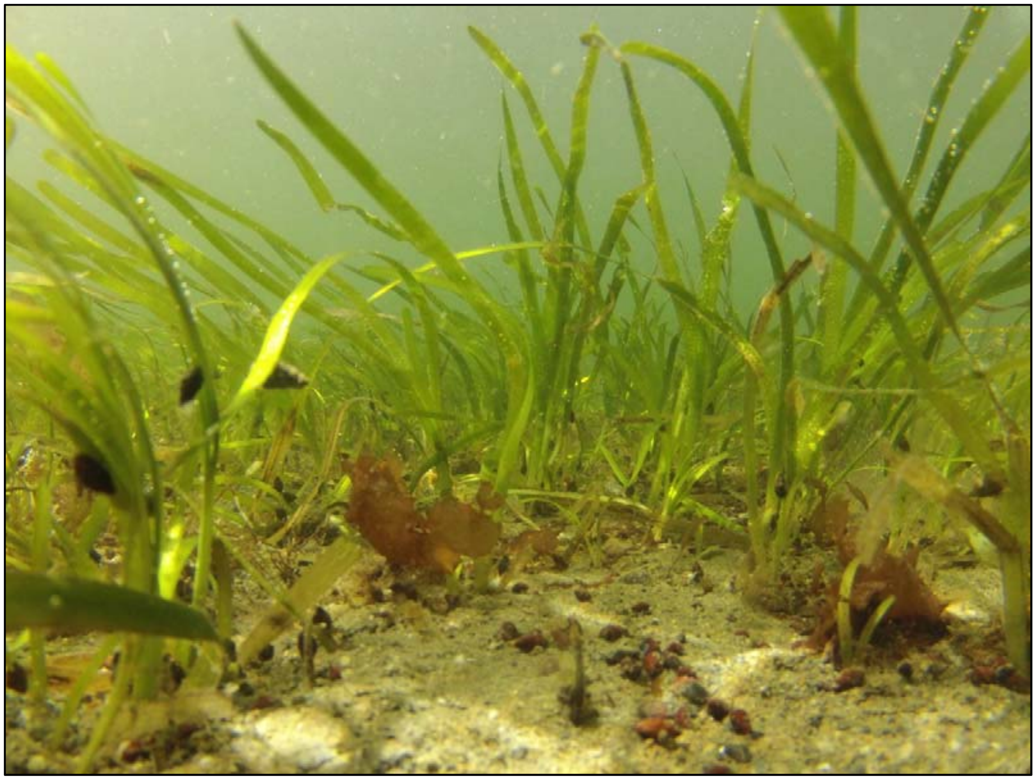
NATURAL RESOURCES

Eelgrass (*Zostera marina*) Restoration in Puget Sound

February 2019



WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
HILARY S. FRANZ | COMMISSIONER OF PUBLIC LANDS

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Jeff Gaeckle
Nearshore Habitat Program
Aquatic Resources Division

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Contents

1 Introduction

The Washington State Department of Natural Resources (DNR) is steward of 2.6 million acres of state-owned aquatic land. The Aquatic Resources Division of DNR manages these aquatic lands for the benefit of current and future citizens of Washington State. DNR's stewardship responsibilities include protection of native seagrasses, an important nearshore habitat in greater Puget Sound. As part of that responsibility, DNR has sought to achieve measurable increases in Puget Sound eelgrass, *Zostera marina* L., area by strategically targeting eelgrass plantings at sites that have a strong likelihood for restoration success. Sites with a high probability of restoration success have been identified through an eelgrass transplant suitability model developed to address the Puget Sound Partnership's "20% More Eelgrass by 2020" goal (Thom et al. 2014, 2018).

The project goals were to restore eelgrass at sites in greater Puget Sound and to investigate the effects of harvest on donor sites, the changes in pH by restored eelgrass beds with respect to ocean acidification, and the performance of eelgrass transplant survival over time. The project was divided into two phases: Phase 1 (2016-17) was designed to transplant eelgrass and monitor water quality (Shannon et al. 2018), while the focus of Phase 2 (2018) was to continue monitoring eelgrass transplants and water quality, specifically pH. Between 2016 and 2017, three different donor beds were used to transplant eelgrass (*Zostera marina* L.) at 15 test-transplant (Table 1) and 7 large-scale transplant (Table 2) sites located within South Puget Sound (Shannon et al. 2018). Eelgrass test-transplant sites were small transplant efforts used to identify suitable sites for large-scale eelgrass restoration. Water quality parameters were also collected during Phase 1 to track the effect of eelgrass on water properties (e.g., pH).

During Phase 2 (2018), the objectives of the project were to monitor restoration performance at test- and large-scale transplant sites planted during Phase 1 (2016-17) and to assess water quality characteristics in three different age large-scale transplant areas at Joemma Beach State Park. Water quality was measured to test the hypotheses that eelgrass influences pH and other sea water parameters and that the age of eelgrass restoration has a more pronounced effect on in situ conditions.

Table 1. Eelgrass test-transplant sites transplanted in 2016 and 2017.

SITE #	SITE NAME	YEAR	SUB-LOCATION	LATITUDE	LONGITUDE
1	Delano Beach	2016	N	47.25804	-122.73927
			S	47.25828	-122.73809
2	Joemma Beach State Park North	2016	N	47.22589	-122.81332
			S	47.22580	-122.81301
3	Joemma Beach State Park North 1	2017	N	47.22627	-122.81467
			S	47.22623	-122.81460
4	Joemma Beach State Park North 2	2017	N	47.22632	-122.81497
			S	47.22627	-122.81483
5	Taylor Bay	2016	N	47.18309	-122.77779
			S	47.18286	-122.77778
6	Penrose State Park	2016	N	47.26407	-122.73926
			S	47.26387	-122.73926
7	McDermott Point 1	2017	N	47.19868	-122.73923
			S	47.19862	-122.73927
8	McDermott Point 2	2017	N	47.19903	-122.73913
			S	47.19898	-122.73917
9	Anderson Island West 1	2017	N	47.18186	-122.71403
			S	47.18183	-122.71405
10	Anderson Island West 2	2017	N	47.17693	-122.72505
			S	47.17690	-122.72510
11	South Head 1	2017	N	47.24985	-122.72317
12	South Head 2		S	47.24963	-122.72338
13	Fudge Point 1	2017	N	47.23726	-122.86145
			S	47.23725	-122.86138
14	Fudge Point 2	2017	N	47.23774	-122.86269
			S	47.23766	-122.86240
15	Fudge Point 3	2017	N	47.23726	-122.86145

Table 2. Eelgrass large-scale transplant site from 2016 and 2017.

