Eelgrass (*Zostera marina* L.) Test Transplant Site Assessments and Restoration.

IAA 93-097520(1) – Deliverable Tasks 7 & 8.

1/9/2023

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Introduction

The Washington State Department of Natural Resources (DNR) contracted with King County to complete a Supplemental Environmental Project (SEP) as part of a settlement agreement between King County and the Washington Department of Ecology (PCHB No. 17-086). The SEP explores native eelgrass (*Zostera marina*) habitat restoration along the King County shoreline (Tasks 6-11) based on findings from a comprehensive submerged aquatic vegetation survey (Tasks 1-5 of IAA 93-097520).

The comprehensive submerged aquatic vegetation survey (Tasks 1-5) found approximately 680 ha of eelgrass along the shoreline of King County, WA (Christiaen et al. 2020). Although eelgrass was widely dispersed throughout the County, beds were relatively small. The largest bed was along Magnolia Bluff (37.6 ±2.4 ha) and the least amount of eelgrass was observed along the southwestern shoreline of Vashon Island, inner Quartermaster Harbor, and the more developed portions of Elliott Bay. The eelgrass depth distribution throughout King County was between 0.2 and -4.45 m relative to Mean Lower Low Water (MLLW). Based on the countywide eelgrass survey, a number of sites were identified as potential areas for restoration.

Habitat restoration efforts (Tasks 6-11) began in 2020 with identification of candidate sites, initiation of test transplants and environmental monitoring (*see* Gaeckle 2022). Task 6 of the SEP evaluated sites throughout the King County shoreline for potential eelgrass transplantation through field visits. In Task 7, test transplants of eelgrass began at Dumas Bay in July 2020 to assess suitability for restoration. In spring and early summer of 2021, eelgrass test transplanting continued at Dumas Bay and expanded to three other sites: Myrtle Edwards Park along the Seattle shoreline, and Raabs Lagoon and Dockton in Quartermaster Harbor, between Vashon and Maury Islands (referred to as QMH-Raabs & QMH-Dockton). Under Task 8, evaluation of test transplant success began at the four sites visited throughout 2021 to evaluate the test transplant success and to maintain and swap environmental sensors.

This interim report documents the continued eelgrass restoration and monitoring at Myrtle Edwards Park, Dumas Bay, Raabs Lagoon and Dockton for the completion of *Task 7. Eelgrass Test Transplants* and *Task 8. Eelgrass Test Transplant Monitoring*. In addition, this report summarizes the environmental monitoring data collected at the four restoration sites since June 2020. These tasks are described in the Interagency Agreement between DNR and King County (DNR IAA 93-097520, Amendment 1, and King County project #1131475).

Task 7. Eelgrass Test Transplants
State DNR will establish up to 10 eelgrass test transplant sites from the recommended list generated in Task 6. At each test transplant site, two site markers will be installed 5 meters apart. At distances 0 m, 2.5 m, and 5 m, 240 eelgrass shoots will be transplanted using the rebar (metal rod) method in a 1 m^2 plot. Twenty eelgrass shoots will be tied to each 50 cm rebar rod using hemp cord with 12 rods placed for each 1 m^2 plot for a total of 3 m^2 of eelgrass at a density of 240 shoots m^{-2} per test site.

Deliverable: WA DNR will provide a detailed summary of the eelgrass test transplant effort conducted at each test transplant site. The test transplant summary will include temporal and spatially explicit data on eelgrass test transplant effort, including geographic coordinates (latitude/longitude), depth range, sediment type and any other pertinent data (e.g., photographs, video, and field notes) that describe the restoration test transplant sites.

Task 8. Eelgrass Test Transplant Monitoring
DNR will monitor eelgrass shoot density at each of the 1 m^2 test plots within each eelgrass test transplant site. Therefore, eelgrass shoot density will be counted at 30 test plots and test transplant success will be determined based on percent survival from the original planting density (240 shoots m^{-2}, 720 shoots $site^{-1}$).

Deliverable:
DNR will provide a detailed summary of the eelgrass test transplant monitoring effort conducted at each test transplant site planted in Task 7. The monitoring summary will include eelgrass shoot count per test plot and test transplant site including any data on lateral expansion beyond the original transplant footprint. The assessment of the eelgrass test transplant sites will identify potential sites for large-scale eelgrass restoration.

Task 7: Eelgrass Test Transplants

Test transplants

In early spring 2022, DNR visited Myrtle Edwards Park, Raabs Lagoon and Dockton in Quartermaster Harbor, and Dumas Bay (Figure 1) to evaluate the status of the eelgrass transplanted in 2021 (Gaeckle 2022) and to determine a restoration and monitoring plan forward.

At Myrtle Edwards Park, only three of the 720 eelgrass shoots transplanted in 2021 persisted into May 2022. Low survival suggested the location might be unsuitable for eelgrass restoration. The 2021 test transplants, referred to as Myrtle Edwards Park 1, were adjacent to large riprap that tends to cause wind and boat waves to reflect back into the nearshore creating a high-energy hydrodynamic environment. To decrease potential effects of reflected wave energy and large waves on eelgrass transplants, a new set of test transplants were placed slightly deeper (~ -2 m, MLLW) and approximately 20 m south in an area identified as Myrtle Edwards Park 2. On May 17, 2022, 620 eelgrass shoots harvested from the DuPont Wharf donor site were transplanted in 10, 0.25 m^2 plots with 30 lengths of rebar at Myrtle Edwards Park 2 (Figure 1). Myrtle Edwards Park 2 is adjacent to a sandy pocket beach where wave energy from boats and storms dissipate across the gradual sandy slope. Planting slightly deeper and adjacent to a pocket beach potentially decreases wave energy exposure for newly transplanted eelgrass.

Since a few eelgrass shoots persisted from 2021 at the original location (Myrtle Edwards Park), a small number of eelgrass shoots were transplanted in the same location in 2022. At Myrtle Edwards Park 1, 120 eelgrass shoots were transplanted in 2, 0.25 m^2 plots with 6 lengths of rebar. Overall, a total of 740 eelgrass shoots harvested from the DuPont Wharf donor site were transplanted on May 17, 2022, at Myrtle Edwards Park (Table 1).

At Dumas Bay, the test transplants showed multiple measures of vigor in Spring 2022, including new shoots, lateral growth and coalescence of the 2020 and 2021 transplant patches. Therefore, on May 19, 2022, 400 eelgrass shoots from the DuPont Wharf donor site were transplanted across 7, 0.25 m^2 plots with 20 lengths of rebar (Table 1). These plants were transplanted slightly offshore from the May 26, 2021 test transplants. On June 16, 2022, an additional 720 eelgrass shoots were transplanted in 20, 0.25 m^2 plots with 60 lengths of rebar (Table 1). These shoots were transplanted along the same bathymetric elevation contour (-1.5 m, MLLW) and northeast of previous transplants. The eelgrass transplant were placed in a checkerboard pattern along a 20 m transect with transplants between 2 to 7 m, and again from 12 to 17 m, along the transect.

Eelgrass transplants failed to survive at Raabs Lagoon and Dockton in 2021. At Dockton, transplants sank into the soft and flocculent sediment and were covered with precipitate that likely inhibited survival. Therefore, on May 31, 2022, eelgrass transplant efforts ended at Dockton and the team removed the environmental sensor and helical anchors at the site. The conditions at Raabs Lagoon were more promising even though transplants failed in 2021. One hypothesis for cause of failure was grazing and bioturbation from crabs. To minimize these hypothesized stressors, on May 19, 2022, 75 eelgrass shoots from the DuPont Wharf donor site were transplanted at -1.5 m (MLLW) on 3 inverted TERFS – Transplanting Eelgrass Remotely with Frame Systems (25 shoots per TERFS, Table 1, Figure 2). Placement on inverted TERFS removes the eelgrass from contact with the sediment and access by crabs.

