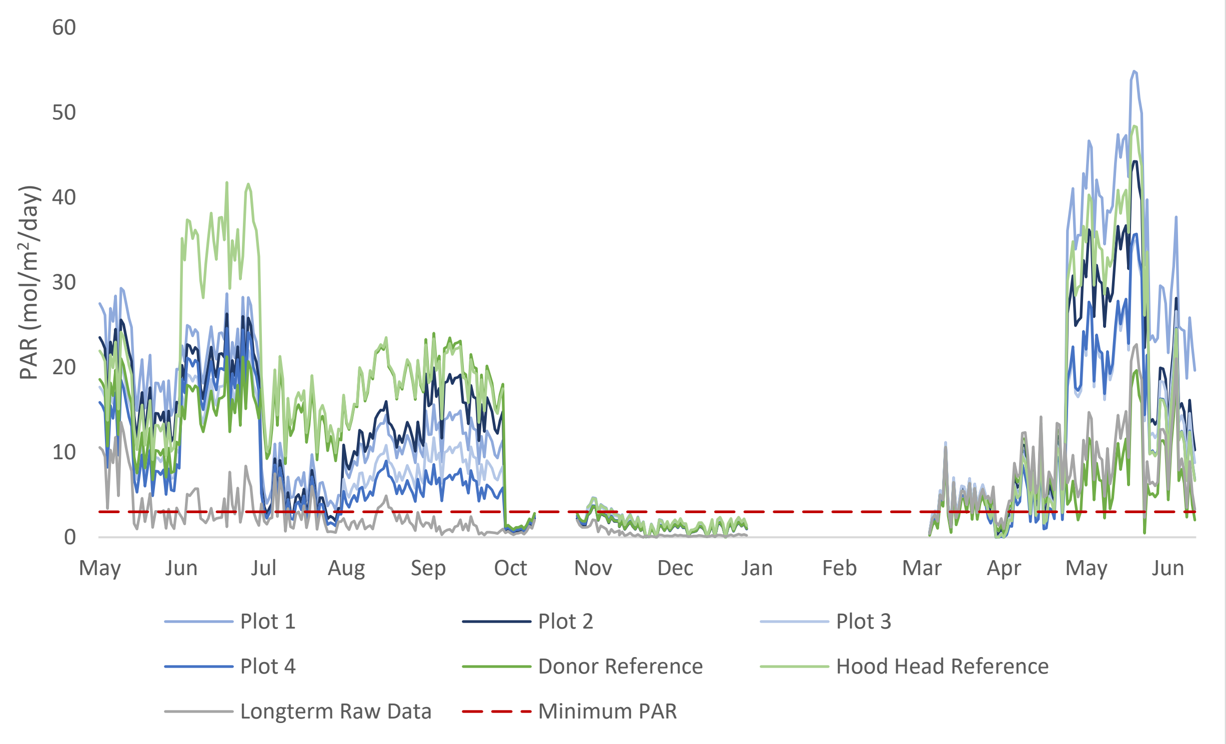


Figure 2. Longterm PAR values corrected using conversion values generated each month May 2016-June 2017 from the individual deployment values for each plot. The conversion value from November was used to correct December data. Weather was too rough during the October sampling event to reach the Hood Head Reference Plot so there is no corrected October data for that plot. The line at 3 mol/m^2/day refers to the suggested minimum average PAR value during spring months to sustain an eelgrass population (Thom et al. 2008). During analysis, raw values less than 5 µmol/m^2/sec were changed to 0 µmol/m^2/sec to standardize nighttime light levels.

Conclusions

Site selection

Prior to the large-scale restoration planting, the survival rate of the Port Gamble Bay test transplant plots ranged between 0.8 and 18% (PNNL 2015). The lack of success was attributed to a late-season planting, a storm event shortly after the planting, and an early season assessment which may have missed some of the smaller plants (PNNL 2015). However, when developing the environmental condition index (ECI) for Puget Sound, Port Gamble Bay was assessed as having a low eelgrass restoration potential (PNNL 2014). In that same study, sites with similar results from test plantings were labeled as “do not plant” while the one test site which exhibited a success rate similar to the best test plot in Port Gamble Bay was selected for a trial planting and ultimately experienced 100% mortality (PNNL 2014). Environmental factors which were not measured during the test planting phase (nutrient loads, year-round light levels) may have precluded eelgrass survival at the south end of Port Gamble Bay.

Planting density

At 20shoots/m^2 (PNNL 2015), the density of shoots planted in Port Gamble Bay was quite low compared to other restoration plantings (Fonesca et al. 1996, Fonesca et al. 1998, Orth et al. 1999, Short et al. 2006). In the future, it may be useful to plant at densities similar to the naturally occurring densities observed in the donor bed (Eelgrass Restoration and Biological Resources Implementation Workplan).

Bioturbation

Dungeness, red rock, graceful, and kelp crabs were all observed moving into the new eelgrass beds during the April 2015 planting (PNNL 2015). Bioturbation, or disturbance by live animals, can be a chronic cause of eelgrass transplant failure (Ralph et al. 2007, Paling et al. 2009). In New England, transplanting methods have been developed specifically with the intent to exclude bioturbating organisms from the vulnerable shoots (Short et al. 2006). Bioturbation is an issue to the extent that the eelgrass restoration model used in Massachusetts requires less than 1 crab/m^2 to meet restoration potential (Short et al. 2002). Reducing bioturbation has been identified as a main challenge for eelgrass restoration throughout Puget Sound and may have been a serious hurdle for transplanted eelgrass in Port Gamble Bay (Mumford 2007, PNNL 2014).

Macroalgal presence & Nitrogen loading

High nutrient loading has been cited as one of the prominent eelgrass stressors in Puget Sound (Hauxwell et al. 2003, Short 2014). High levels of ammonium and nitrates can be toxic to eelgrass, as it has no mechanism to inhibit nitrogen uptake (Moore and Short 2006, Vaudrey 2008). In areas of high nutrient loads eelgrass maybe totally absent and the system may be dominated by macroalgae, as was observed during the PGST dive surveys in Port Gamble Bay (Bohrer et al. 1995, Figure 3). Increased temperature can also exacerbate these effects (Bintz et al. 2003).

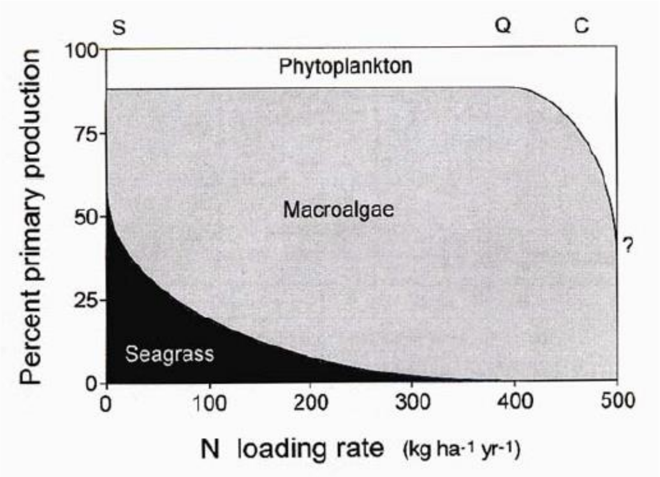


Figure 3. Nitrogen loading proportions for seagrass, macroalgae, and phytoplankton as observed in three New England estuaries from Valiela et al. 1997.

Eelgrass has been shown to recover naturally when nutrient levels are reduced. In Long Island Sound, wastewater outfall from a municipal facility was diverted to another location from a cove which had 74% *Ulva* cover (Vaudrey et al. 2010). Eelgrass naturally established five years after the outfall relocation, and spread to cover a third of the cove nine years later (Vaudrey et al. 2010). Low circulation and macroalgal presence the southern end of Port Gamble Bay may have created similar conditions where natural recolonization is more likely with reduced nutrient loads and time.

Low light levels & Turbidity

Based on the longterm PAR values (Figure 2 & Appendix C), while not the sole factor, light was likely limiting potential growth and survival during the months of July, October, November, December, January, February, March, and April. Additionally, macroalgae abundance, as apparent in the relatively high chlorophyll measurements recorded at the restoration sites, likely exacerbated low light conditions (Appendix A, Figure 1). Mvungi et al. (2012) found that one layer of macroalgae may decrease light by up to 50%, and three layers may decrease it by 80%.

Restoration efforts can be ineffective because of high turbidity levels. In some cases the high turbidity may be a direct result of the lack of eelgrass, which is benefited by a positive feedback loop (vanderHeide et al. 2007). In Port Gamble Bay, the restoration sites frequently showed higher turbidity than the two reference sites (Appendix A, Figure 6). PGST divers observed higher turbidity resulting from the Port Gamble Bay cleanup which occurred between September 2015 and January 2017. The project included excavating and dredging 120,000 cubic yards of marine sediment and placement of over 100,000 tons of capping material to restore Port Gamble Bay and the former mill site at the mouth of the bay, approximately 1.6km from the PNNL eelgrass restoration plots (http://www.portgamblebaycleanup.com/). A combination of high nutrient loads and sediment stirred up by the Port Gamble Bay cleanup may have caused turbidity to increase to levels harmful to the growth of the newly planted eelgrass.