SITE #	SITE NAME	YEAR	SUB-LOCATION	LATITUDE	LONGITUDE
1	Delano Beach	2016	SE	47.25753	-122.73820
			SW	47.25754	-122.73814
			NE	47.25784	-122.73817
			NW	47.25784	-122.73824
2	Joemma Beach State Park 1	2016	SE	47.22180	-122.80988
			SW	47.22174	-122.80997
			NE	47.22199	-122.80993
			NW	47.22197	-122.81002
3	Joemma Beach State Park 2	2017	SE	47.22145	-122.80969
			SW	47.22141	-122.80973
			NE	47.22151	-122.80975
			NW	47.22146	-122.80984
4	Joemma Beach State Park 3	2017	SE	47.22132	-122.80962
			SW	47.22128	-122.80979
			NE	47.22142	-122.80965
			NW	47.22141	-122.80973
5	Joemma Beach State Park 4	2017	SE	47.22115	-122.80956
			SW	47.22112	-122.80964
			NE	47.22123	-122.80963
			NW	47.22128	-122.80979
6	Anderson Island South 1	2017	E	47.13892	-122.72556
			W	47.13875	-122.72511
7	Anderson Island South 2	2017	E	47.13844	-122.72417
			W	47.13825	-122.72369

2 Methods

2.1 *Eelgrass monitoring*

One objective for the Phase 2 of the project was to measure eelgrass shoot density at all transplant sites that had eelgrass remaining in July 2017 (Table 3). This included 10 test-transplant sites and 6 large-scale transplant sites (Table 3, Figure 1) (Shannon et al. 2018). In the spring and summer of 2018, a census of all eelgrass shoots was recorded at the test-transplant sites, while at the large-scale transplant sites shoot density was measured in thirty random 0.25 m^2 quadrats and presented as mean shoots m^{-2} (± SE). Eelgrass area was measured if transplanted eelgrass expanded beyond the original transplant area in the test- and large-scale transplant sites.

Table 3. Test- and large-scale transplant sites with eelgrass present during last monitoring effort in July 2017 (Shannon et al. 2018).

TYPE	SITE NAME	YEAR PLANTED	EELGRASS PRESENT in 2017?
Test-transplant			
1	Delano Beach	2016	No
2	Joemma Beach State Park North	2016	Yes
	Joemma Beach State Park North 1	2017	Yes
3	Joemma Beach State Park North 2	2017	Yes
4	Taylor Bay	2016	No
5	Penrose State Park	2016	No
6	McDermott Point 1	2017	No
7	McDermott Point 2	2017	No
8	Anderson Island West 1	2017	Yes
9	Anderson Island West 2	2017	Yes
10	South Head 1	2017	Yes
11	South Head 2	2017	Yes
12	Fudge Point 1	2017	Yes
13	Fudge Point 2	2017	Yes
14	Fudge Point 3	2017	Yes
Large-scale			
1	Delano Beach	2016	No
2	Joemma Beach State Park 1	2016	Yes
3	Joemma Beach State Park 2	2017	Yes
4	Joemma Beach State Park 3	2017	Yes
5	Joemma Beach State Park 4	2017	Yes
6	Anderson Island South 1	2017	Yes
7	Anderson Island South 2	2017	yes

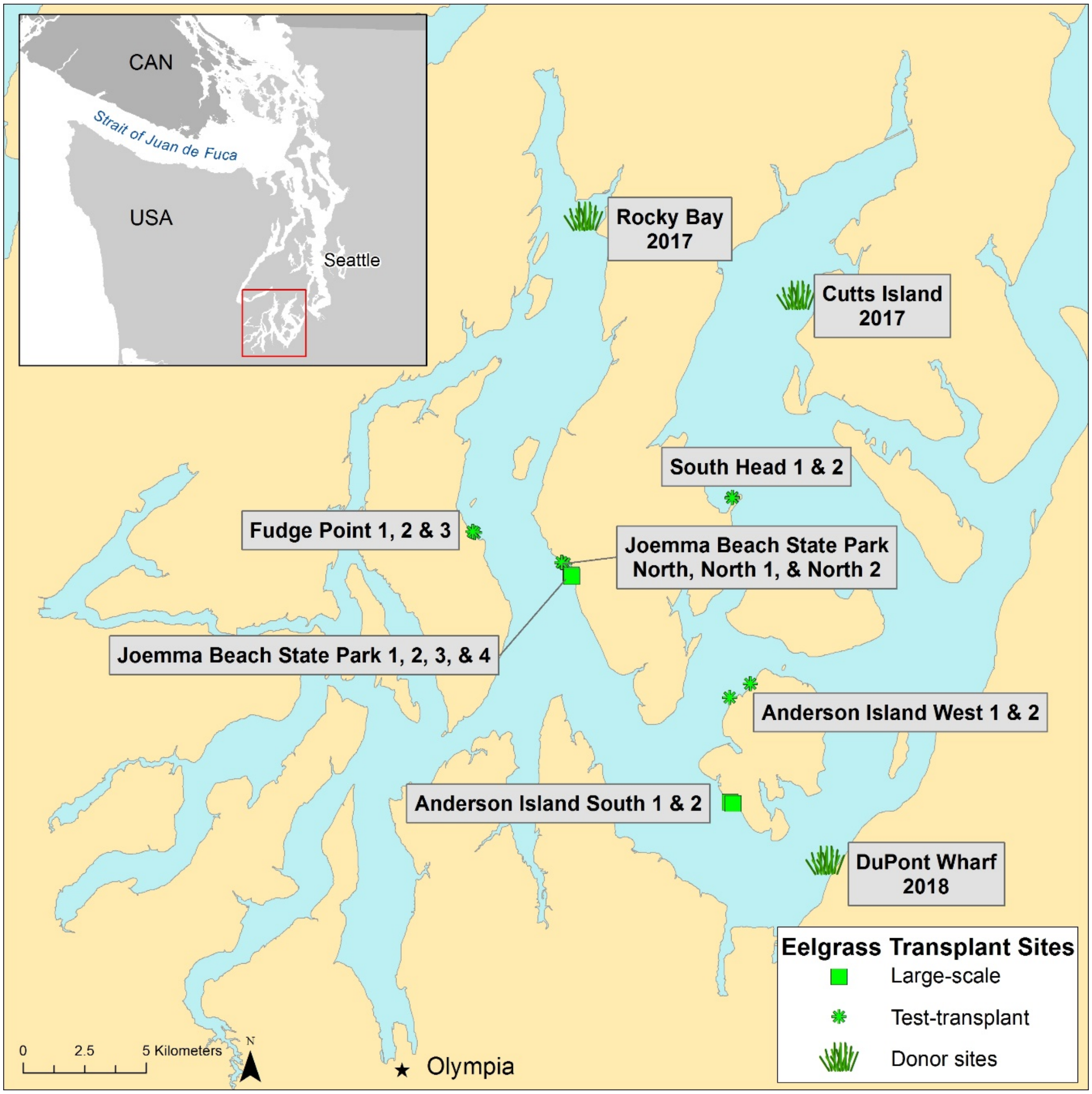


Figure 1. Map of test- and large-scale transplant sites with eelgrass present in July 2017 (Shannon et al. 2018). Also shown are donor sites from 2017 and 2018.

2.2 *Water quality monitoring*

To evaluate differences between eelgrass and non-eelgrass areas pH, temperature and salinity were measured in three different age, large-scale transplant sites and in three adjacent unvegetated areas at Joemma Beach State Park. A sensor array was deployed at each site that consisted of 2 pH sensors, 1 alkalinity sensor, and a temperature sensor (Figure 2) (Gaeckle 2017, Shannon et al. 2018). The large-scale transplant sites at Joemma

Beach State Park included one planted in 2015 as part of a separate study (Aston et al. 2015), and two planted in Phase 1 of this project (Shannon et al. 2018).

Figure 2. Water quality sensor array in large-scale eelgrass transplants (left) and adjacent unvegetated areas at Joemma Beach State Park.