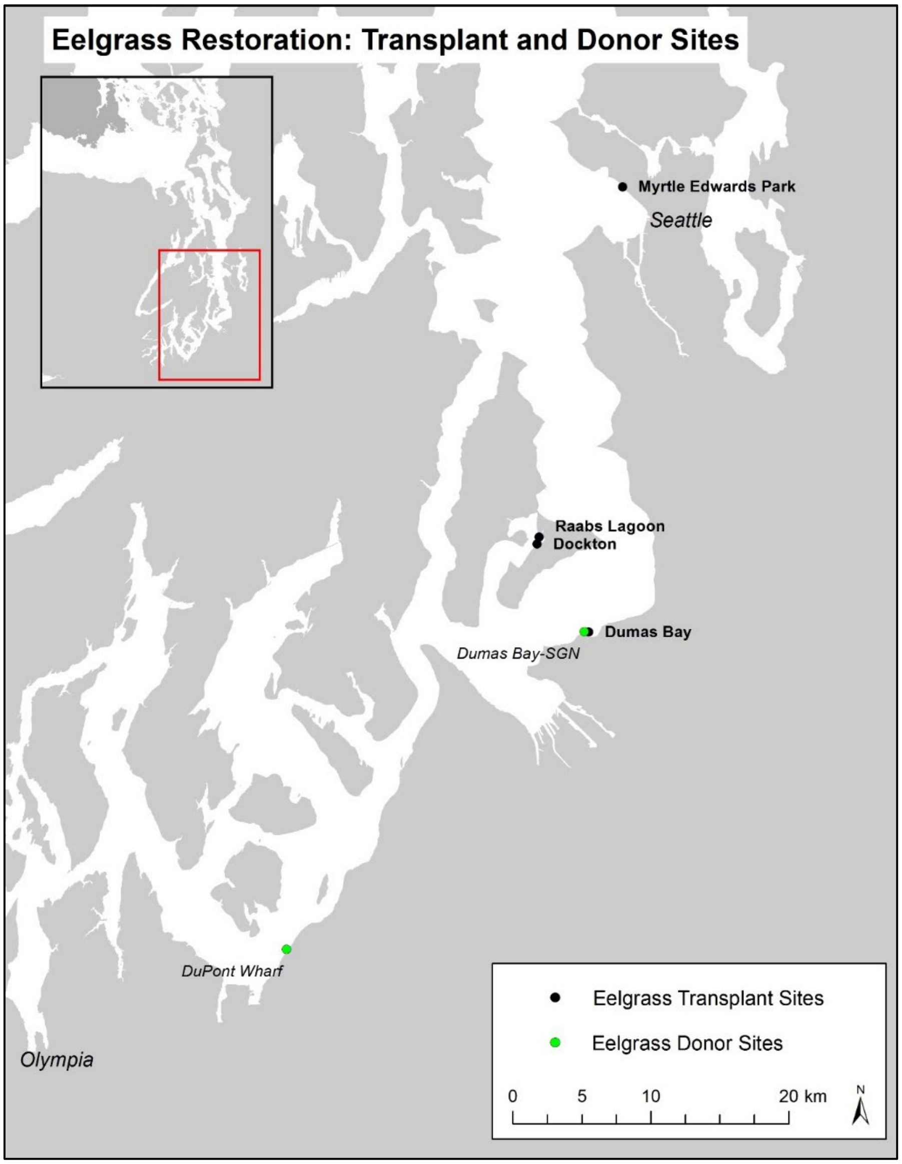
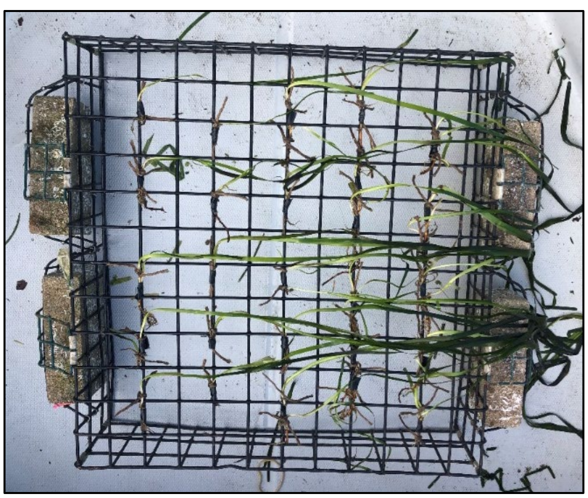


Figure 1. Map of four eelgrass test transplant sites (Myrtle Edwards Park, Raabs Lagoon, Dockton, and Dumas Bay) in King County from 2020-2022 relative to the eelgrass donor sites (DuPont Wharf, Dumas Bay-SGN). Eelgrass was not transplanted at Dockton in 2022, instead the site was removed from test transplant consideration. The Dumas Bay-SGN donor site was only used in 2020 and 2021 (see Table 1).

Table 1. Summary of the 2020 – 2022 eelgrass test transplant effort at four King County sites.

SITE	TRANSPLANT DATE	PLOTS	REBAR	# SHOOTS	DONOR SOURCE
		(0.25 m^2)	(3 plot^{-1})		
Myrtle Edwards Park 1	5/28/2021	5	15	300	DuPont Wharf
	5/28/2021	4	12	300	Dumas Bay-SGN
	5/17/2022	2	6	120	DuPont Wharf
Myrtle Edwards Park 2	5/17/2022	10	30	620	DuPont Wharf
Raabs Lagoon, QMH	5/13/2021	4	12	240	DuPont Wharf
	5/14/2021	5	15	375	Dumas Bay-SGN
	5/26/2021	6	18	270	DuPont Wharf
	5/19/2022	3	*	75	DuPont Wharf
Dockton, QMH	5/13/2021	3	9	180	DuPont Wharf
	5/14/2021	3	9	225	Dumas Bay-SGN
Dumas Bay	7/6/2020	6	18	300	Dumas Bay-SGN
	4/28/2021	4	12	300	Dumas Bay-SGN
	5/13/2021	3	9	180	DuPont Wharf
	5/26/2021	3	9	180	DuPont Wharf
	6/26/2021	6	18	270	DuPont Wharf
	5/19/2022	7	20	400	DuPont Wharf
	6/16/2022	20	60	720	DuPont Wharf
Subtotal		72	206	3,555	DuPont Wharf
		22	66	1,500	Dumas Bay-SGN
TOTAL		94	272	5,055	

* = 3 Transplanting Eelgrass Remotely with Frame Systems (TERFS) were deployed.



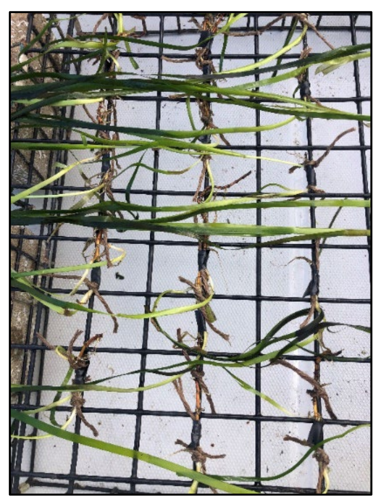


Figure 2. Transplanting Eelgrass Remotely with Frame System (TERFS) with eelgrass from DuPont Wharf attached to the underside of the frame with hemp cord and electrical tape. In an effort to limit access to the eelgrass by crabs, TERFS were deployed upside down at Raabs Lagoon on May 19, 2022.

Donor Sites

Two donor sites, DuPont Wharf and Dumas Bay-SGN, were used for the test transplants in 2020 and 2021. The DuPont Wharf site (47.1173, -122.6678) located in South Puget Sound, northeast of the Nisqually Delta, was the only eelgrass donor site used for transplanting in 2022 (Figure 1). As in previous years, approximately 20 DuPont Wharf eelgrass shoots were attached to each length of rebar and three 50 cm lengths of rebar were transplanted in each 0.25 m^2 of bare sediment.

Task 8: Eelgrass Test Transplant Monitoring

2021 Test transplant monitoring

In early spring 2022, Myrtle Edwards Park and Dumas Bay test transplant sites were visited to evaluate the over-winter survival of the eelgrass transplants from 2021. On May 3, 2022, a team of snorkelers visited Myrtle Edwards Park to swap the environmental sensors and to determine if any eelgrass survived (Table 3). The scientists found three eelgrass shoots at the site and recovered the metal rod from the 2021 test transplants. Eelgrass transplants were successful at Dumas Bay since 2020, therefore on May 19, 2022, a team of snorkelers visited the site to re-evaluate the site potential and to add eelgrass to the previous test transplants (Tables 1 and 3).

Scientists did not prioritize the two sites in Quartermaster Harbor, Raabs Lagoon and Dockton, as sites to monitor since no eelgrass persisted through the summer of 2021.

2022 Test transplant monitoring

A series of snorkeling based monitoring efforts continued throughout the summer until September 9, 2022, to evaluate previous eelgrass transplants and new 2022 test transplants at Myrtle Edwards Park, Dumas Bay and Raabs Lagoon (Table 3). Each monitoring event qualitatively assessed the number and condition of eelgrass transplants and documented potential stressors that may have inhibited transplant success. Table 3 outlines the monitoring events and status of the 2020, 2021, and 2022 transplants. Roughly every three months throughout the winter divers swapped environmental sensors at Myrtle Edwards Park, Raabs Lagoon, and Dumas Bay and, when possible, captured photos of eelgrass transplants to document presence (Table 2).

Table 1. Deployment and retrieval dates for environmental sensor arrays, identified by sensor type and serial number, at the King County eelgrass test transplant sites between 2020 and 2022. Each environmental sensor array included temperature, depth, and photosynthetically active radiation (PAR) loggers that recorded data at 15 minute intervals. Environmental sensor arrays also included Zebra-Tech Hydro-Wiper that reduced fouling on PAR loggers to improve data quality.