Photo of restoration capping in Port Gamble Bay in July 2016 by Hans Daubenberger

Recommendations

PGST recommends testing nutrient levels in Port Gamble Bay. If nitrate and ammonium concentrations are not too high for eelgrass growth, a follow up test planting at a higher density, possibly using cores or sod, may be appropriate (see pilot study summary, Appendix D). PGST biologists have previously observed eelgrass on the western shore of Port Gamble Bay north of the restoration planting site. In the future, test sods or cores with naturally occurring eelgrass density and preserved root structures could be planted at intervals starting at the southern extent of the existing eelgrass bed as shown in Figure 4. Higher densities may encourage a positive feedback loop to promote healthy conditions for growing eelgrass, and planting at these intervals may help determine the southernmost extent of viable eelgrass habitat in Port Gamble Bay. See Appendix A for details on a pilot study conducted to investigate alternate planting methods.

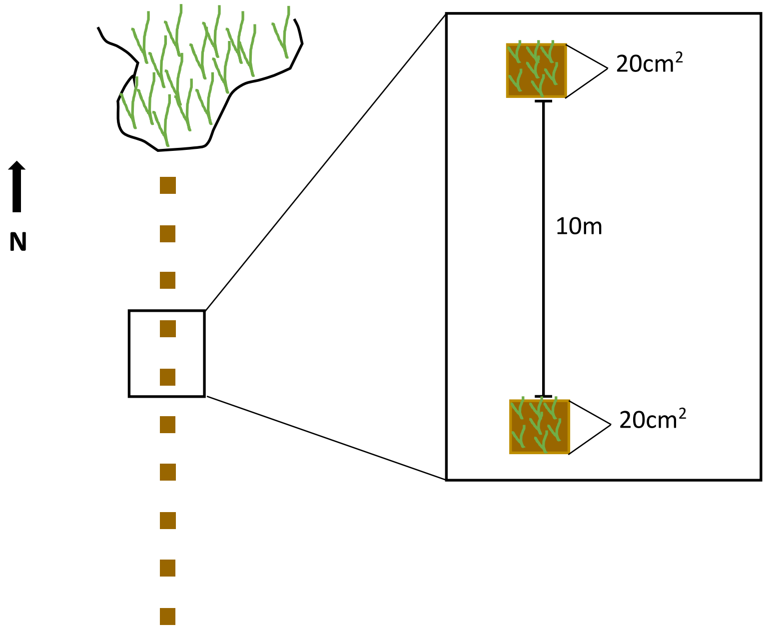


Figure 4. Proposed planting plan for testing sod transplantation. Starting at the southernmost extent of eelgrass currently in Port Gamble Bay, PGST proposes planting 20cm^2 sod every 10m for 100m towards the South end of the bay. Figure is not to scale.

Citations

Bintz, J.C., Nixon, S.W., Buckley, B.A., Granger, S.L. (2003). Impacts of temperature and nutrients on coastal lagoon plant communities. Estuaries 26:765.

Bohrer, T., Wright, A., Hauxwell, J., and Valiela, I. (1995). Effect of epiphyte biomass on growth rate of *Zostera marina* in estuaries subject to different nutrient loading. Biol. Bul. 189:260.

Dennison, W.C. (1987). Effects of light on seagrass photosynthesis, growth, and depth distribution. Aquat. Bot. 27(1):15-26.

Eelgrass Restoration and Biological Resources Implementation Workplan. Grette Associates, Battelle Marine Sciences Laboratory, King County Dept. of Nat. Resources & Parks. Revised April 2008.

Ehlers, A., Worm, B., Reusch, T. (2008). Importance of genetic diversity in eelgrass *Zostera marina* for its resilience to global warming. Mar. Eco. Prog. Ser. 355:1-7.

Fonesca, Mark.S., et al. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, MD. 222 pp.

Hauxwell, J., Cebrian, J., Valiela, I. (2003). Eelgrass Zostera marina loss in temperate estuaries: relationship to land derived nitrogen loads and effect of light limitation imposed by algae. Mar. Ecol. Prog. Ser. 247:59-73.

Hughes, A.R., Stachowicz, J.J. (2004). Genetic diversity enhances the resistance of a seagrass ecosystem to disturbance. PNAS 101(24):8998-9002.

Moore, K.A., Short, F.T. (2006). *Zostera*: Biology, Ecology, and Management. Seagrasses: Biology, Ecology and Conservation, pp. 361-386.

Mumford, T.F. (2007). Kelp and eelgrass in Puget Sound. Puget Sound Nearshore Partnership Report No. 2007-05. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington.

Mvungi, E.F., Lyimo, T.J., Bjork, M. (2012). When *Zostera marina* is intermixed with *Ulva*, its photosynthesis is reduced by increased pH and lower light, but not changes in light quality. Aquat. Bot. 102:44-49.

Paling, E.I., Fonseca, M., van Katwijk, M.M., and van Keulen, M. (2009). Seagrass restoration. Coastal wetlands: an integrated ecosystem approach, pp. 687-713.

Ralph, P.J., Durako, M.J., Enriquez, S., Collier, C. J., Dobin, M.A. (2007). Impact of light limitation on seagrasses. Jol. Exp. Mar. Biol. Ecol. 350:176-193.

Short, F.T., Davis, R.C., Kopp, B.S., Gaeckle, J.L., Burdick, D.M., (2006). Using TERFS and site selection for improved Eelgrass restoration success. In: Treat, S.F., Lewis III., R.R. (Eds.), Seagrass Restoration: Success, Failure, and the Costs of Both. Selected Papers presented at a workshop, Mote Marine

Laboratory, Sarasota, Florida, March 11–12, 2003. Lewis Environmental Services, Valrico, Florida, pp. 59–68.

Short FT. 2014. Nitrogen as an Eelgrass Stressor in Puget Sound, 2014, Aquatic Resources Division, Washington State Department of Natural Resources, Olympia, WA. 37p.

Thom, R.M., Diefenderfer, H.L. Vavrinec, J., Borde, A.B. (2012). Restoring resiliency: Case studies from Pacific Northwest estuarine eelgrass (*Zostera marina L.*) ecosystems. Estuar. Coast. 35:78-91.

Thom, R.M., Southard, S.L., Borde, A.B., Stoltz, P. (2008). Light requirements for growth and survival of eelgrass (Zostera marine L.) in Pacific Northwest (USA) Estuaries.

Thom, R. M., Vavrinec, J., Gaeckle, J. L., Aston, L., Buenau, K. E., & Woodruff, D. L. (2014). Eelgrass (*Zostera marina L.*) Restoration in Puget Sound: Development and Testing of Tools for Optimizing Site Selection. Pacific Northwest National Laboratory. PNNL-23635.

Valiela, I., McClellans, J., Hauxwell, J., Behr., P.J., Hersh, D., Foreman, K. (1997). Macroalgal blooms in shallow estuaries: Controls and ecophysiological and ecosystem consequences. Limnol. Oceanogr. 42(5, part 2):1105-1118.

Vaudrey, J.M.P. (2008). Establishing restoration objectives for eelgrass in Long Island Sound Part 1: Review of the seagrass literature relevant to Long Island Sound.

Vaudrey, J.M.P., Kremer, J.N., Branco, B.F., Short, F.T. (2010). Eelgrass recovery after nutrient enrichment reversal. Aquat. Bot. 93:237-243.

Vavrinec, J., Borde, A.B. (2015). Port Gamble eelgrass restoration project summary. Pacific Northwest National Laboratory. PNNL-24432.

van derHeide, T., van New, E.H, Geerling, G.W., Smolders, A.J.P., Bouma, T.J., van Katwijk, M.M. (2007). Positive feedbacks in seagrass ecosystems: implications for success in conservation and restoration. Ecosystems 10:1311-1322.