Water quality sensors arrays were deployed on March 6, 2018 and cleaned in situ on June 15 and 16, 2018, and again on July 13, 2018. Sensors were retrieved from Joemma Beach State Park on August 8, 2018 for data download and calibration. Sensors were then re-deployed on August 13, 2018. All six sensor arrays were collected again on October 15, 2018, for data download and calibration and then re-deployed on October 22, 2018. The sensor arrays will remain in the field for 3 months.

Two Photosynthetically Active Radiation (PAR) sensors were deployed at the deep edge of eelgrass near the center of the four large-scale transplant sites planted in Phase 1 (Shannon et al. 2018). The top and bottom PAR sensors were set 50 cm apart on a PVC post facing south (Gaeckle 2017, Shannon et al. 2018). Daily average PAR (mol m^{-2} d^{-1}) was calculated for daylight hours based on sunrise to sunset observed in Olympia, WA. Sunrise to sunset data were downloaded from the U.S. Naval Observatory website (Astronomical Applications Department 2018). Daily light attenuation coefficient (K_d m^{-1}) was calculated within ±3 hours of solar noon as a tool to check data quality and to determine whether sensors functioned properly and were not fouled by epiphytes and macroalgae.

Photosynthetically Active Radiation data were removed from analyses if attenuation coefficients were outside a biologically sustainable range that supported eelgrass (0.22 – 0.92 K_d m^{-2}, Dennison et al. 1993). Since the sensors were only 50 cm apart there should not have be much difference in PAR values between the two sensors and the top sensor should have consistently received more PAR than the bottom sensor. Therefore, excessively high attenuation coefficient values suggest the lower sensor was fouled or the upper sensor was exposed during spring low tide series (Table 9). Whereas negative attenuation coefficient values suggest the top sensor was fouled. Data were removed from analyses in cases where attenuation coefficients were excessively high or negative values.

2.3 *Eelgrass test-transplant enhancement*

To supplement the proposed work, eelgrass shoots were added to two test-transplant sites to enhance existing transplants and to test the performance of eelgrass from different donor sources at these sites. The two sites were South Head 1 & 2 and Fudge Point 1 & 2 (Figure 1). During Phase 1 of the project eelgrass from the Cutts Island donor site was planted at South Head 1 & 2 and eelgrass from Rocky Bay was planted at Fudge Point 1 & 2 (Shannon et al. 2018). Eelgrass from DuPont Wharf was transplanted at these two sites in 2018 during Phase 2 (Figure 1).

3 Results

3.1 *Eelgrass monitoring*

Eelgrass shoot density and area were sampled by a team of divers at six large-scale eelgrass transplant sites on May 8 and 9, 2018. Eelgrass was present at the four Joemma Beach State Park sites and at only one of the Anderson Island South sites (Table 4). Shoot density measured at the Joemma Beach State Park sites ranged from 158 ± 17.8 to 266 ± 17.9 shoots m^{-2} (mean ± SE shoots m^{-2}). A total of 44 shoots were measured in the 160 m^2 transplant area of the Anderson Island South 2 site. Transplanted eelgrass did not expand beyond the any of the delineated site areas and therefore was not measured.

Table 4. Average eelgrass shoot density (average m^{-2} ± SE) at six large-scale eelgrass transplant sites measured in May 2018.

DATE MONITORED	SITE	YEAR PLANTED	SITE AREA	SHOOT DENSITY
			(m^2)	(average m^{-2} ± SE)
8 May 2018	Joemma Beach State Park – 1	2016	160	249.7 ± 15.6
8 May 2018	Joemma Beach State Park – 2	2017	160	158.5 ± 17.8
9 May 2018	Joemma Beach State Park – 3	2017	160	266.1 ± 17.9
9 May 2018	Joemma Beach State Park – 4	2017	160	208.7 ± 16.5
9 May 2018	Anderson Island South 1	2017		0
9 May 2018	Anderson Island South 2	2017	1.25*	44.0**

* - area determined based on number of 0.25 m^2 quadrats measured at the site (n=5).

** - total number of eelgrass shoots counted

A team of snorkelers measured shoot density at the 10 test-transplant sites between May 30 and June 16, 2018. Eelgrass was present at eleven 0.25 m^2 patches at two sites, South Head 1 & 2 (Table 5). No eelgrass was observed at the other eight test-transplant sites planted in 2016 and 2017 (Table 5).

Table 5. Total eelgrass shoot count measured at eelgrass test-transplant sites in South Puget Sound between May 31 and June 16, 2018.

DATE MONITORED	SITE	YEAR PLANTED	EELGRASS AREA	TOTAL SHOOT COUNT
			(m^2)	
30 May 2018	Anderson Island West N	2017		0
30 May 2018	Anderson Island West S	2017		0
30 May 2018	Fudge Point 1	2017		0
30 May 2018	Fudge Point 2	2017		0
30 May 2018	Fudge Point 3	2017		0
30 May 2018	South Head 1 & 2 (combined)	2017	2.75*	308
16 June 2018	Joemma Beach State Park – North	2016		0
16 June 2018	Joemma Beach State Park – North 1	2017		0
16 June 2018	Joemma Beach State Park – North 2	2017		0

* - area determined based on number of 0.25 m^2 quadrats measured at the site (n=11).

Later in the 2018 field season, snorkelers measured eelgrass shoot density and area at the four large-scale eelgrass transplant sites at Joemma Beach State Park and two large-scale sites at Anderson Island South from August 10-12, 2018 (Table 6). During the August sampling effort a buoy marking system was also established at Joemma Beach State Park to delineate the four large-scale sites in anticipation of future monitoring that would be conducted by divers (Appendix A).

During the August 2018 monitoring at Joemma Beach State Park-1 snorkelers used a 0.0625 m^2 quadrat to increase accuracy of high density counts. Mean shoot density measured by snorkelers at Joemma Beach State Park – 1 was 1,410 ± 106.1 shoots m^{-2} (mean ± SE shoots m^{-2}) (Table 6). Eelgrass was sparse at Joemma Beach State Park sites 2 – 4, therefore snorkelers used 0.25 m^2 quadrats to measure shoot density. Average shoot densities across Joemma Beach State Park sites 2 – 4 ranged from 65.5 ± 7.1 to 108.8 ± 13.5 shoots m^{-2} (mean ± SE shoots m^{-2}) (Table 6).

Eelgrass shoot density was measured a final time at the four large-scale eelgrass transplant sites at Joemma Beach State Park on September 5, 2018 (Table 6). Divers also used a 0.0625 m^2 quadrat at Joemma Beach State Park – 1 to increase accuracy of high shoot density counts. Mean shoot density measured by divers at Joemma Beach State Park – 1 was 1,347 ± 89.1 shoots m^{-2} (mean ± SE shoots m^{-2}), while at Joemma Beach State Park sites 2 – 4 mean eelgrass shoot density ranged from 39 ± 5.3 to 141 ± 20.9 shoots m^{-2} (mean ± SE shoots m^{-2}) (Table 6).

Table 6. Average eelgrass shoot density (mean m^{-2} ± SE) measured in four large-scale eelgrass transplant areas at Joemma Beach State Park by snorkelers (August 10-12, 2018) and by divers (September 5, 2018).