SITE	LAT	LONG	DEPLOY DATE	RETRIEVE DATE	TEMP	DEPTH	PAR
					(serial #)	(serial #)	(serial #)
Myrtle Edwards Park	47.6205	-122.3640	7/7/2020	12/30/2020	20047929	10777817	5996
			12/30/2020[†]	5/4/2021	20359578	20574098	6009
			5/4/2021	7/11/2021	20604504	20566014	4599
			7/11/2021	10/6/2021	20604506	10777822	4590
			10/6/2021[†]	3/10/2022	20604511	20574104	8048
			10/6/2021	3/10/2022	21159985	*	*
			3/10/2022[†]	6/1/2022	21159976	20574098	6010
			6/1/2022	8/9/2022	21159978	10777819	8046
			8/9/2022	9/9/2022	21159993	20566108	5993
			9/9/2022	11/1/2022	21159978	21316701	6427
			11/1/2022[†]		21159994	20566108	7998
Raabs Lagoon	47.3907	-122.4361	7/2/2020	12/10/2020	20047935	20331318	8001
			12/10/2020[†]	4/29/2021	20047937	20566086	6427
			4/29/2021	7/25/2021	10128315	10777829	4592
			7/25/2021	10/5/2021	20359579	20566009	4599
			10/5/2021[†]	3/10/2022	20604509	20566108	8047
			3/10/2022[†]	5/31/2022	21159983	10777817	5993
			5/31/2022	8/11/2022	21159995	20331317	7992
			8/11/2022	11/1/2022	21159988	10777817	5996
			11/1/2022[†]		21159976	20574104	7997
Dockton	47.3859	-122.4379	7/2/2020	12/10/2020	20047933	20331317	8000
			12/10/2020[†]	4/29/2021	20047936	20566024	6420
			4/29/2021	7/25/2021	10128316	10777819	4593
			7/25/2021	10/5/2021	20359580	20565970	4600
			10/5/2021[†]	3/10/2022	20604507	20566024	8046
			3/10/2022[†]	5/31/2022**	21159986	10777818	5994
Dumas Bay	47.3293	-122.3862	6/4/2020	12/29/2020	20359587	20566009	8002
			12/29/2020[†]	4/28/2021	20604511	20565978	6004
			4/28/2021	7/10/2021	20604507	20565970	4591
			7/10/2021	10/5/2021	20047928	10777821	8050
			10/5/2021[†]	3/15/2022	20604504	20331318	7999
			3/15/2022[†]	5/31/2022	21159981	20566005	6425
			5/31/2022	8/11/2022	21159985	20331320	7997
			8/11/2022	11/1/2022	21159986	10777818	5991
			11/1/2022[†]		21195553	20331319	5990

* = An extra temperature logger was deployed at Myrtle Edwards Park on 10/6/2021.

** = The environmental sensor array and all ground tackle were removed from Dockton on 5/31/2022.

[†] = DNR Geoduck Compliance Dive Team swapped sensors and, when possible, captured photos of eelgrass transplants.

Scientists visited Raabs Lagoon on May 31, 2022 (12 days from the 5/19/2022 transplant date), to swap environmental sensors and to evaluate eelgrass transplants that used the modified TERFS method and found no seagrass remaining due to disturbance or grazing by northern kelp crabs, *Pugettia producta* (Figure 3). The team removed the TERFS and re-visited the site on August 11, 2022, to swap the environmental sensors (Table 2, Table 3).

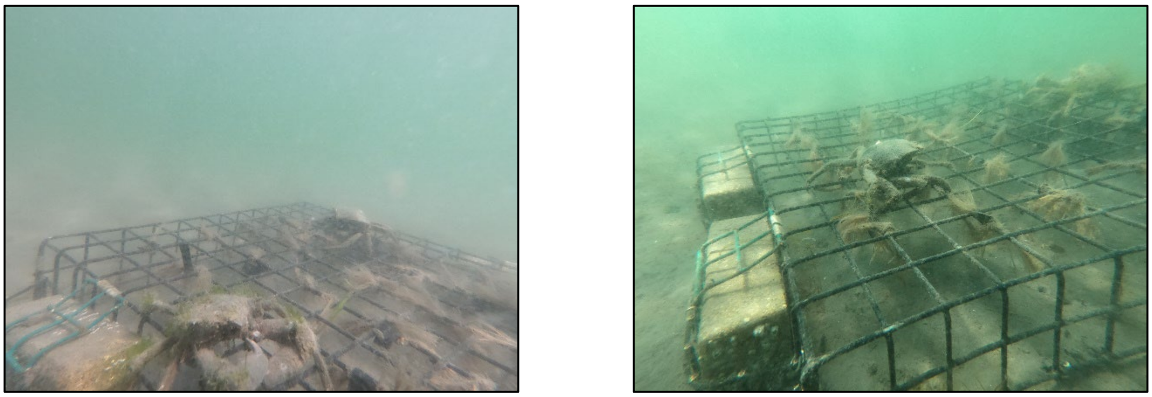


Figure 3. Northern kelp crab, *Pugettia producta*, on upside down TERFS at Raabs Lagoon on May 31, 2022. No eelgrass survived 12 days post transplanting.

Table 3. Summary of eelgrass transplant monitoring at four King County sites from 2020-2022.

SITE	DATE TRANSPLANTED	DATE MONITORED	DAYS	STATUS	COMMENTS
			post transplant		
Myrtle Edwards Park 1	5/28/2021	6/9/2021	12	present	Eelgrass looked good, sensor maintenance.
		7/11/2021	44	present	Eelgrass looked great. Promising site. Sensor maintenance.
		5/3/2022	300	present	3 eelgrass shoots survived from 2021 test transplant. Sensor maintenance.
	5/17/2022	6/1/2022	15	present	Eelgrass still present from mid-May transplant effort. Sensor maintenance.
		6/28/2022	42	unknown	Unable to locate eelgrass transplants due to poor water clarity.
		7/14/2022	58	present	Eelgrass looked healthy. Both patches of eelgrass from the 5/17 transplant were present with some *Smithora naiadum* growing on leaf tips. The surviving shoots from the 2021 test transplant increased from a total of 3 to 10.
		8/9/2022	84	present	Eelgrass looked healthy. Sensor maintenance.
		9/9/2022	115	present	Eelgrass looked healthy. Sensor maintenance.
Myrtle Edwards Park 2	5/17/2022	6/1/2022	15	present	Eelgrass still present from mid-May transplant effort.
		6/28/2022	42	unknown	Unable to locate eelgrass transplants due to poor water clarity.
		7/14/2022	58	unknown	Unable to locate eelgrass due to poor water clarity.
		8/9/2022	84	unknown	Unable to locate eelgrass transplants due to poor water clarity.
		9/9/2022	115	present	Eelgrass looked healthy.
Raabs Lagoon	5/13/2021	5/26/2021	13	0	No surviving eelgrass shoots. Recovered rebar, sensor maintenance.
	5/14/2021	5/26/2021	12	0	No surviving eelgrass shoots. Recovered rebar, sensor maintenance.
		6/26/2021	43	0	No surviving eelgrass shoots. Recovered remaining rebar, sensor maintenance.
	5/19/2022	5/31/2022	12	0	Northern kelp crab (*Pugettia producta*) present and clipped eelgrass shoots provided evidence of disturbance Recovered TERFS. Sensor maintenance.

Table 3 – con't. Summary of eelgrass transplant monitoring at four King County sites from 2020-2022.

SITE	DATE TRANSPLANTED	DATE MONITORED	DAYS	STATUS	COMMENTS
			post transplant		
Dockton	5/13/2021	5/26/2021	13	0	No surviving eelgrass shoots. Recovered rebar, sensor maintenance.
	5/14/2021	5/26/2021	12	0	No surviving eelgrass shoots. Recovered rebar, sensor maintenance.
		6/26/2021	43	0	No surviving eelgrass shoots. Sensor maintenance.
		5/31/2022	382	0	No eelgrass transplants to check on. Environmental sensor and ground tackle removed.
Dumas Bay	7/6/2020	8/19/2020	44	present	Eelgrass present, looked promising, sensor maintenance
		4/28/2021	296	present	Eelgrass present, recovered rebar, sensor maintenance.
	4/28/2021	5/13/2021	311	present	Eelgrass looked good. Sensor maintenance.
	5/13/2021	5/26/2021	324	present	Eelgrass looked good. Sensor maintenance.
	5/26/2021	6/11/2021	340	present	Eelgrass present, sensor maintenance.
		6/26/2021	355	present	Eelgrass present, sensor maintenance. Planted more eelgrass.
	6/26/2021	7/10/2021	14	present	Eelgrass present at all sites. Sensor maintenance.
		5/19/2022	724	present	All previously transplanted eelgrass looked healthy. Planted 400 more eelgrass shoots adjacent to the 2021 transplants. Evaluated site for additional locations.
	5/19/2022	5/31/2022	12	present	All eelgrass looked great. Sensor maintenance.
	5/19/2022	6/16/2022	28	present	2020, 2021, and early 2022 eelgrass transplants looked great. Transplanted an additional 720 eelgrass shoots northeast of previous transplants.
	6/16/2022	6/30/2022	14	present	All transplants looked good. Sensor maintenance.
	6/16/2022	8/11/2022	56	present	Eelgrass looked healthy. Quite a bit of green algae and ulvoids present and covering plants.