Appendix A. Bar graphs showing results of monthly water quality measurements

Figure 1 Average chlorophyll values by site May 2016-June 2017

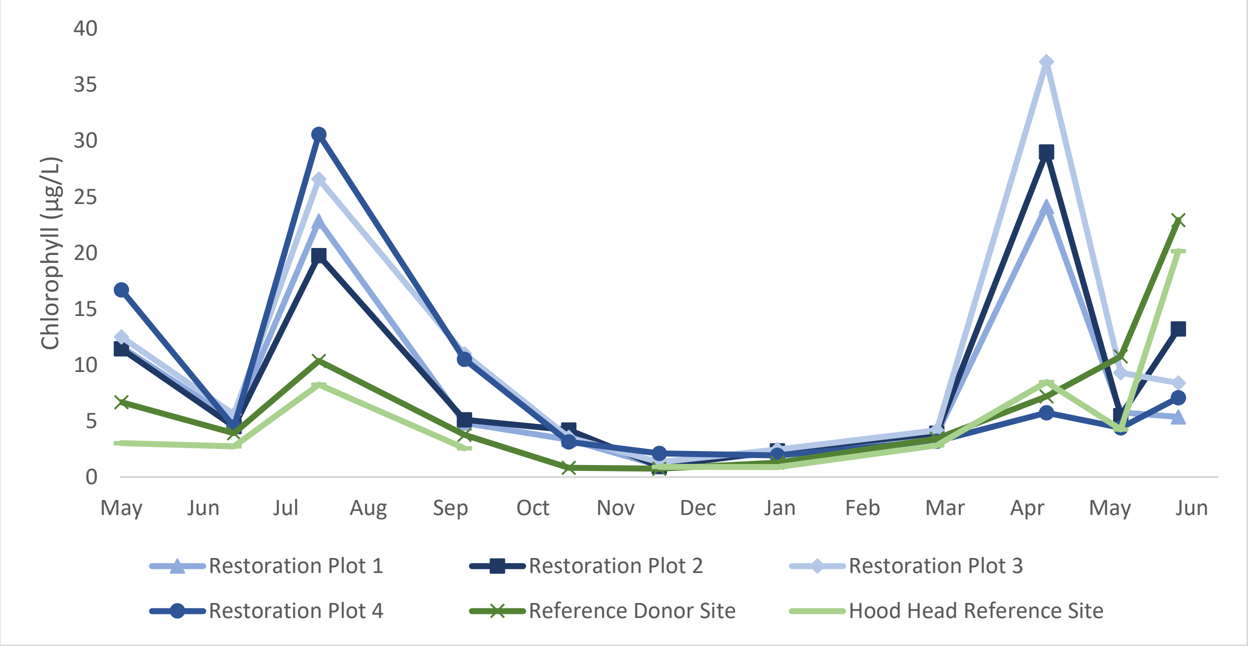


Figure 2 Average dissolved oxygen values by site May 2016-June 2017

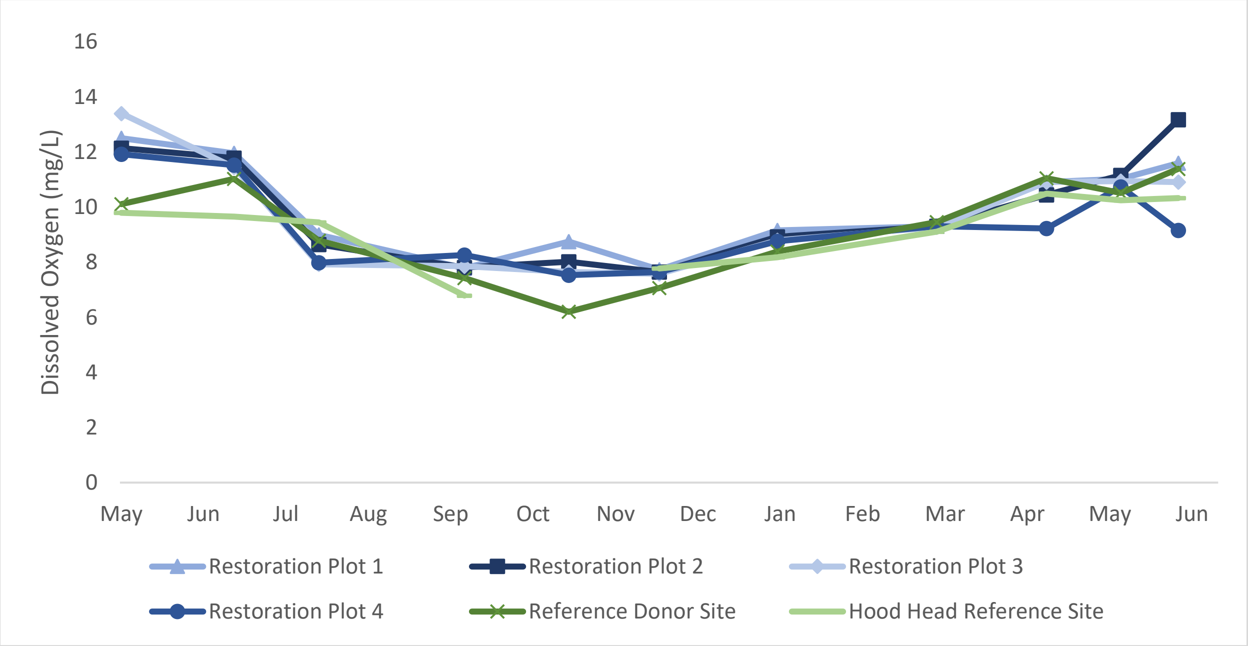


Figure 3 Average pH values by site May 2016-June 2017

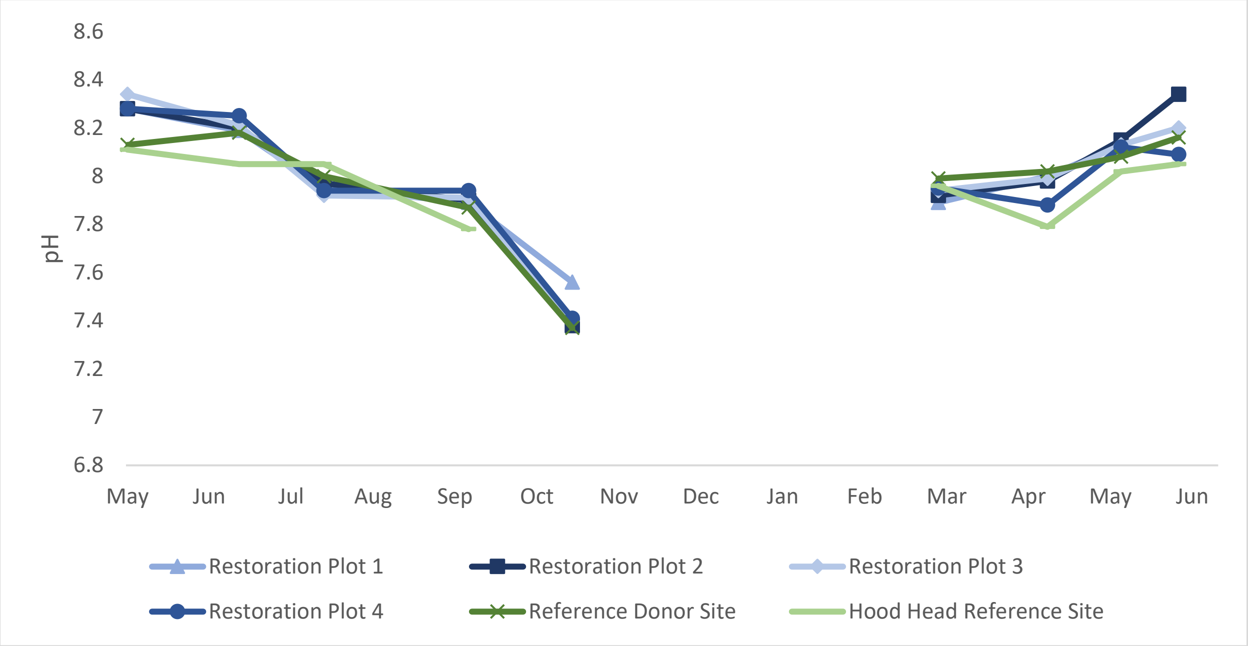


Figure 4 Average salinity values by site May 2016-June 2017

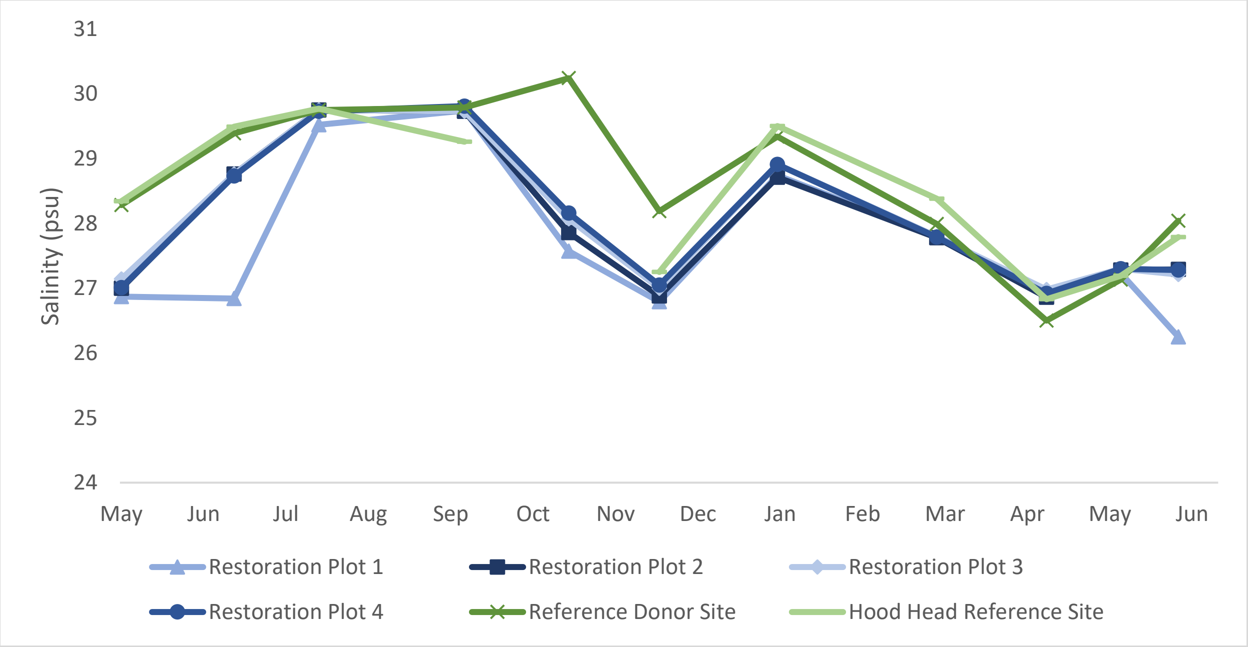


Figure 5 Average temperature values by site May 2016-June 2017

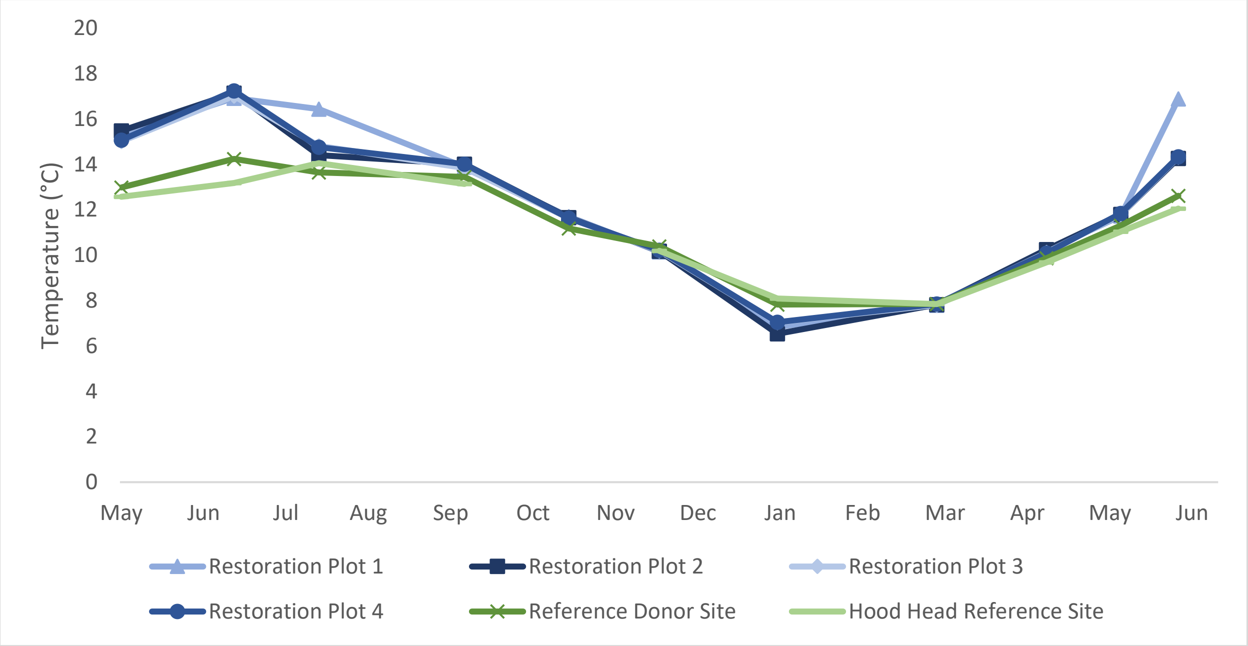
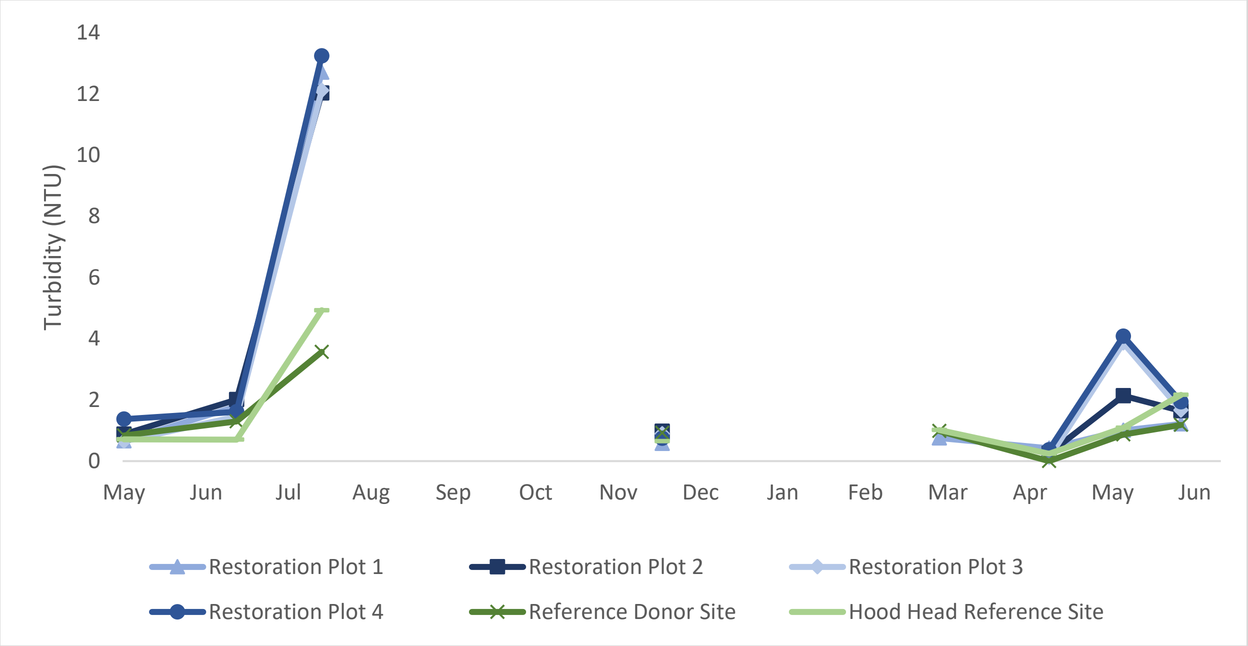