SITE	**YEAR PLANTED**	**SHOOT DENSITY**	**SHOOT DENSITY**
		August 10-12	**September 5**
		(average m^{-2} ± SE)	(average m^{-2} ± SE)
Joemma Beach State Park – 1	2016	1,410.1 ± 106.1	1,347.2 ± 89.1
Joemma Beach State Park – 2	2017	108.8 ± 13.5	39.5 ± 5.3
Joemma Beach State Park – 3	2017	65.5 ± 7.1	61.9 ± 10.4
Joemma Beach State Park – 4	2017	106.8 ± 24.4	141.3 ± 20.9

There was no significant difference in mean shoot density at the four large-scale transplant sites at Joemma Beach State Park measured by snorkelers (August 12, 2018) and divers (September 5, 2018) (ANOVA, $p = 0.667$) (Figure 3). There was, however, a significant difference in shoot density between the Joemma Beach State Park – 1 (planted in 2016) site compared to sites 2 – 4 (planted in 2017) that showed transplant age had an effect on shoot density ($p < 0.001$) (Figure 3).

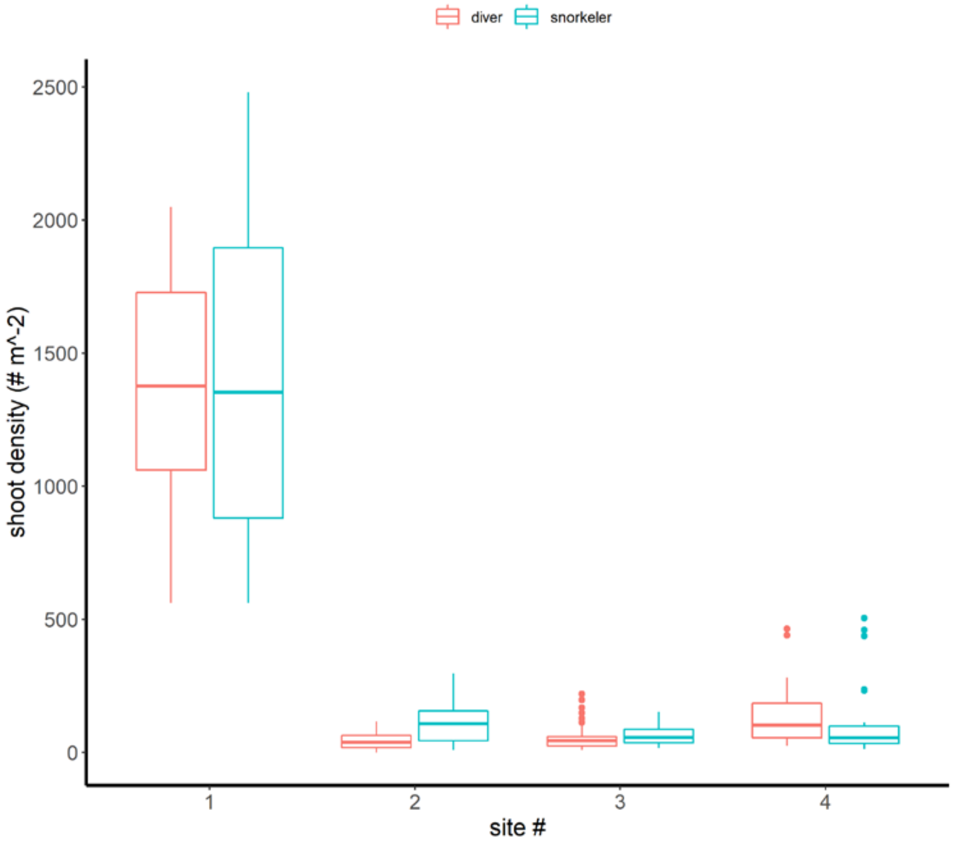


Figure 3. Boxplot of eelgrass shoot density (shoots m^{-2}) measured by snorkelers (August 12, 2018) and divers (September 5, 2018) at four large-scale eelgrass transplant sites at Joemma Beach State Park planted during Phase 1 of the project (site 1 was planted in 2016 and sites 2 – 4 were planted in 2017).

The ability to acquire eelgrass shoot density data in mid-August and again in early September with snorkeler and divers, respectively, provided data to compare survey methods. Shoot density measured by snorkelers and divers at the three large-scale transplant sites planted in 2017 at Joemma Beach State Park was not significantly different between methods ($p = 0.313$). There was a significant difference in eelgrass shoot density among the three sites ($p = 0.001$) and a significant interaction between data collected by snorkeler or divers and sites ($p < 0.001$) based on a two-way ANOVA analysis (Figure 4).

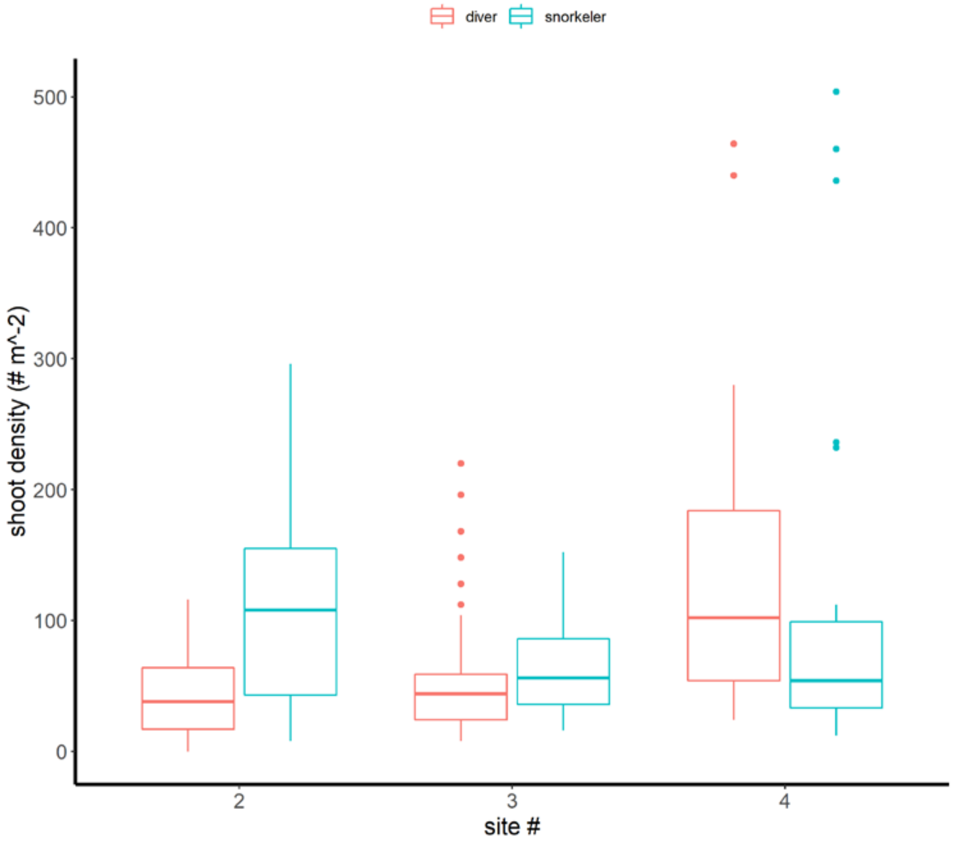


Figure 4. Boxplot of eelgrass shoot density (shoots m^{-2}) measured by snorkelers (August 12, 2018) and divers (September 5, 2018) at the three large-scale eelgrass transplant sites at Joemma Beach State Park (sites 2 – 4) planted during Phase 1 of the project (2017).