Environmental Sensor Data

Environmental sensors were deployed to evaluate whether seawater temperature and light levels (i.e., photosynthetically active radiation, PAR) potentially limited transplant success at each eelgrass restoration site. Eelgrass productivity in Puget Sound can be affected by site specific factors such as water temperatures (Thom et al. 2005; Sawall et al., 2021), or inadequate radiation necessary to sustain physiological demands to maintain a net positive photosynthesis:respiration (P:R) ratio (Simenstad et al. 1997, Thom et al. 2008). Prior to transplanting eelgrass in 2020, environmental sensor arrays that consisted of Photosynthetically Active Radiation loggers (Dataflow Systems Ltd), and temperature and depth loggers (Onset Computer Corp) were deployed at approximately -1.5 m (MLLW) at each restoration site (Figure 4, Table 4). The environmental sensors were first deployed in June 2020 and swapped every 2-3 months (8-12 weeks) to limit excessive biofouling and to ensure the collection of quality data (Table 2). The last swap occurred on November 1, 2022, with the next one scheduled for mid to late January 2023.

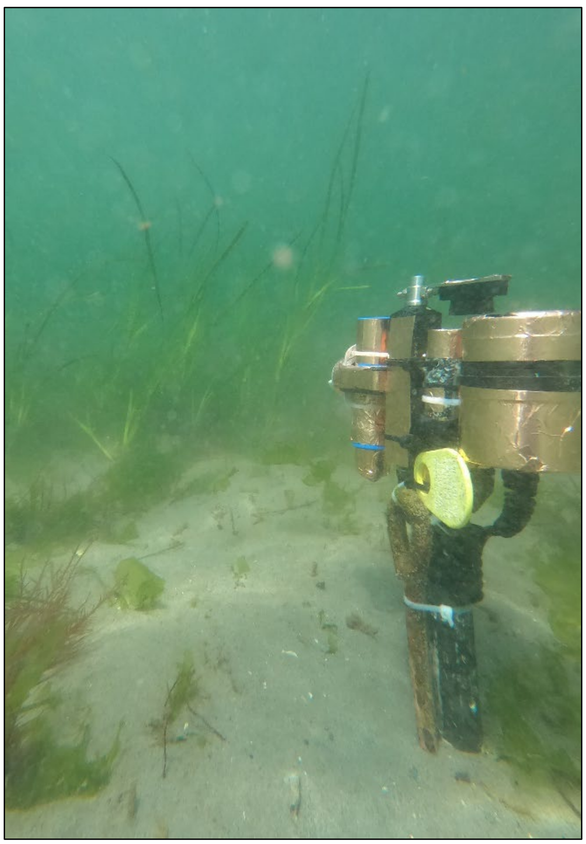


Figure 4. Environmental sensor array with 2020 eelgrass transplants in the background at the Dumas Bay transplant site (5/31/2022). Additional information on the environmental sensor arrays described in an earlier report (Gaeckle 2022).

Table 4. Mean depth* (m, ± se, MLLW) for the environmental sensor arrays deployed at each eelgrass transplant location.

	Myrtle Edwards	QMH-Raabs	QMH-Dockton	Dumas Bay
Mean (m, MLLW)	-1.712	-1.283	-1.578	-1.597
Standard Error (± se)	0.002	0.002	0.003	0.002

* measured using the Hobo Water Level Data Logger, U20L-01. https://www.onsetcomp.com/products/data-loggers/u20l-0x .

The differences in the measured sensor deployment depths between sites (< 0.5 m; Table 4) reflect some uncertainty in vertical positioning during each deployment. The original sensor location was based on the actual water depth and the predicted tidal elevation for each site at the time of setting the helical anchor to which each sensor was attached. The other potential source of error in the sensor array depth could be the vertical placement of the array relative to the surface of the substrate. The sensors are secured to a PVC post that is pressed into the substrate and zip-tied to the helical anchor. The actual depth of the sensor arrays can vary as much as ±20 cm depending on the depth at which the PVC post is pressed into the sediment by the snorkeler or diver. The depths for each sensor array location will be assessed again in 2023 to verify the measured depths (Table 4).

Photosynthetically Active Radiation (PAR)

Daily cumulative PAR at the four test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay, showed seasonal light variation and ranged from near 0 mol photons m^{-2} d^{-1} during the winter months, November through February, to over 30 mol photons m^{-2} d^{-1} during the summer months, June through August (Figure 5, Appendix A). During most of the growing season (June – September 2020, and March – September 2021 & 2022), daily cumulative PAR exceeds the 7 mol photons m^{-2} d^{-1} threshold for non-light limited growth and the 3 mol photons m^{-2} d^{-1} threshold for long term survival (Thom et al. 2008). During the 2021 and 2022 winter months, daily cumulative PAR was typically below the 3 mol photons m^{-2} d^{-1} threshold necessary for long term survival. During this period, eelgrass likely relied on stored carbohydrate reserves and infrequent periods of light during clear weather days (Burke et al. 1996, Govers et al. 2014, Marín-Guirao et al. 2022).

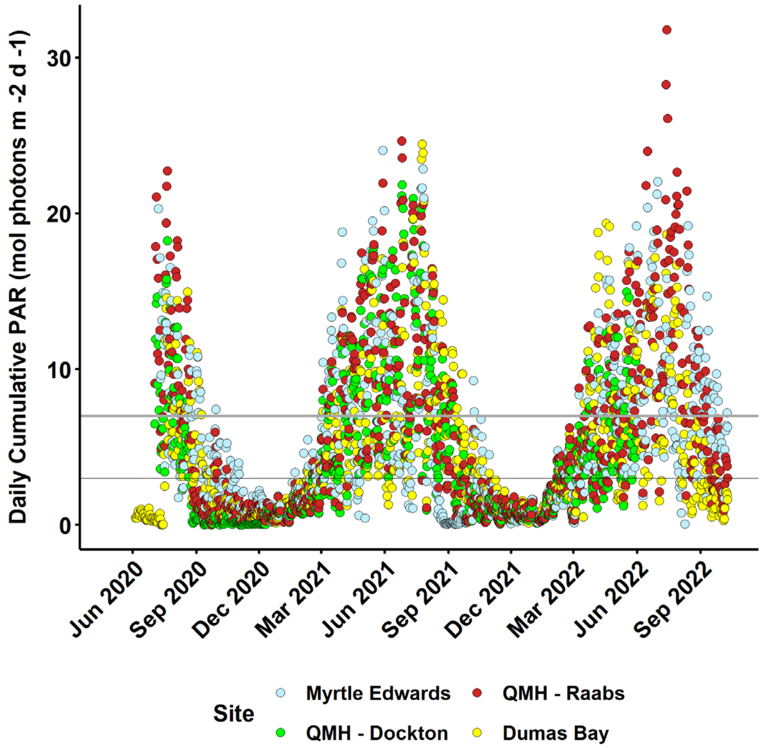


Figure 5. Daily cumulative PAR (mol photons m^{-2} d^{-1}) measured at the eelgrass test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay, from June 2020 through October 2022. The top grey line indicates the 7 mol photons m^{-2} d^{-1} threshold for non-light limited growth for eelgrass and the lower grey line indicates the 3 mol photons m^{-2} d^{-1} threshold for long-term survival in Puget Sound, WA (Thom et al. 2008).

The measured daily cumulative PAR at the four eelgrass test transplant sites followed similar patterns of available light throughout the course of the sample period from June 2020 through October 2022. Daily cumulative PAR (mol photons m^{-2} d^{-1}) exceeded the 3 mol photons m^{-2} d^{-1} and 7 mol photons m^{-2} d^{-1} thresholds for long-term survival and non-light limited growth, respectively during the growing season of March through September (Figure 6). Daily cumulative PAR (mol photons m^{-2} d^{-1}) during the winter months was typically below the threshold for long-term survival (3 mol photons m^{-2} d^{-1}) and very close to zero.

A limited number of periods within the data series fall outside the expected pattern. At Myrtle Edwards Park, measured PAR values fell below expectations or showed higher variability than expected during four periods. Lower and more variable than expected PAR data could be associated with fouling events in mid-May, July and September 2021 and again in July 2022 (top panel, Figure 6).

At QMH-Raabs, three anomalously high PAR values occurred on July 13, 14, and 15, 2022, where daily cumulative PAR was 28.3, 31.7, and 26.1 mol photons m^{-2} d^{-1}, respectively (second panel from top, Figure 6). These high daily cumulative PAR values likely resulted from exposure during extremely low spring tides that ranged between -1.13 to -1.25 m (MLLW) on July 13-15, 2022. The mean depth at QMH-Raabs during these low tides would position the PAR logger just below the surface with very little attenuation of light from the water column. Besides these three points, visual assessment of these data suggest that effects of variation in sensor depth were minimal.