Figure 6 Average turbidity values by site May 2016-June 2017



Appendix B. Box Plots for selected water quality parameters

Figure 1 Average chlorophyll values by site May 2016-June 2017

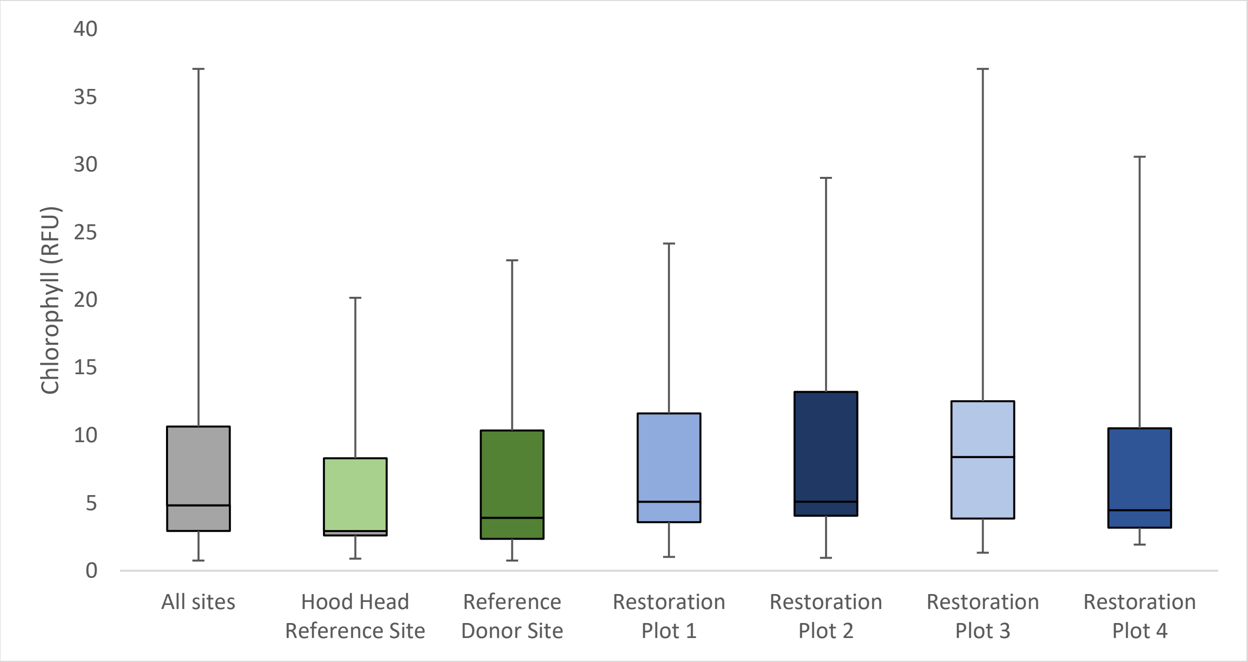


Figure 2 Average dissolved oxygen values by site May 2016-June 2017

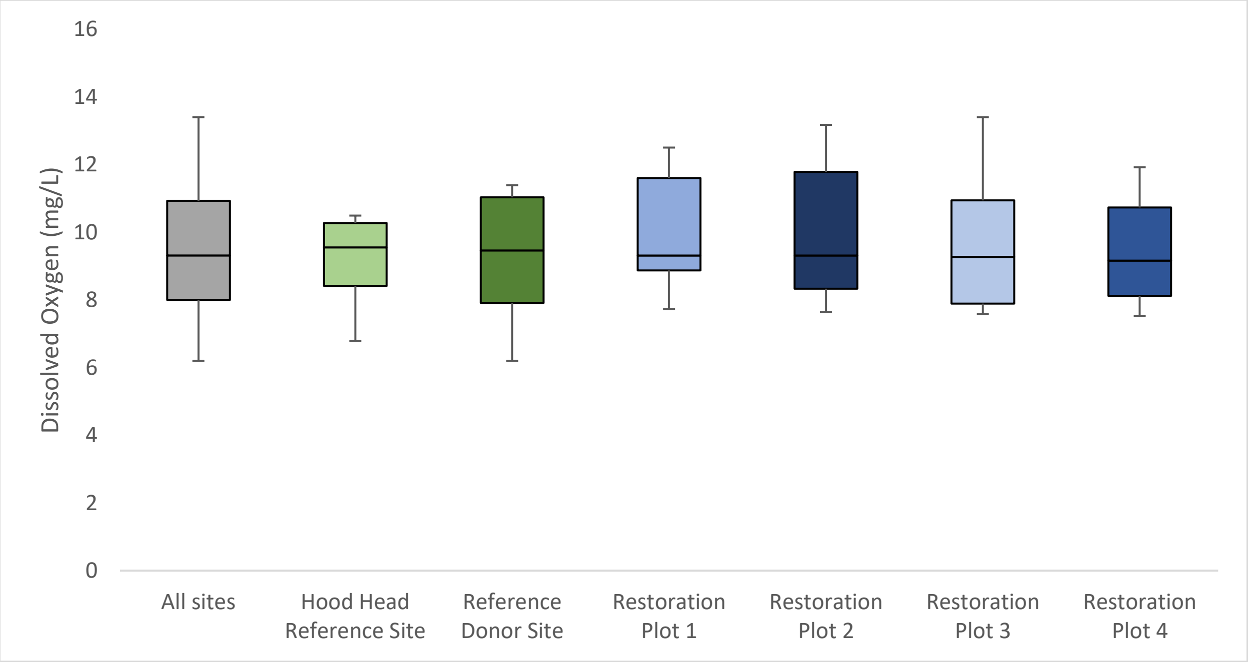