The original transplant area for each of the Joemma Beach State Park sites was 160 m^2 and there was no evidence that eelgrass expanded beyond the original transplant boundary. However, there was evidence that eelgrass patches at Joemma Beach State Park – 1 coalesced to form a more continuous eelgrass bed within the original transplant boundary (Appendix B). At the other three large-scale transplant sites at Joemma Beach State Park, there were fewer patches of eelgrass, and subsequently vegetated eelgrass area, compared to the original amount transplanted in 2017. There was also no evidence of transplanted eelgrass growing outside of the original transplanted boundary at these sites.

The eelgrass shoot density at the Anderson Island South sites was also measured by snorkelers during the early August 2018 field effort. Anderson Island South – 1, the northwest site of the two, did not have any eelgrass present. These results were expected since a dive team did not find any eelgrass at the site in May 2018 (Progress Report 1 – Jan to Jun 30, 2018). Anderson Island South – 2, southeast of Anderson Island site 1, had a total of 34 eelgrass shoots counted in four 0.25 m^2 quadrats for a total of 1 m^2 of vegetation (Table 7). The number of eelgrass shoots counted in August was down from the May 2018 shoot count at Anderson Island South – 2. In May 2018, the team counted five 0.25 m^2 plots for a total of 44 eelgrass shoots at Anderson Island South – 2 (Table 4; Progress Report 1 – Jan to Jun 30, 2018).

Table 7. Average eelgrass shoot density (mean m^{-2} ± SE) measured at six large-scale eelgrass transplant sites by snorkelers from August 10-12, 2018.

DATE MONITORED	SITE	YEAR PLANTED	AREA	SHOOT DENSITY
			(m^2)	(average m^{-2} ± SE)
12 August 2018	Anderson Island South – 1	2017		0
12 August 2018	Anderson Island South – 2	2017	1	34.0 *

* - total number of eelgrass shoots counted in 4, 0.25 m^2 quadrats (1 m^2) at Anderson Island South – 2.

Shoot density was not measured at Anderson Island South – 2 by divers on September 5, 2018. Between the May and August 2018 monitoring events, overall shoot count decreased by 10 shoots and one less patch was observed at the Anderson Island South – 2 site. Although eelgrass likely still persisted at Anderson Island South – 2 into September 2018, the low number of eelgrass shoots measured in August did not justify committing a dive team to monitor the site in September.

3.2 *Water quality monitoring*

The six sensor arrays deployed to evaluate differences between pH, temperature and salinity in three different age eelgrass and non-eelgrass areas were successfully deployed on March 6, 2018, at three large-scale transplant sites (planted in 2015, 2016 and 2017) and in adjacent unvegetated areas at Joemma Beach State Park. Three sensors arrays were deployed in large-scale sites transplanted in 2015 (PNNL-2015-S, Aston et al. 2015), 2016 (HC-2016-1), and 2017 (HC-2017-2), and three sensors arrays were deployed in unvegetated, sandy habitat adjacent to the transplant sites (Table 8, Figure 5).

Table 8. GPS location of sensor arrays deployed in transplanted eelgrass and unvegetated, sandy habitat at Joemma Beach State Park in March 2018.

HABITAT TYPE	REP	SITE LOCATION	LATITUDE	LONGITUDE
Unvegetated	1	North of PNNL–2015–3	47.22252	-122.81044
Eelgrass	1	PNNL–2015–S	47.22203	-122.81008
Unvegetated	2	South of PNNL–2015–S	47.22196	-122.81005
Eelgrass	2	HC–2016–1	47.22191	-122.81002
Unvegetated	3	South of HC-2017-3	47.22120	-122.80956
Eelgrass	3	HC-2017-2	47.22165	-122.80997

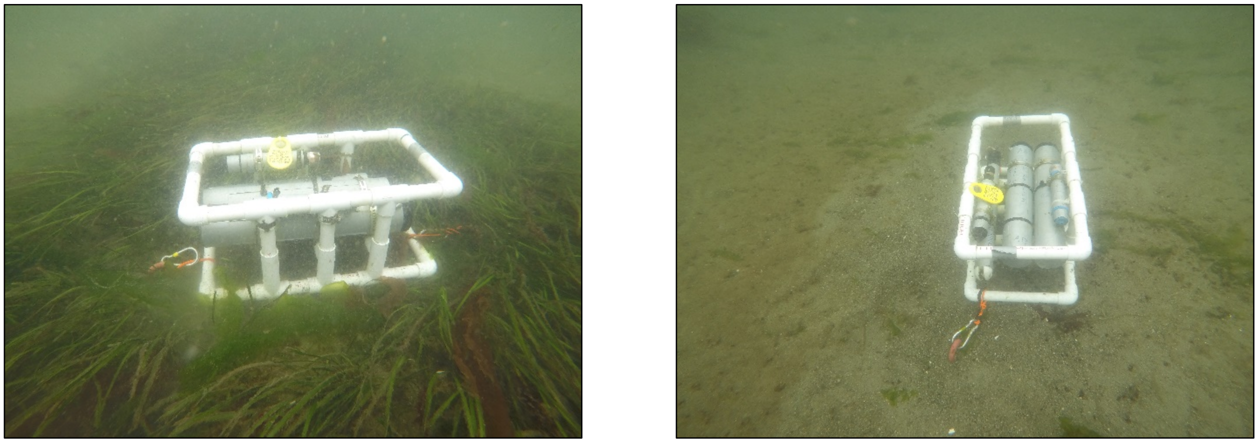


Figure 5. Example of sensor array deployed in transplanted eelgrass (left) and adjacent unvegetated, sandy areas (right) at Joemma Beach State Park in March 2018.

Sensors were heavily colonized by barnacles, epiphytes, green algae (ulvoids) and red spaghetti algae (*Gracilaria*) and required periodic cleaning during deployment. Sensor arrays were cleaned in situ on June 15 and 16, 2018, and again on July 13, 2018 (Figure 6).

Figure 6. Water quality sensor array at Joemma Beach State Park being cleaned. Excessive fouling with epiphytes, barnacles, and macroalgae required cleaning. Sensors were cleaned on June 15 – 16, 2018 and on July 13, 2018.

Between August 8, 2018, and August 13, 2018, sensors were successfully retrieved from the Joemma Beach State Park sites and re-deployed (Figure 7).