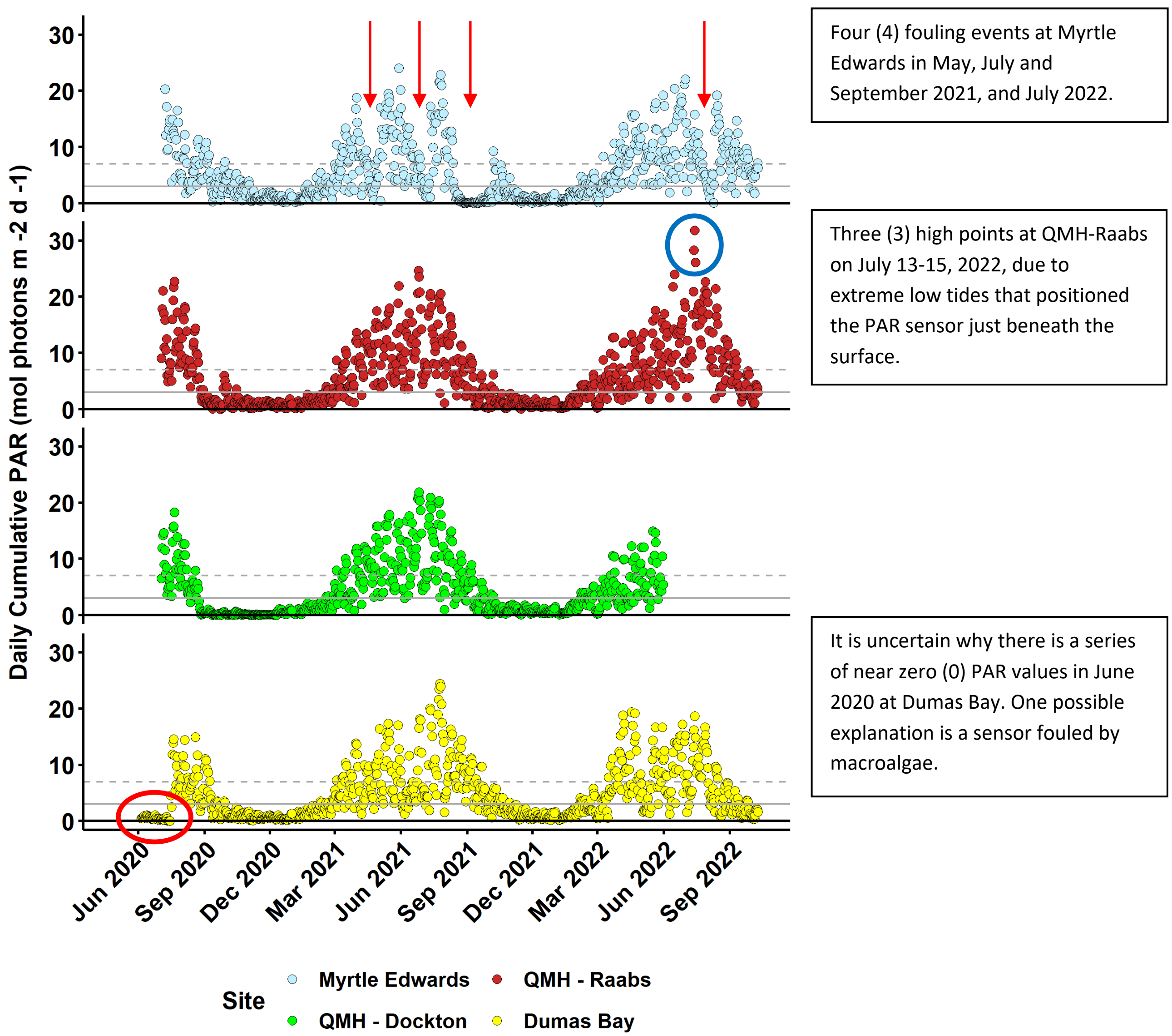


Figure 6. Daily cumulative PAR (mol photons m^{-2} d^{-1}) measured at the eelgrass test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay, from June 2020 through October 2022. The top dashed grey line in each plot indicates the 7 mol photons m^{-2} d^{-1} threshold for non-light limited growth for eelgrass and the lower grey line indicates the 3 mol photons m^{-2} d^{-1} threshold for long-term survival in Puget Sound, WA (Thom et al. 2008). Explanation of unexpected data patterns are in the text to the right of the figures and emphasized in each figure with arrows (Myrtle Edwards Park) or circles (QMH-Raabs and Dumas Bay).

At Dumas Bay there were a series of low to near zero (0) data points in June 2020 that were likely due to a fouled sensor after deployment (bottom panel, Figure 6). Although the sensor arrays have Zebra-tech Hydro-Wipers installed (Figure 4), large blades of macroalgae can still obstruct the PAR sensor.

Temperature

Daily mean temperatures (°C) at the four test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay, showed expected seasonal patterns. Mean winter temperatures were typically below 10°C while summer mean temperatures were often above 13°C (Figure 7, 8, Table 5, and Appendix B). The coolest temperatures during the winter months from November to February were 5.6°C observed at QMH-Dockton in 2020 and 4.3°C at QMH-Raabs in 2021 (Table 5). However, daily mean temperatures throughout the sample period were cooler at Myrtle Edwards Park and Dumas Bay compared to QMH-Raabs and QMH-Dockton (Figure 8). The warmest summer water temperatures were observed at QMH-Raabs each summer and reached 21.0°C, 23.9°C, and 23.6°C, in 2020, 2021, and 2022, respectively (Figure 9, Table 5).

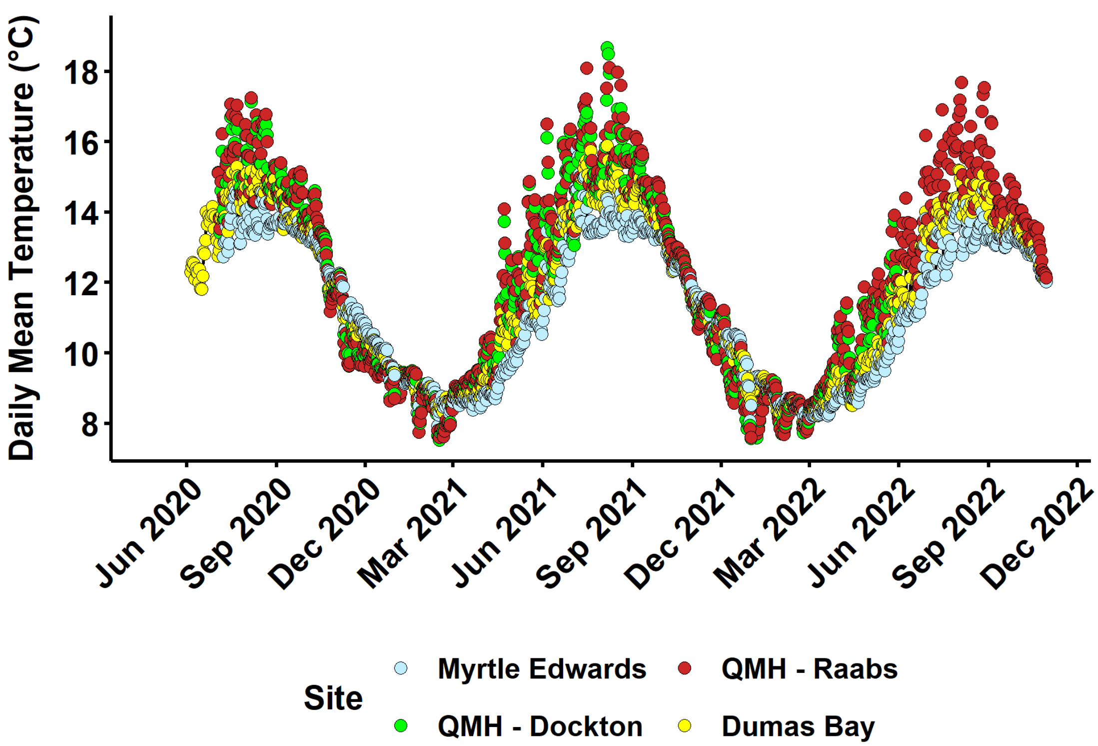


Figure 7. Daily mean water temperature (°C) measured at the eelgrass test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay, from June 2020 through October 2022.

At Myrtle Edwards, the summer daily mean water temperatures were within the optimal water temperatures (6-17°C) for eelgrass in Puget Sound (Thom et al. 2005, 2014). These water temperatures averaged 13.7°C, 13.4°C, and 12.6°C across June, July and August for 2020, 2021, and 2022, respectively (Figure 8, Table 5). The summer mean water temperatures at the other three sites were slightly warmer ranging between 13.5 and 15.4°C, but all within the optimal range (Figure 8, Table 5). Winter water temperatures from November through February were consistently above 9°C at all four sites in 2020 and 2021 (Figure 9, Table 5).