Figure 3 Average pH values by site May 2016-June 2017

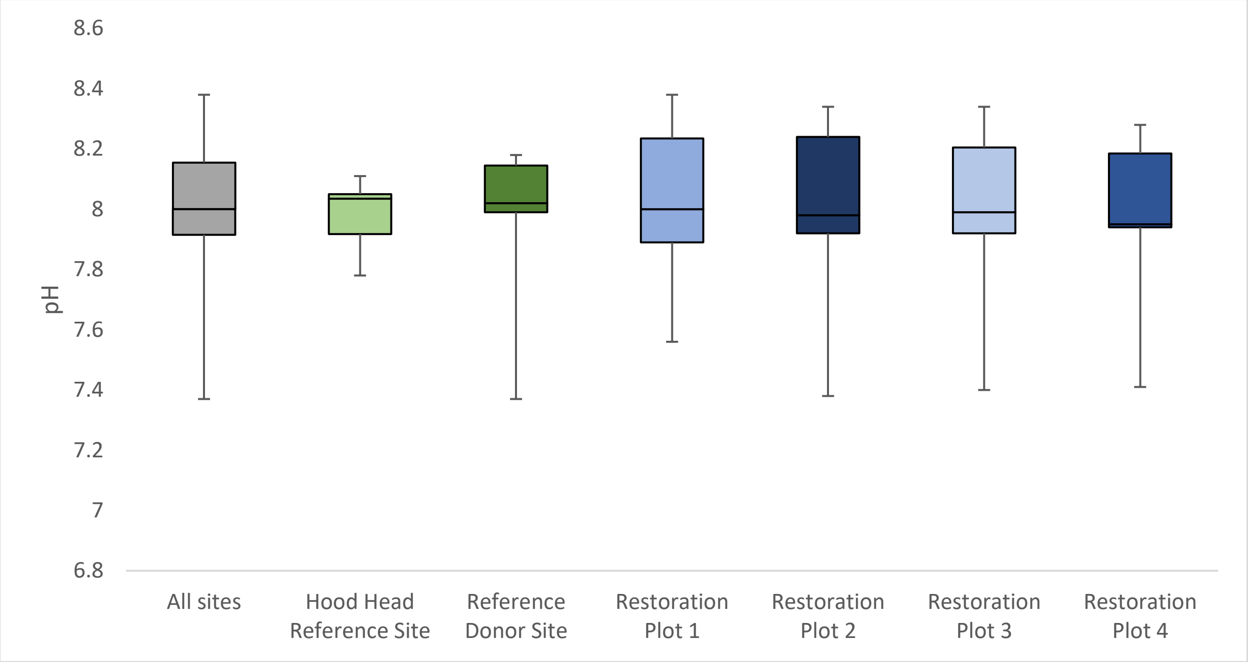


Figure 4 Average salinity values by site May 2016-June 2017

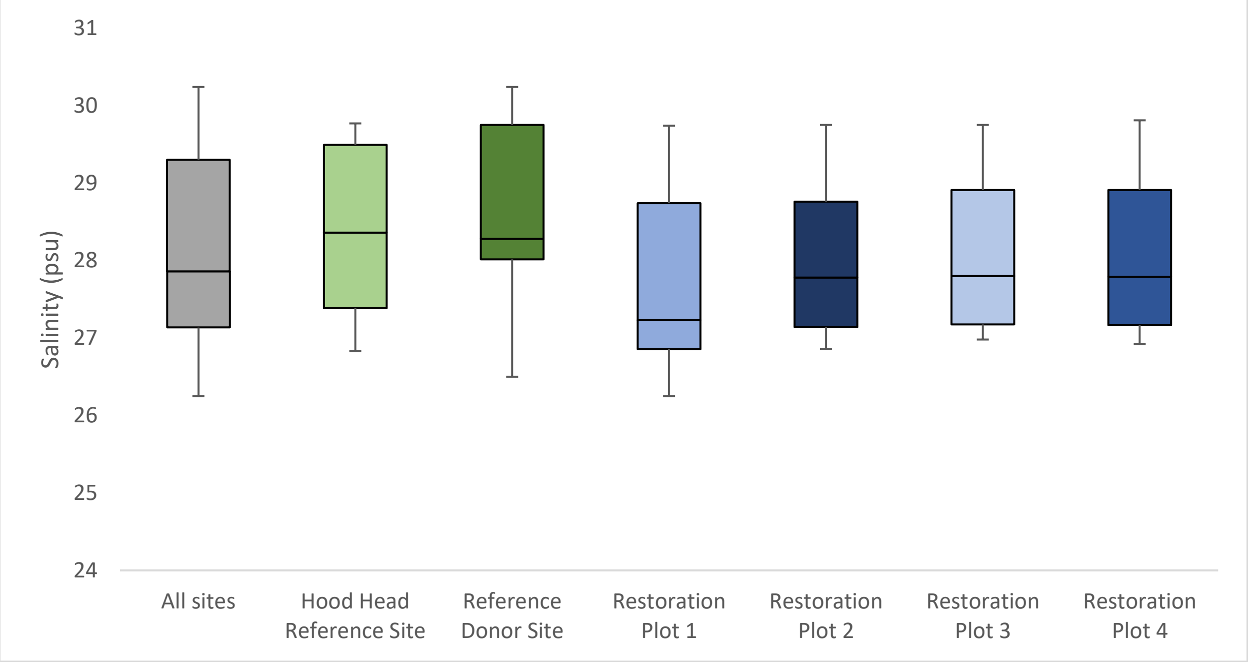


Figure 5 Average temperature values by site May 2016-June 2017

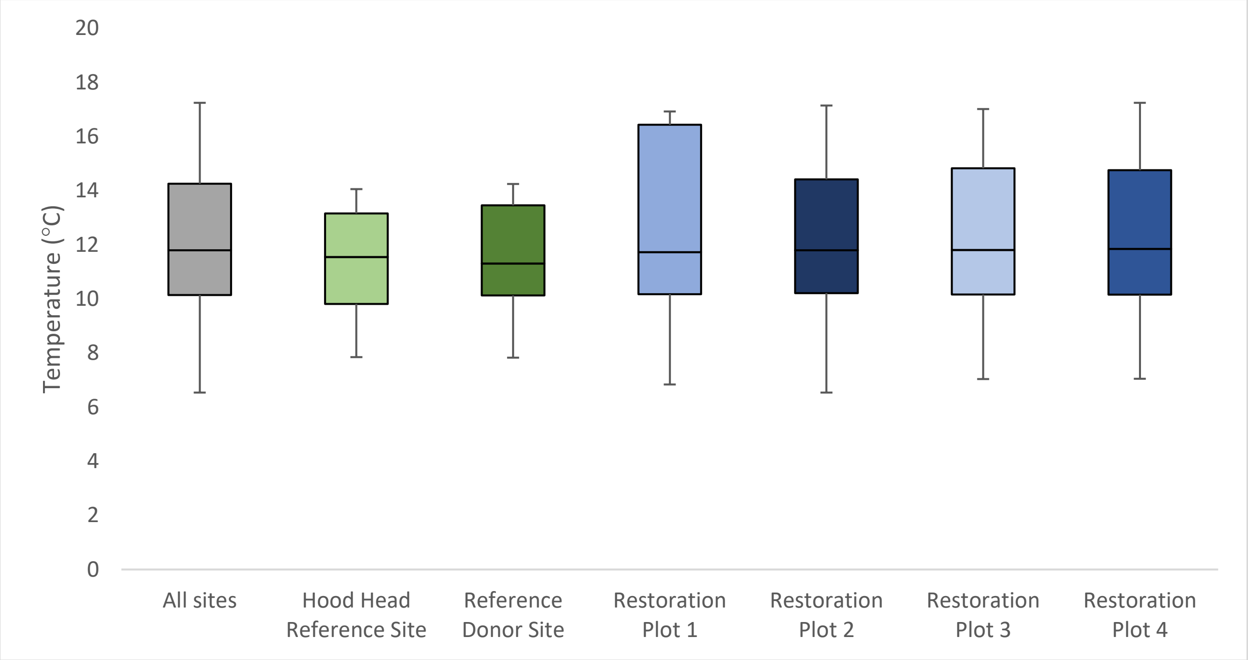
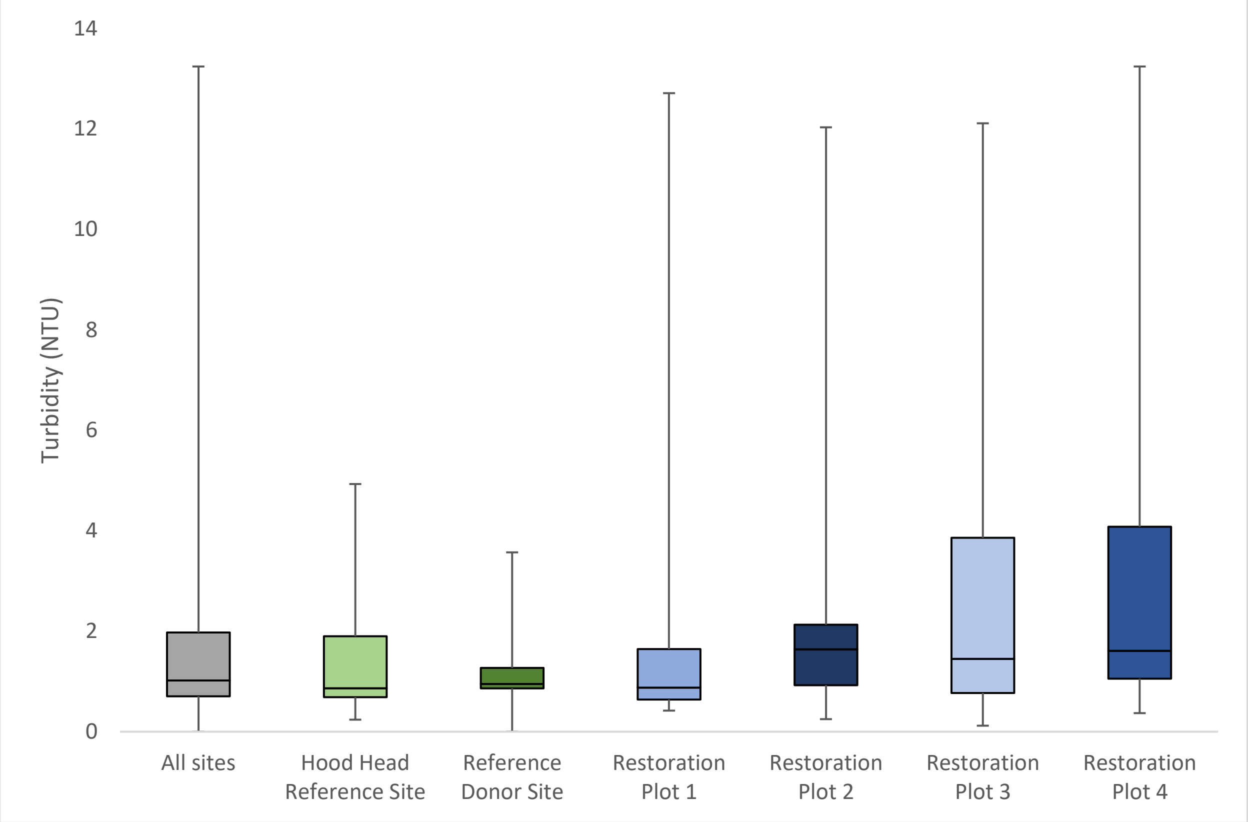