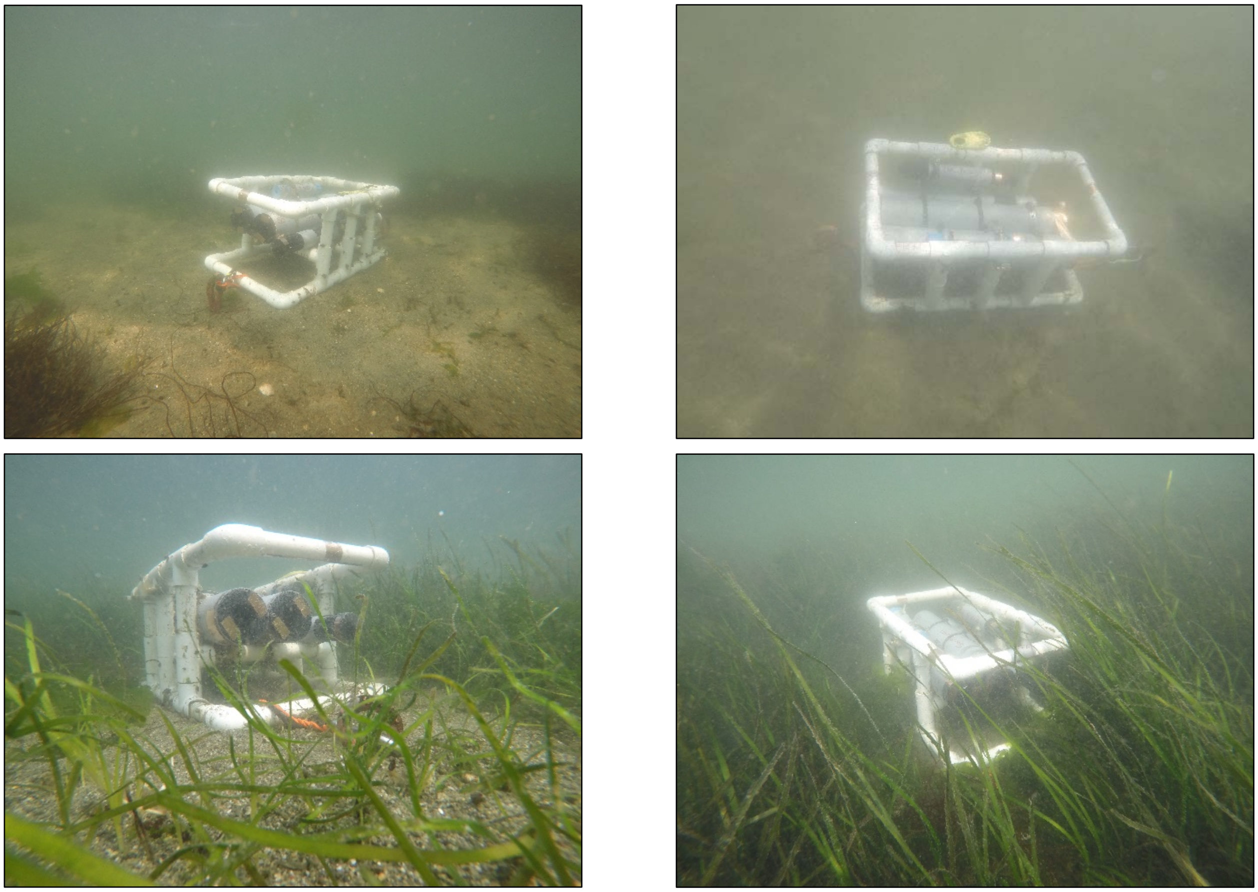


Figure 7. Sensor arrays deployed in restored eelgrass (bottom 2 images) and unvegetated areas (top 2 images) at Joemma Beach State Park. Sensors were retrieved on August 8, 2018, and re-deployed on August 13, 2018.

Although sensors were cleaned and swapped throughout the field season from March through October 2018, there were cases where data quality was compromised due to fouling or lost due to sensors that malfunctioned. The period from May 15 to August 10, 2018, provided the most complete data record from the paired sensors at the large-scale sites. Overall, data from co-located sensors deployed in unvegetated areas (B1) were more variable than data from eelgrass areas (E1) during the May 15 to August 10, 2018 deployment (Figure 8).

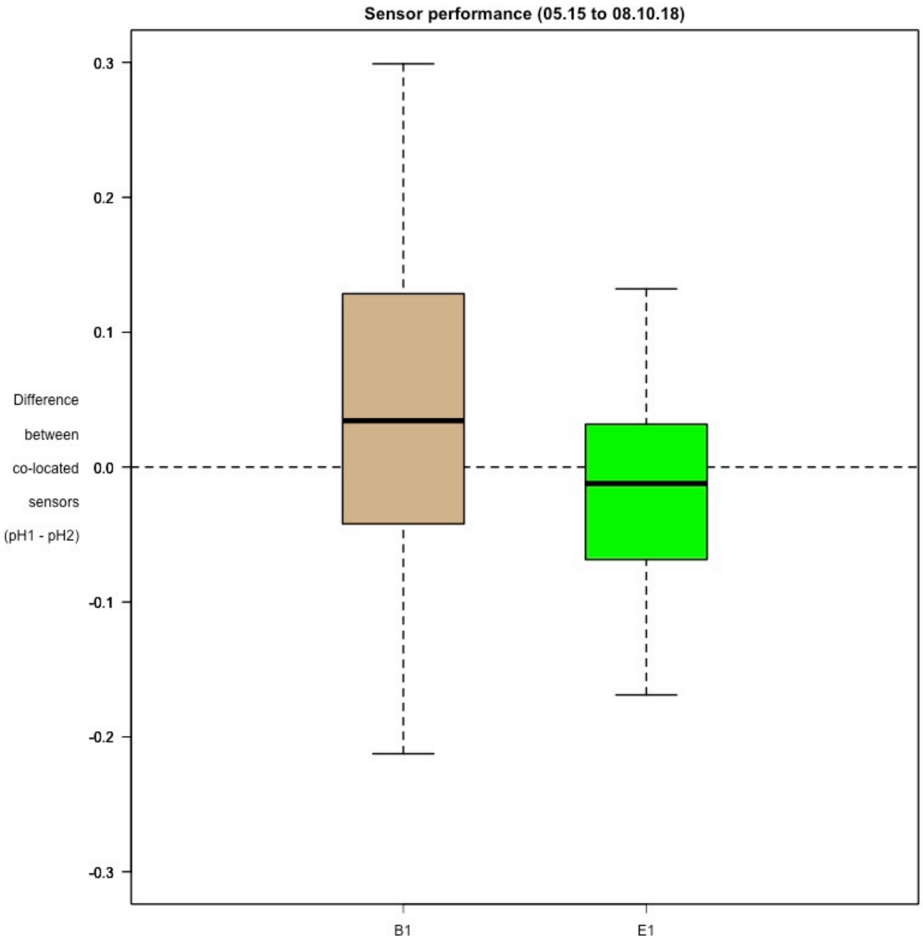


Figure 8. Difference in pH values between co-located sensor pairs in unvegetated (B1, brown) and eelgrass (E1, green) from May 15 to August 10, 2018.

Average hourly pH was higher in eelgrass relative to unvegetated areas at the two more established large-scale transplant sites at Joemma Beach State Park planted in 2015 (PNNL-2015-S, Aston et al. 2015) and 2016 (HC-2016-1) for the period from May 15 to August 10, 2018 (Figures 9 and 10).