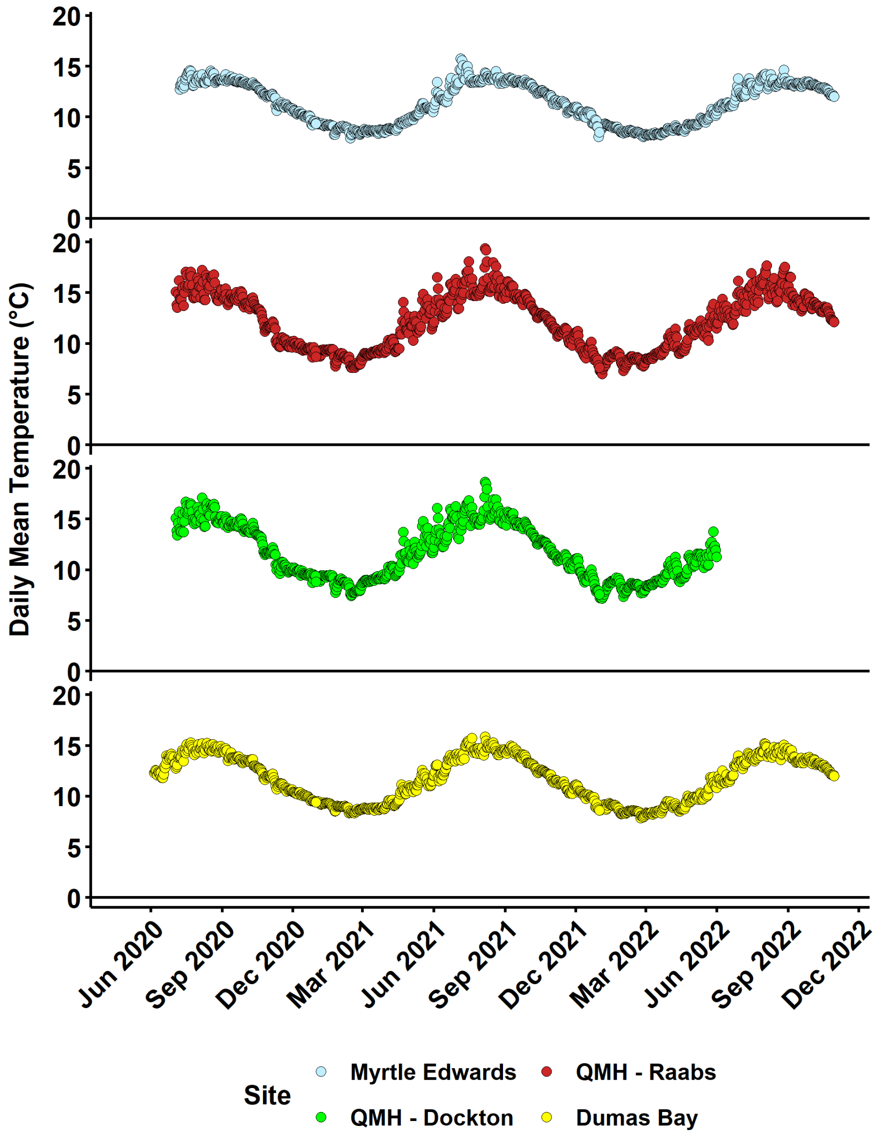


Figure 8. Daily mean water temperature (°C) measured at the eelgrass test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay, from June 2020 through October 2022.

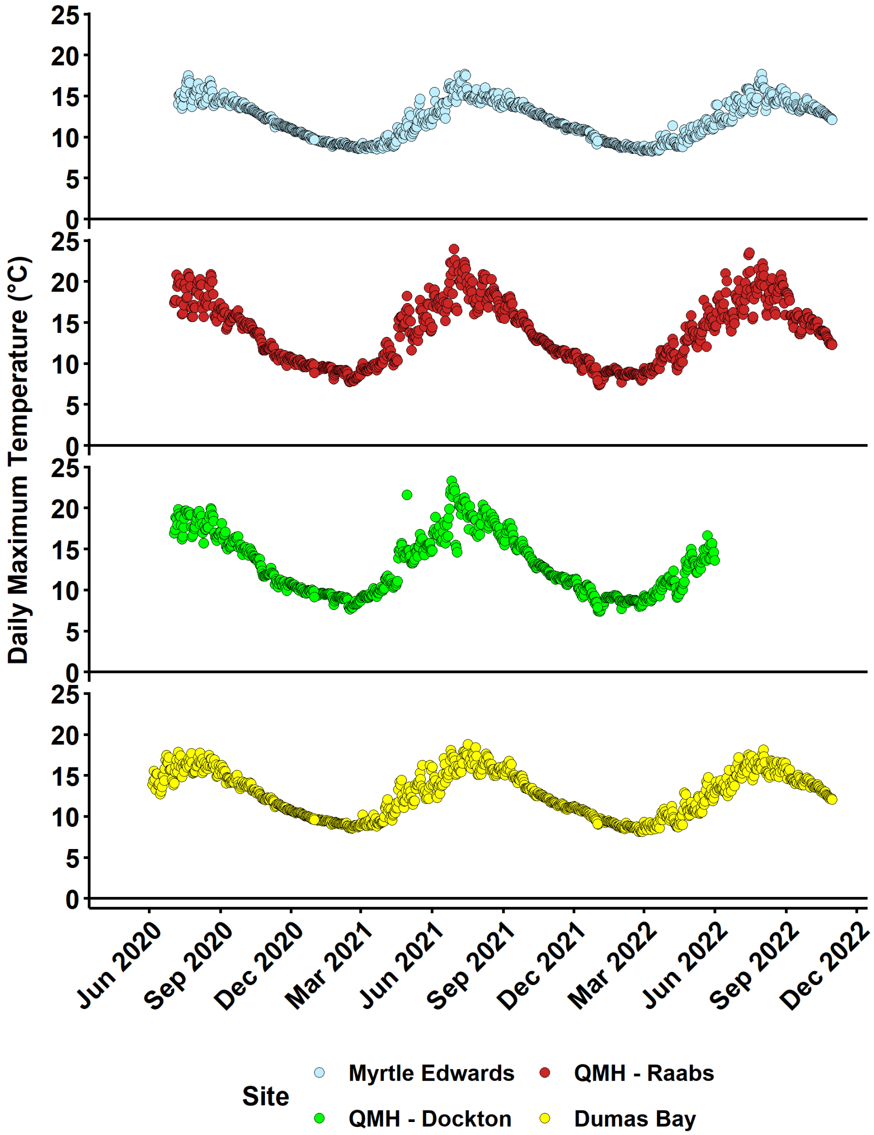


Figure 9. Daily maximum water temperature (°C) measured at the eelgrass test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay, from June 2020 through October 2022.

Table 5. Monthly mean, maximum and minimum water temperatures (°C) measured at four eelgrass transplant sites (Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay) from June 2020 through October 2022.

2020

Site	value	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Myrtle Edwards	**Mean**							**13.67**	**13.78**	**13.64**	**12.80**	**11.33**	**10.09**
	Maximum							17.53	16.87	15.39	14.07	12.53	11.08
	Minimum							12.00	12.61	13.06	10.93	9.44	7.75
QMH - Raabs	**Mean**							**15.31**	**15.53**	**14.49**	**13.09**	**10.52**	**9.47**
	Maximum							21.03	20.89	16.84	14.98	12.53	10.69
	Minimum							11.98	13.11	13.26	10.57	8.92	7.57
QMH - Dockton	**Mean**							**15.16**	**15.51**	**14.55**	**13.14**	**10.61**	**9.56**
	Maximum							19.87	19.98	18.18	15.25	12.68	10.71
	Minimum							12.07	13.23	13.21	10.93	8.74	7.52
Dumas Bay	**Mean**						**12.94**	**14.21**	**14.73**	**13.91**	**12.78**	**11.15**	**10.00**
	Maximum						17.51	17.87	17.80	16.27	14.15	12.34	10.79
	Minimum						10.96	11.57	12.75	12.99	10.39	9.88	8.27

2021

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Myrtle Edwards	**Mean**	**9.10**	**8.66**	**8.64**	**9.17**	**10.56**	**12.30**	**13.97**	**13.79**	**13.53**	**12.60**	**11.22**	**10.06**
	Maximum	9.71	9.36	9.41	12.05	14.65	16.56	17.70	16.06	15.37	13.69	11.90	11.22
	Minimum	7.27	6.48	7.82	8.39	9.19	10.35	12.32	12.78	12.99	10.91	9.14	5.49
QMH - Raabs	**Mean**	**9.03**	**8.25**	**9.12**	**10.69**	**12.45**	**14.25**	**15.37**	**16.13**	**14.84**	**12.85**	**10.95**	**9.32**
	Maximum	9.68	9.21	11.08	18.27	19.22	23.98	22.42	20.89	18.18	14.89	11.83	11.32
	Minimum	7.19	6.99	8.42	8.64	9.49	10.59	12.32	13.43	13.28	10.96	8.57	4.30
QMH - Dockton	**Mean**	**9.08**	**8.26**	**9.09**	**10.59**	**12.36**	**14.09**	**15.07**	**15.85**	**14.76**	**12.83**	**10.98**	**9.30**
	Maximum	9.68	9.26	10.39	21.60	16.84	23.33	21.29	20.44	18.18	14.79	11.81	11.35
	Minimum	6.84	5.62	8.07	8.72	9.56	10.52	12.39	13.35	13.31	10.54	8.79	6.31
Dumas Bay	**Mean**	**9.16**	**8.69**	**8.81**	**9.86**	**11.36**	**12.94**	**14.53**	**14.68**	**14.23**	**12.55**	**11.04**	**9.97**
	Maximum	9.68	9.21	10.25	14.48	16.30	18.11	18.84	17.68	16.80	13.55	11.83	11.25
	Minimum	7.90	7.24	8.30	8.57	9.53	10.52	12.12	12.97	13.19	10.44	9.51	7.82