Figure 6 Average turbidity values by site May 2016-June 2017



Appendix C. Daily PAR average between 10:00 and 2:00 May 2016-June 2017

Raw PAR data was converted using conversion values generated from the monthly PAR sensor deployments (see Methods). The conversion value from November was used to correct December data. The Minimum PAR line represents the minimum light requirement to sustain eelgrass in the long-term (Thom et al. 2008).

Figure 1 Longterm PAR values 10am-2pm corrected for Plot 1

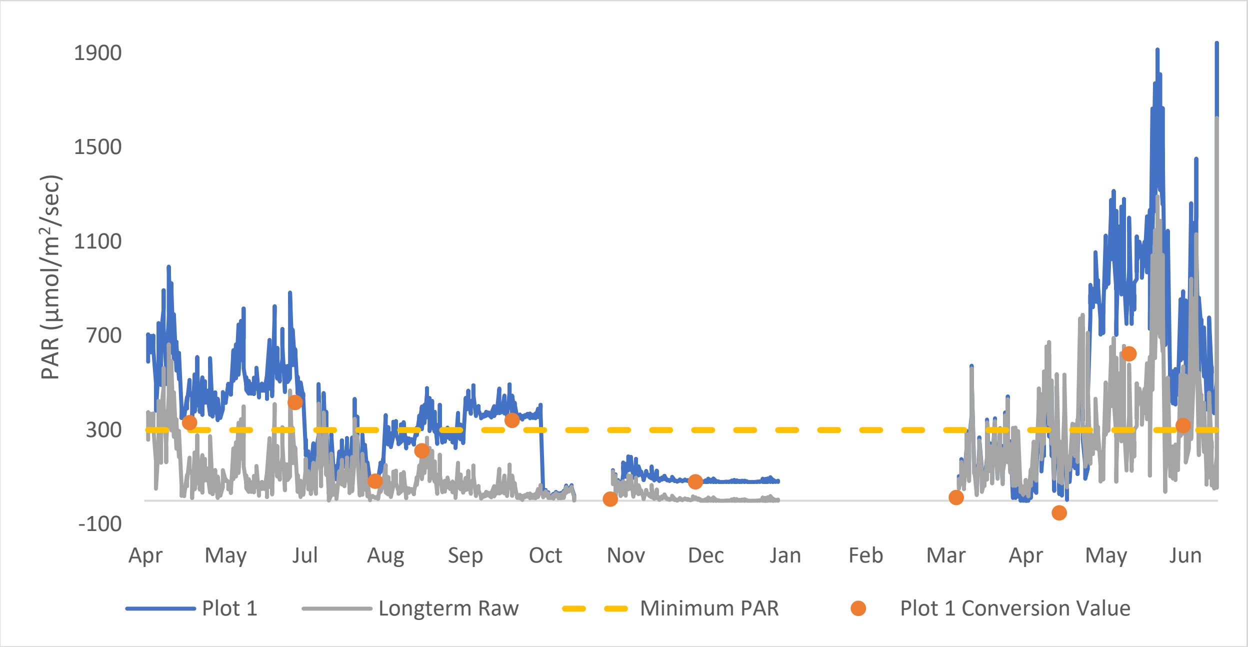


Figure 2 Longterm PAR values 10am-2pm corrected for Plot 2

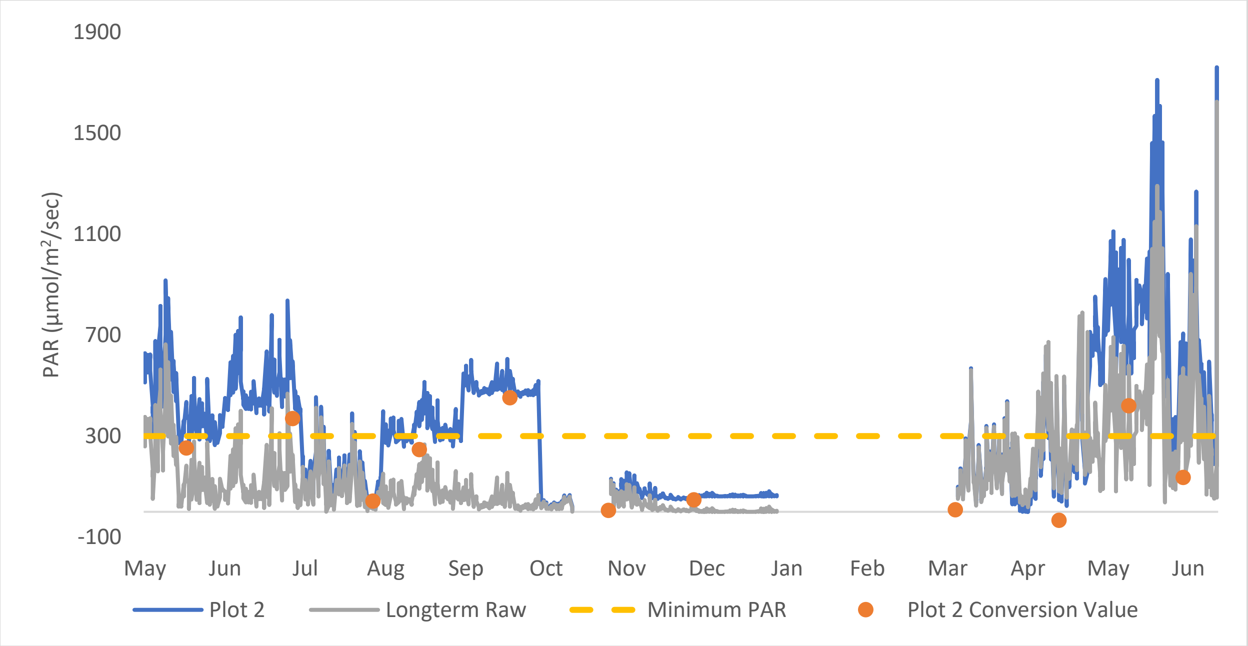


Figure 3 Longterm PAR values 10am-2pm corrected for Plot 3

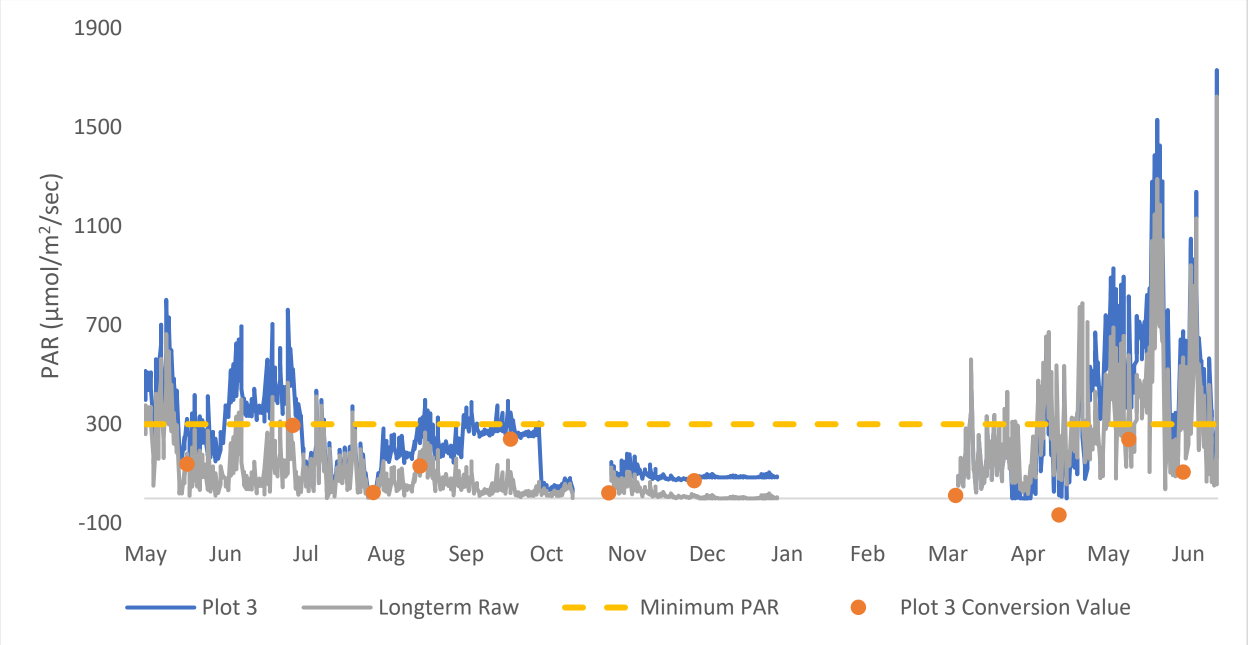


Figure 4 Longterm PAR values 10am-2pm corrected for Plot 4

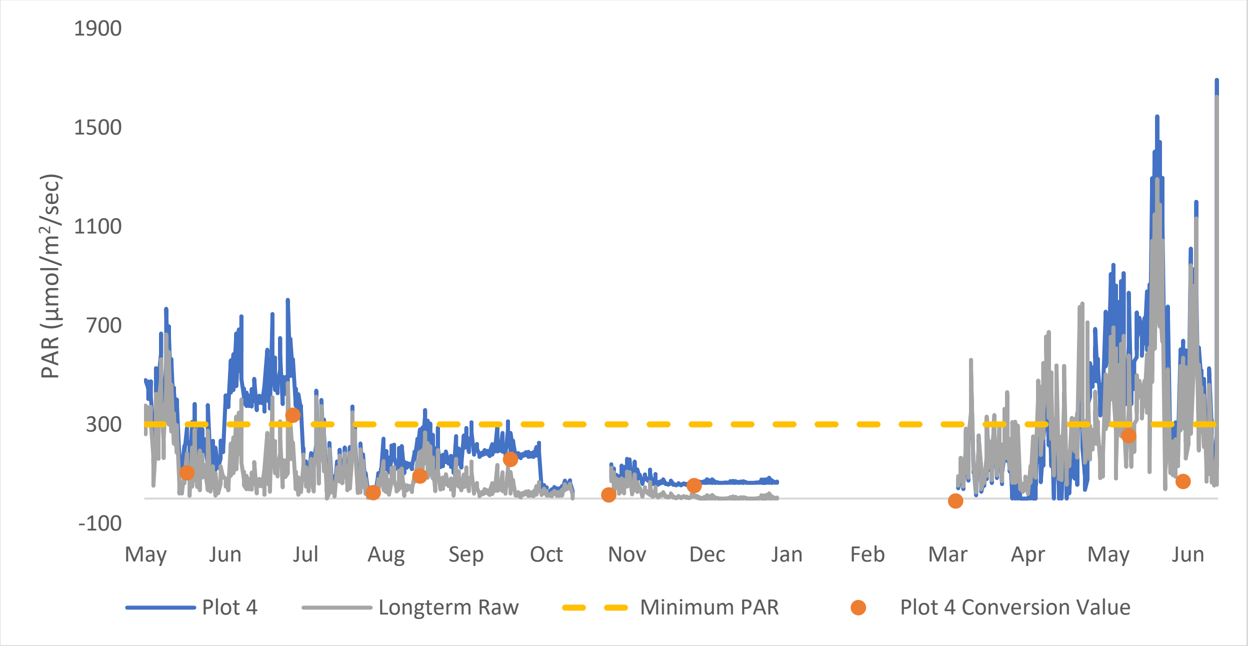