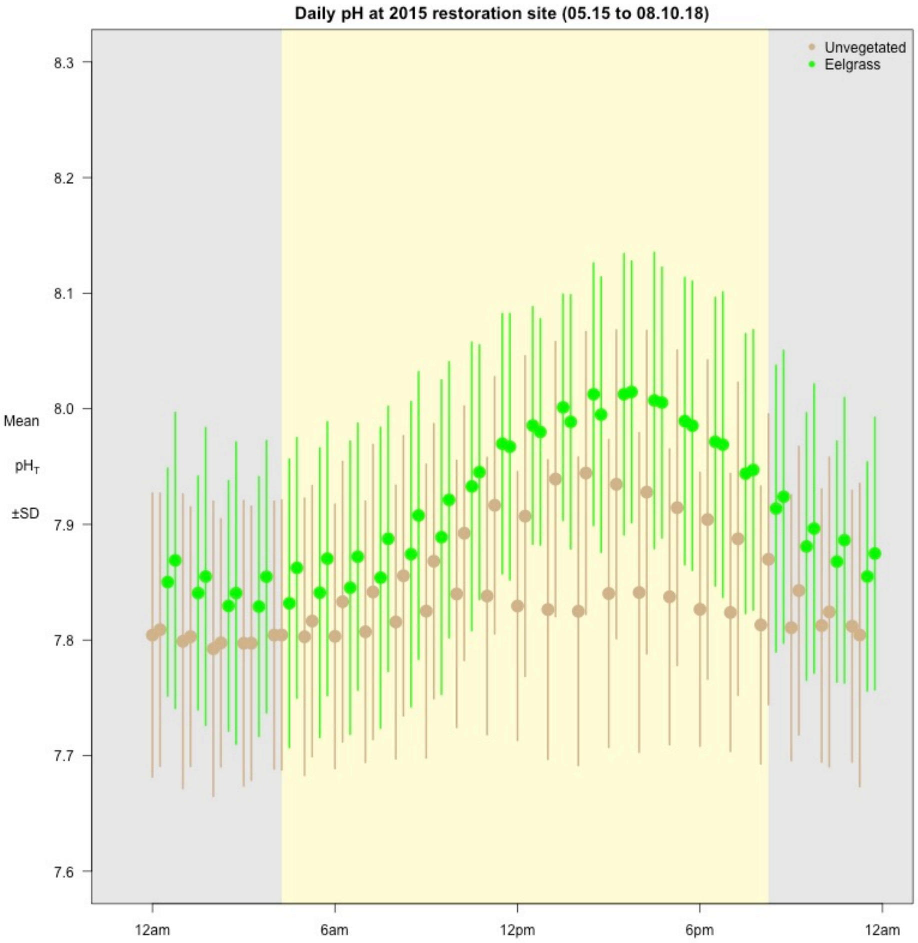


Figure 9. Mean (± se) hourly pH averaged for the period from May 15 – August 10, 2018, at Joemma Beach State Park 2015 large-scale transplant site (PNNL-2015-S, Aston et al. 2015). Sensors were deployed in eelgrass and in adjacent unvegetated, bare substrate.

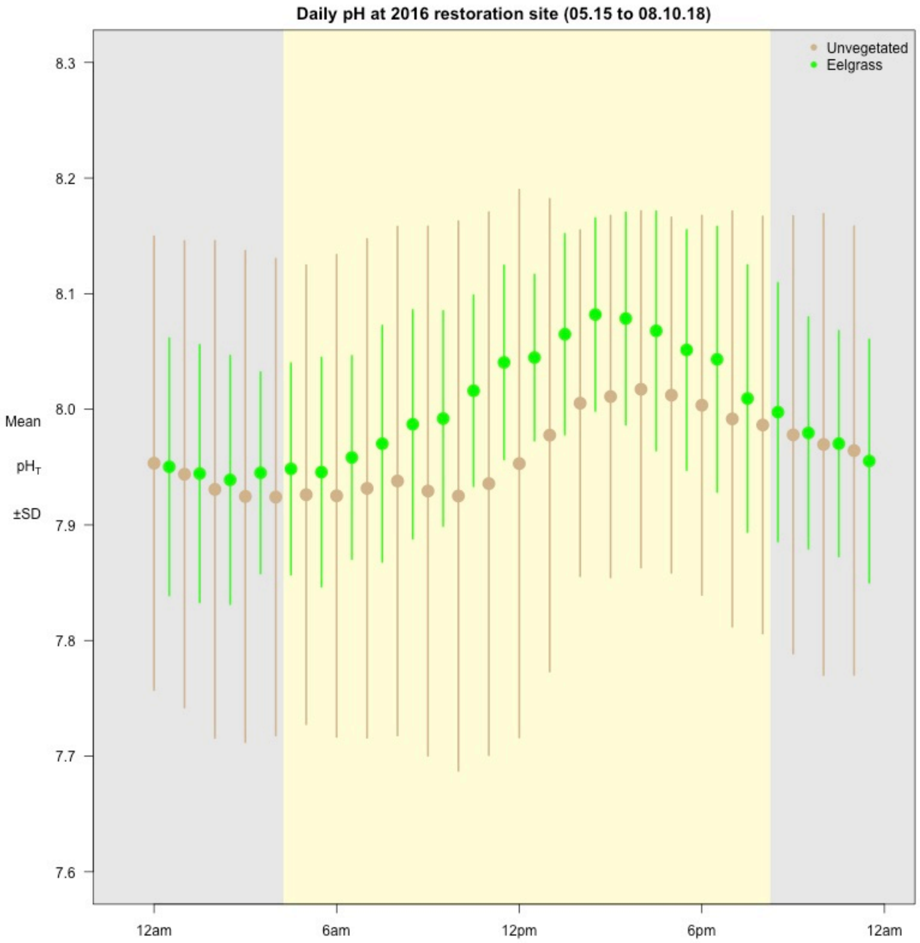


Figure 10. Mean (± se) hourly pH averaged for the period from May 15 – August 10, 2018, at Joemma Beach State Park 2016 large-scale transplant site (HC-2016-1). Two sensors were deployed in eelgrass and in adjacent unvegetated, bare substrate, however, only data from one sensor were suitable for analysis.

Patterns observed at the 2015 and 2016 sites did not hold up at the 2017 large-scale transplant site (HC-2017-2) at Joemma Beach State Park (Figure 11). The data quality was compromised at the 2017 large-scale transplant site due to fouling and sensor malfunctions that resulted in more variable and inconsistent data over the 11 day period from May 15 – 26, 2018. Sensor fouling and malfunctions limited suitable data for analysis.