2022

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Myrtle Edwards	**Mean**	**9.00**	**8.52**	**8.30**	**8.92**	**9.82**	**11.49**	**12.94**	**13.52**	**13.27**	**12.73**	**12.08**	
	Maximum	9.73	9.16	8.94	11.41	12.16	15.00	17.72	16.91	14.93	13.97	12.16	
	Minimum	5.67	6.91	7.77	7.96	8.71	10.13	11.17	12.10	12.64	11.81	11.78	
QMH - Raabs	**Mean**	**8.33**	**8.28**	**8.55**	**10.21**	**11.69**	**13.18**	**15.02**	**15.67**	**14.41**	**13.22**	**11.98**	
	Maximum	9.49	8.97	9.51	14.69	17.75	20.99	23.55	22.21	18.65	15.45	12.13	
	Minimum	5.85	6.54	8.22	8.57	8.86	10.54	11.56	12.98	12.93	11.62	11.77	
QMH - Dockton	**Mean**	**8.35**	**8.24**	**8.51**	**10.03**	**11.35**							
	Maximum	9.41	8.87	9.34	14.19	16.64							
	Minimum	5.67	6.36	8.10	8.34	8.82							
Dumas Bay	**Mean**	**8.88**	**8.38**	**8.36**	**9.15**	**10.43**	**12.13**	**13.80**	**14.43**	**13.72**	**12.84**	**11.87**	
	Maximum	9.78	9.21	9.31	12.92	14.80	16.45	17.55	18.13	15.91	14.40	11.99	
	Minimum	7.47	6.81	8.00	8.06	8.93	10.00	11.07	12.27	12.69	11.86	11.54	

The warming of marine waters in Puget Sound could have potential effects on nearshore habitats and the organisms that use them. The effects of increases in water temperatures for eelgrass transplants will vary depending on seasons. During the growing season, warmer waters will trigger increases in seagrass metabolism and subsequent respiratory demands that should be balanced by adequate PAR in shallow nearshore waters (i.e., Figure 5, Hammer et al. 2018). Another major concern for warmer summertime seawater temperatures could be nuisance macroalgal blooms that compete for space and light with new eelgrass transplants. There was evidence of large ulvoid mats covering the Dumas Bay test transplant site on August 11, 2022, that were likely due to seasonal increases in seawater temperatures and localized circulation.

During the winter periods, warmer seawater temperatures will also trigger increases in eelgrass metabolism, however, there is typically inadequate photosynthetic activity due to low light (i.e., Figure 5) to balance respiratory demands (Sawall et al. 2021). The imbalanced P:R ratio during winter months from rising seawater temperatures may have more dire effects on seagrass resilience than previously known (Sawall et al. 2021, Yang and Gaeckle, unpublished data). Although the seawater temperature data from the eelgrass transplant sites does not indicate a threshold that might trigger physiological stresses in seagrass, the ongoing research could provide insight on future transplant performance and success.

Conclusions

The project transplanted 94, 0.25 m^2 eelgrass plots over the course of two years from July 2020 to June 2022 at Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay in King County. The total number of eelgrass shoots transplanted was 5,055 sourced from two donor locations, Dumas Bay-SGN (30%) and DuPont Wharf (70%). Over the course of the eelgrass restoration effort, 28 monitoring events evaluated test transplant success, explored modified approaches to improve success (i.e., QMH-Raabs), and maintained environmental sensors. Eelgrass transplants survived at Myrtle Edwards Park and Dumas Bay, and failed at QMH-Raabs and QMH-Dockton.

The environmental sensor data indicated adequate PAR for long-term eelgrass survival and non-light limited growth (Thom et al. 2008) over the course of the monitoring period at all test transplant sites. Although marine water temperatures were slightly warmer than the optimal range of 6-17°C (Thom et al. 2008, 2014), eelgrass can tolerate temperatures in excess of 20°C throughout its range (Moore et al. 2006, Lee et al. 2007). Therefore, it is not likely elevated summer seawater temperature had a significant effect on test transplant success. However, there are concerns of the potential metabolic effects to eelgrass that could result due to elevated winter temperatures (Hammer et al. 2018, Sawall et al. 2021, Yang and Gaeckle, unpublished data). Increasing seawater temperatures during low winter light periods could shift the photosynthesis:respiration (P:R) ratio and lead to a greater occurrence of eelgrass mortality. The increases in winter temperatures not only relates to newly transplanted eelgrass, but existing stable beds throughout Puget Sound.

The two observed factors that limited eelgrass transplant success at QMH-Raabs and QMH-Dockton were disturbance by crabs and unsuitable sediment conditions, respectively. It is possible to cap sediments and successfully transplant eelgrass (Brodin 2021). However, this practice can be cost prohibitive and constrained by permitting. Controlling crustaceans from disturbing eelgrass transplants is more feasible on a small scale. Because light conditions at QMH-Raabs were favorable for eelgrass growth, a small-scale installation of a crustacean control mechanism might lead to eelgrass transplant success. It is possible that survival is density-dependent – an established patch of eelgrass with natural densities would likely be more resilient to disturbance (Olesen and Sand-Jensen 1994) by crabs.

Finally, eelgrass transplants were successful at Myrtle Edwards Park (Appendix C) and Dumas Bay (Appendix D) suggesting both sites are strong candidates for large-scale eelgrass transplanting. Adding eelgrass to the existing test transplants could accelerate the establishment of stable, self-supporting meadows at each site and provide critical nearshore habitat for forage fish, waterfowl, and salmonids among other species.