Figure 5 Longterm PAR values 10am-2pm corrected for the Donor Reference Plot

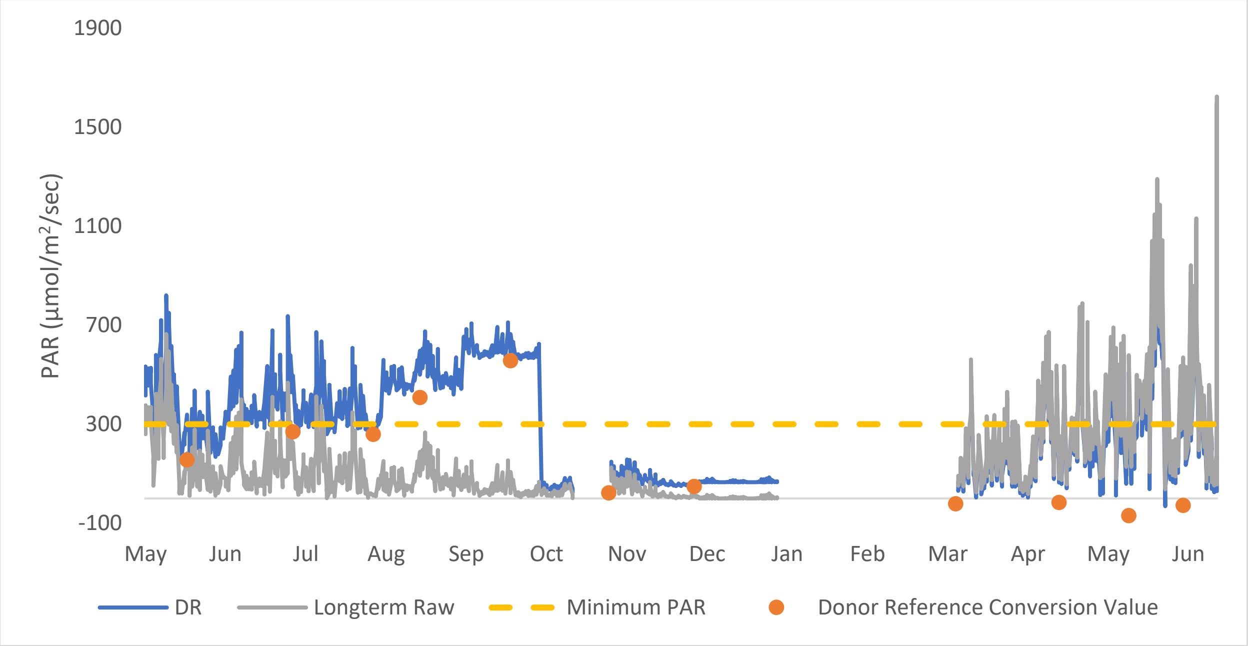
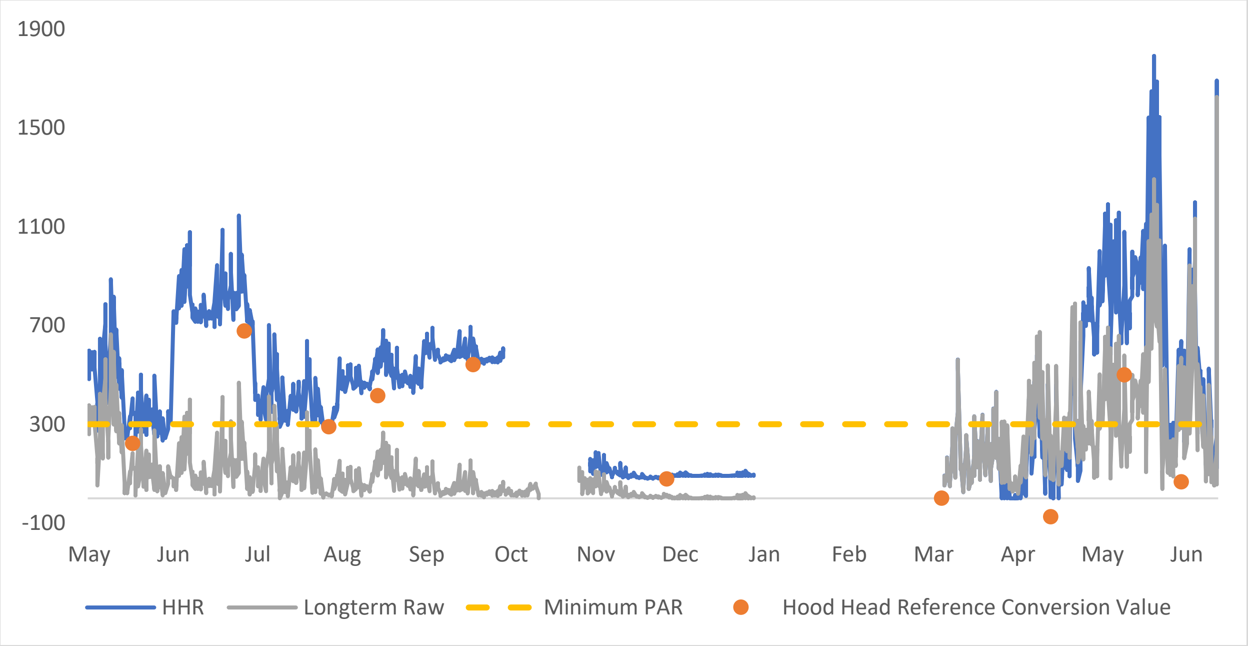


Figure 6 Longterm PAR values 10am-2pm corrected for the Hood Head Reference Plot



Appendix D. PGST On-Reservation Eelgrass Planting Pilot Study

Given the lack of survival of the large-scale eelgrass planting at the southern end of Port Gamble Bay, and informed by results of a literature review conducted in preparation of Task 3 report development, we proposed test plantings on the PGST reservation to investigate whether greater success can be achieved using different planting methods. By re-planting eelgrass back in the bed from which it was removed, we hope to eliminate several variables likely to impact transplantation success because site conditions are proven to support healthy eelgrass.

We identified two planting sites, one on the south side and one on the north side of Point Julia, on September 18, 2017. Using a weighted pvc quadrat, we marked six 1m^2 plots, with plots 1-4 on the north side of Point Julia and 5 and 6 on the south side of Point Julia (Figure 1, Table 1). Plots were marked with helical screw anchors in each of the four corners, tagged with assorted fluorescent zip ties. Plots 2 and 3 had full eelgrass coverage, and plots 1, 4, and 5 were staked in patches of bare ground within the existing eelgrass bed. Plot 6 was a bare patch of ground with very little eelgrass in the surrounding area. Depth measurements were taken with a sounding line (Table 1). All work was completed with chest waders and snorkel gear on day one.

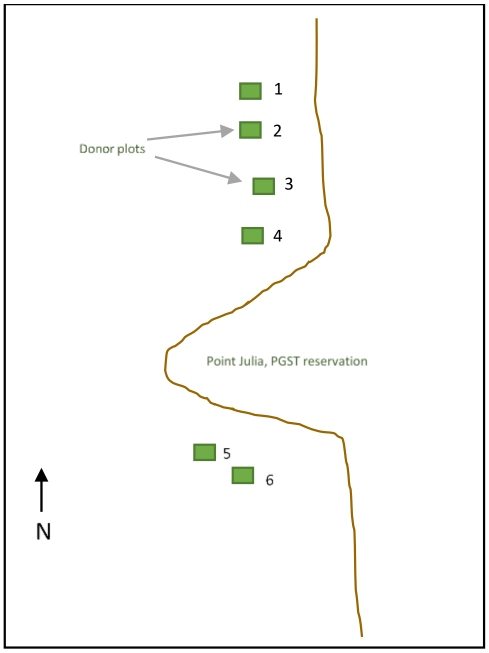


Figure 1. Pilot planting scheme. Figure is not to scale.

	Latitude	Longitude	Depth (cm)	Time of depth measurement
Plot 1	47.857545	-122.576303	~39	10:45
Plot 2*	47.857329	-122.576327	~44	10:29
Plot 3*	47.857014	-122.576398	~63	10:32
Plot 4	47.856907	-122.576382	~62	10:35
Plot 5	47.853235	-122.574847	~34	11:06
Plot 6	47.852997	-122.574580	~35	11:13

Table 1. Coordinates and depths of each plot. Asterisk denotes a donor plot. Low tide was -0.19ft at 10:01. Depths are relative to Mean Lower Low Water.

On September 19th we collected donor material from plots 2 and 3. Sods approximately 10x10cm were scooped up using a Gardease Handigger, and placed in gardening trays set inside of weighted lobster crates (Figure 2). We also tried using a large grill spatula but found the handigger to be a more useful tool because of its raised sides and handle placement. Individual shoots were collected, maintaining root structure as much as possible, and set in a mesh bag within a lobster crate. One of the crates containing donor sods remained weighted on the bottom. The other crate containing additional sods and individual shoots was tied to a float and left on the surface overnight. In plots 2 and 3, we removed all of the eelgrass and scraped the sediment with the handigger to remove as much root material as possible. We snorkeled and used scuba to do the collection, and experienced a very strong current during the second half of the day.

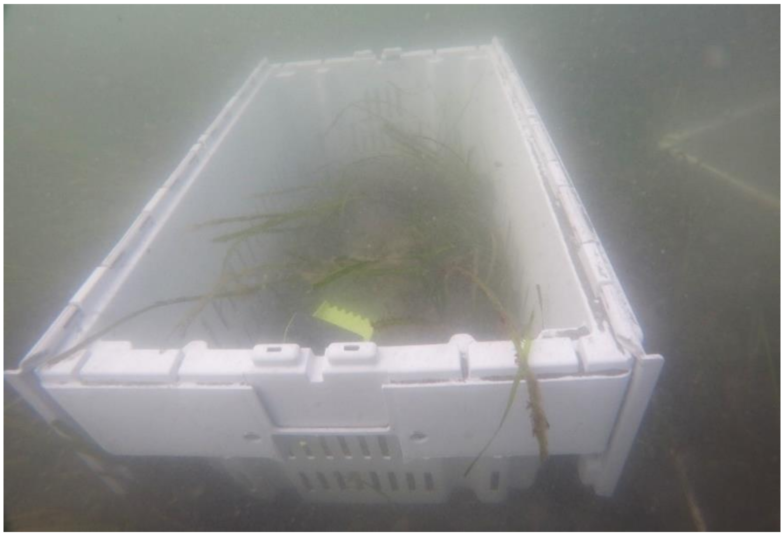


Figure 2. A lobster crate on the bottom containing eelgrass sods set in gardening trays.

On September 20th we prepared the individual shoots by using wire ties to secure four roots, each with several eelgrass shoots, to metal landscape fabric pins (staples, Figure 3). We utilized plant material from the floating crate for the staples, as most of the sediment in this crate had washed away in the current overnight. The sunken crate still contained plant material with sediment intact around the root systems, so material from this crate was used for donor sods. A diver descended at each plot and used the pvc quadrat to delineate planting areas (Figure 4).

Figure 3. Preparation of individual shoots wire tied to 6” metal staples

The northwest quarter was left bare in each plot. This will act as a control for natural recruitment. In the center of the northeast quarter, a 10 x 10cm sod was planted and secured with three 6” GreenStake biodegradable stakes. The stakes were arranged to “lock” around each other and prevent the root clump from becoming dislodged during winter storms. The southwest quarter was planted with a 10 x 10cm sod secured with three staples, again arranged so they would lock against each other. An extra layer of sediment was added to each sod to make sure roots were fully buried. In the final, southeast, quarter two of the prepared staples with eelgrass were planted.

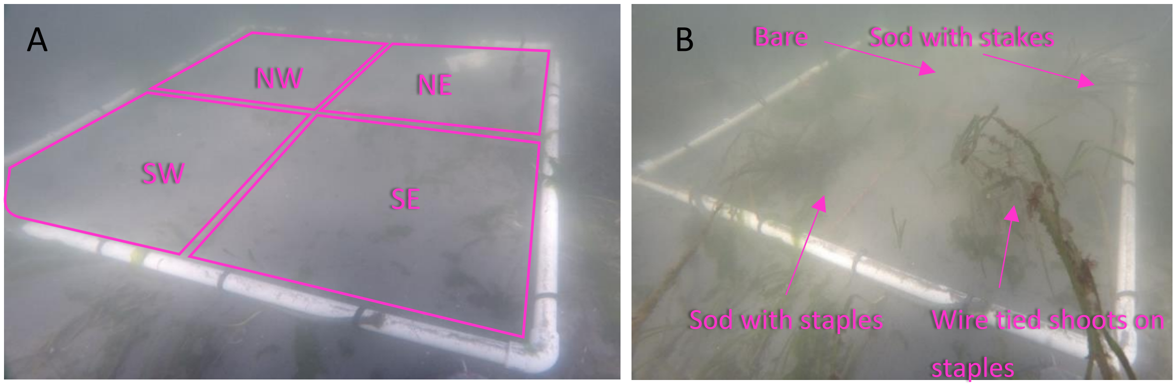


Figure 4. Quadrat laid on bare ground before transplantation (A). After transplantation (B).

It took just over one minute to bundle and wire tie the individual shoots to planting staples. It took another minute to plant the staples with shoots. The sods took a total of three minutes each to scoop out of the gardening trays and plant, because there were so many roots that needed to be buried and shoots that needed to be kept out of the stakes and staples. Overall, the stakes were just as easy to insert as the staples, and seemed more secure. We do not yet know how quickly they will biodegrade or whether the roots will come free. It was difficult to standardize the amount of plant material in each sod, but each one should have plant material in the same densities as the donor plots had pre-harvest. We did not take the time to count the number of shoots in each sod, but they generally appeared to have 1.5-2 times the amount of above-ground biomass as the wire-tied shoots on staples.

We successfully planted all of the plots on September 20th. Leftover wire-tied shoots on staples were trimmed and planted in a very dense clump just outside of the southeast corner of plot 6. No bioturbating organisms were seen around the plots the first two days, but when plot 2 was planted, a Dungeness Crab was observed immediately entering the plot. The gopro housing flooded so underwater photo documentation of this project was limited.

The success of the planting staple technique will be compared to the success rate at the southern end of the bay where this technique was used for the large-scale restoration project. We hypothesize that transplanting the eelgrass as sods will be the most successful method, as this will maintain root structure and plants will be established with the same density as the naturally occurring bed. By maintaining sediment from the donor plots in the sods, we hope some of the bacterial community that may be facilitating the natural eelgrass bed was transferred to the bare areas. We also hypothesize that trimming the leaves of the leftover material will further promote establishment by reducing drag during storm events and encouraging carbon allocation to below-ground biomass for roots to take hold before the spring growing season.

Outside the scope of this contract, we will measure success by comparing the abundance of shoots at the time of planting to post-planting 6 months later. Additionally, we will calculate the survival and new growth planting efficiency between the different methods which could be used in the future to estimate restoration method costs.