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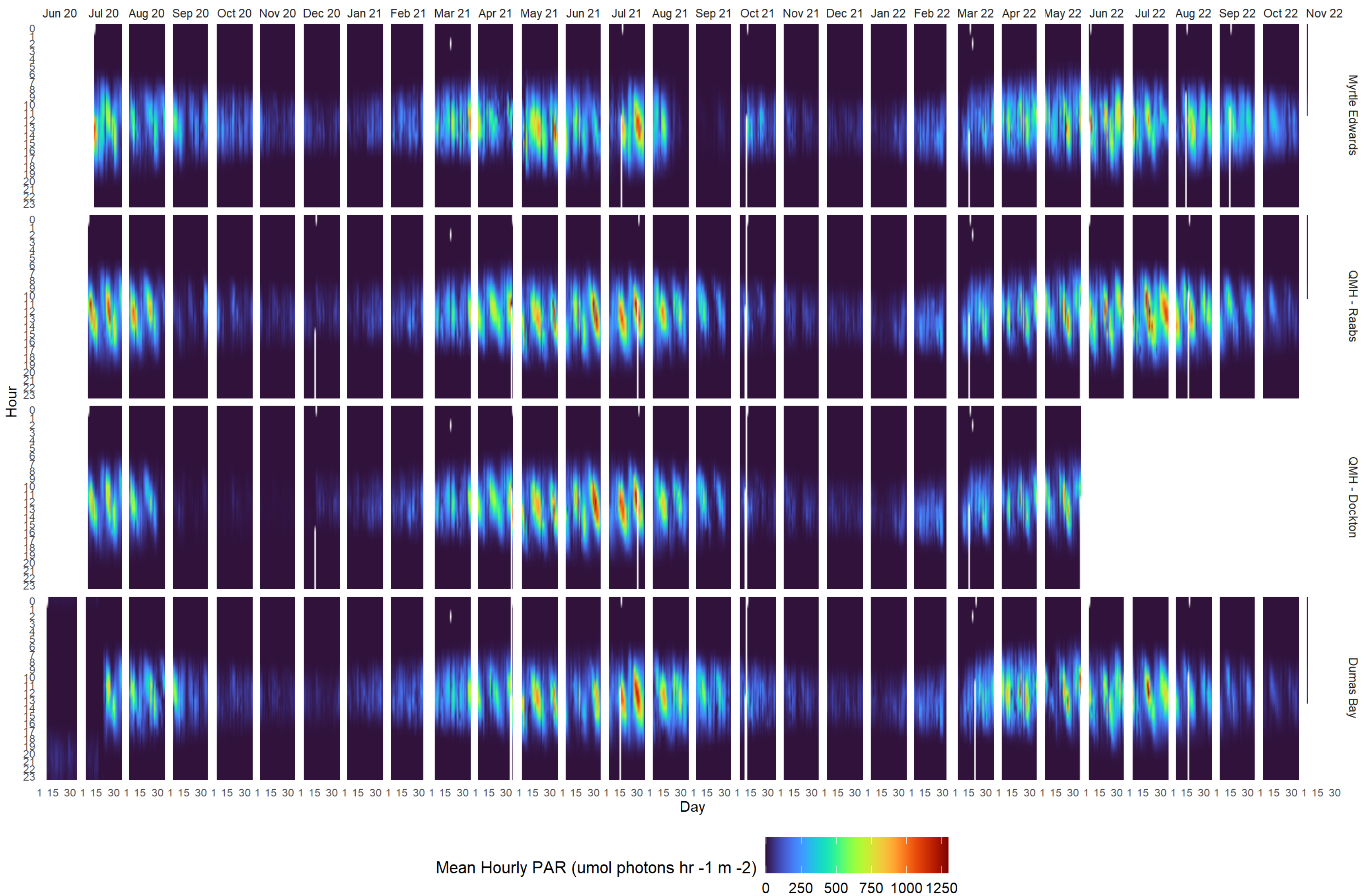
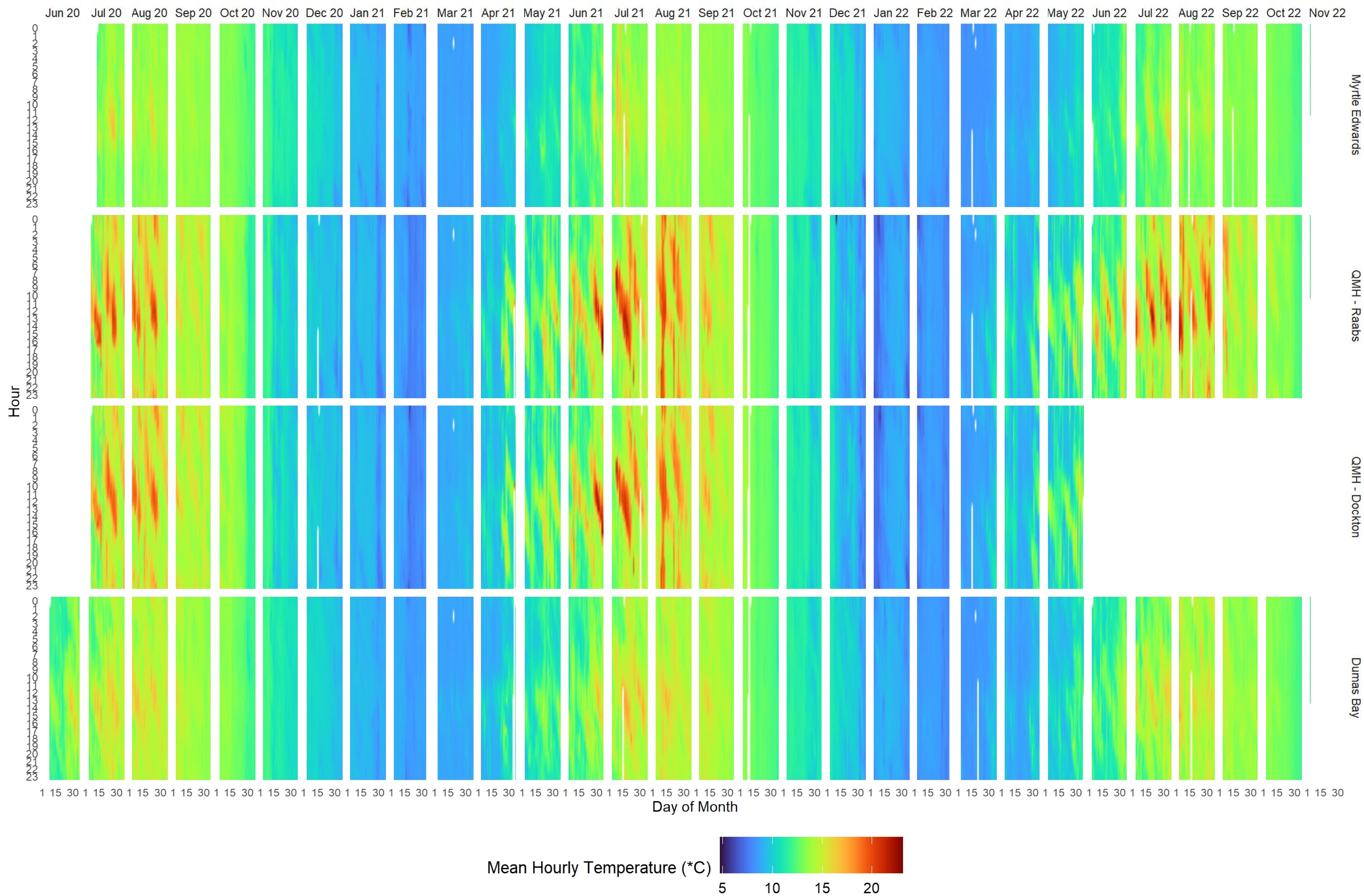
Appendix A. Average hourly Photosynthetically Active Radiation (PAR, µmol photons m^{-2} d^{-1}) for each month at eelgrass test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay from June 2020 through October 2022.



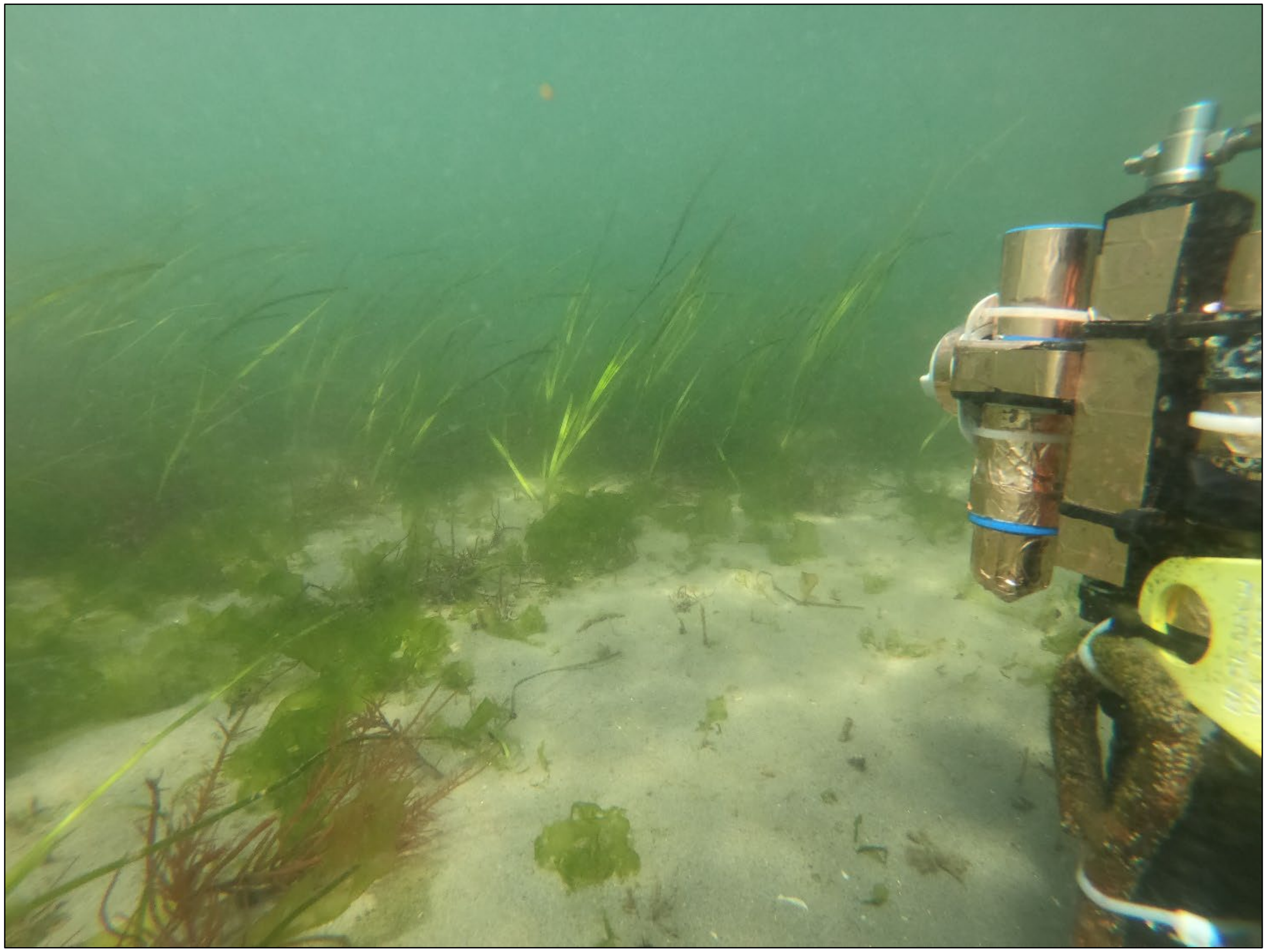
Appendix B. Average hourly temperature (°C) for each month at eelgrass test transplant sites, Myrtle Edwards Park, QMH-Raabs, QMH-Dockton, and Dumas Bay from June 2020 through October 2022.



Appendix C. Successful eelgrass transplants at Myrtle Edwards Park from 2022. Additional images will be provided digitally.

Appendix C – con't. Successful eelgrass transplants at Myrtle Edwards Park from 2022. Additional images will be provided digitally.

Appendix D. Successful eelgrass transplants at Dumas Bay from 2022. Additional images will be provided digitally.



Appendix D – con't. Successful eelgrass transplants at Dumas Bay from 2021. Additional images will be provided digitally.