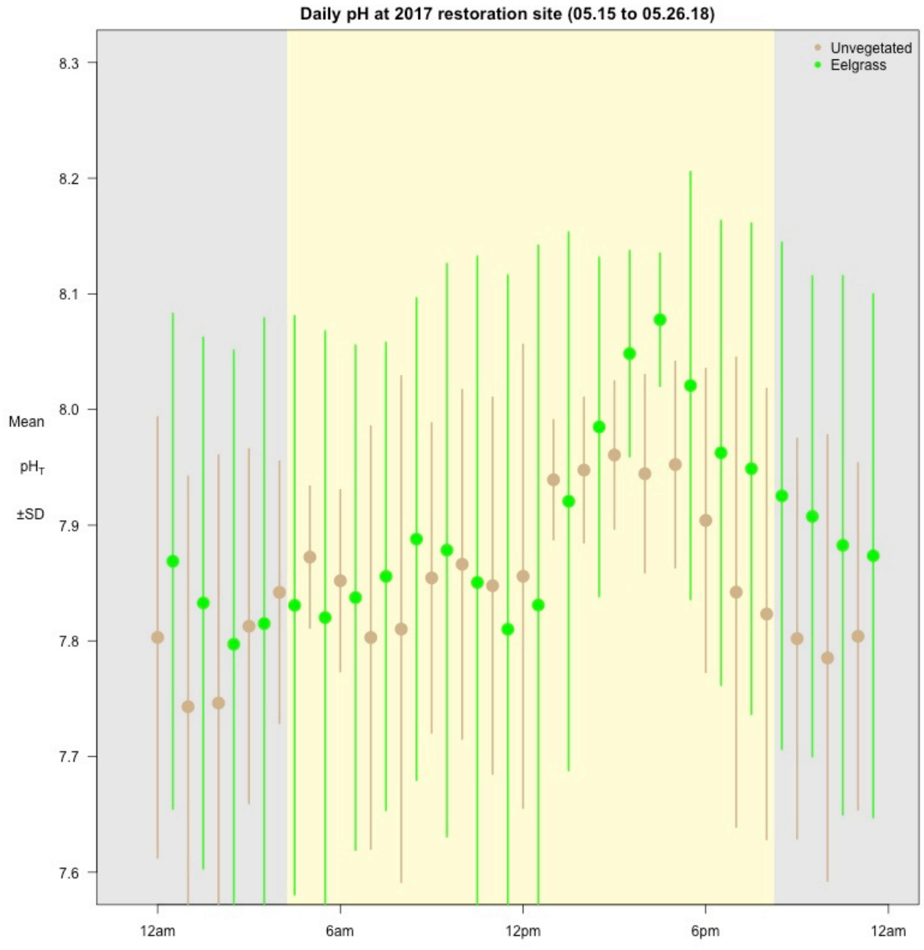


Figure 11. Mean (± se) hourly pH averaged for the period from May 15 – 26, 2018, at Joemma Beach State Park 2017 large-scale transplant site. Two sensors were deployed in eelgrass and in an adjacent unvegetated, bare substrate, however, only data from one sensor were suitable for analysis due to sensor fouling and sensor malfunction.

In addition to the water quality sensor arrays, two Photosynthetically Active Radiation (PAR) sensors were deployed adjacent to transplanted eelgrass near the center of the four large-scale transplant sites. The PAR sensors were deployed on March 7, 2018, and recovered on May 19, 2018. Another set of PAR sensors were deployed on May 19, 2018, and these were removed from the site on August 13, 2018.

Due to the shallow location of these sensors, there were a number of days during the spring low tides when the top sensor was exposed to air (Table 9). Since the eelgrass at the sensor location was always submerged, data collected from the sensors when exposed were removed from analyses as the measured PAR and attenuation was not a true representation of in situ conditions for eelgrass.

Table 9. Dates that Photosynthetically Active Radiation (PAR) data collected by the top sensors were omitted because the sensor was exposed to air during extreme low spring tides.

MONTH	DATES	LOW TIDE RANGE (m, MLLW)
May	16, 17, 18, 19	-0.81 to -0.98
June	13, 14, 15, 16, 17	-0.86 to -1.23
July	11, 12, 13, 14, 15	-0.98 to -1.22
August	10, 11, 12	-0.82 to -0.95

Photosynthetically Active Radiation (PAR, mol m^{-2} d^{-1}) data were cropped from the analyses after data screening and review of attenuation coefficient results (Figures 12-15). For example, data from the first deployment was cropped to cover March 7 to April 9, 2018, as it was evident both sensors became fouled from April 10 onward indicated by the consistently low PAR values. The total daily PAR measured from March 7 – April 9, 2018, ranged between 0.81 – 10.58 mol m^{-2} d^{-1} at the bottom sensor and 1.13 and 13.65 mol m^{-2} d^{-1} at the top sensor (Figure 12). The average PAR for the bottom sensor, an indication of the minimum PAR eelgrass would receive, was 5.87 ± 0.47 mol m^{-2} d^{-1} (mean ± SE).

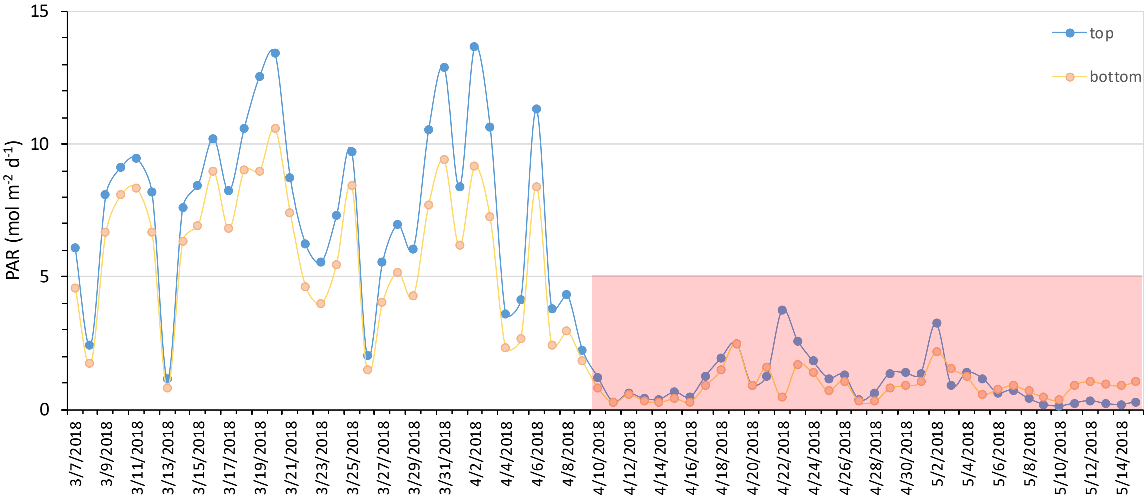


Figure 12. Total daily Photosynthetically Active Radiation (PAR) measured 15 cm (bottom) and 65 cm (top) above the sediment surface during daylight hours between March 7 and May 15, 2018. The sensor was deployed at the same location in 2017 (Shannon et al. 2018) near the center of the four large-scale transplant sites at Joemma Beach State Park. Data after April 9, delineated by the red shaded box, were considered not valid due to potential fouling of the sensors.

The calculated light attenuation coefficient (K_d m^{-1}), amount of light reduction relative to the depth of the water column, measured within ±3 hours around solar noon ranged between 0.18 and 0.88 K_d m^{-1}, with an average of 0.53 ± 0.03 (mean ± SE) for the period from March 7 to May 15, 2018 (Figure 13).

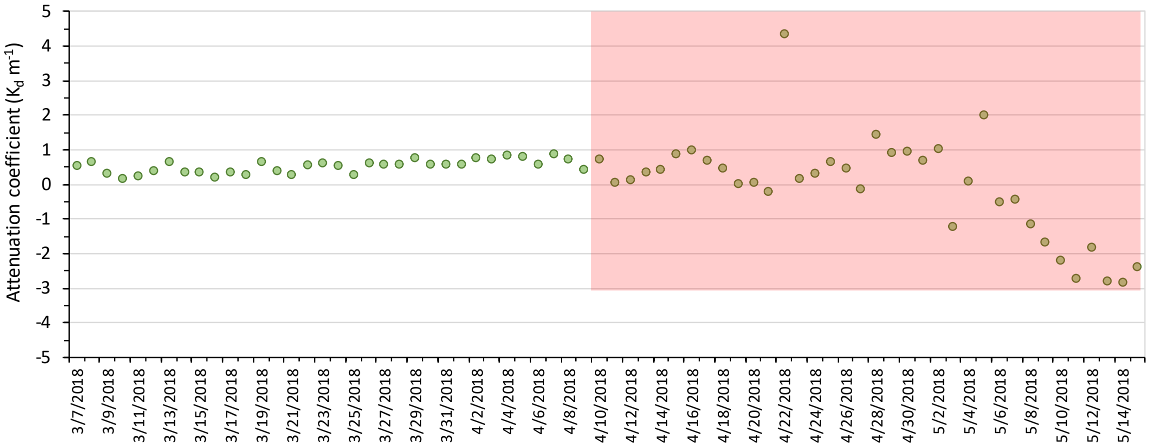


Figure 13. Attenuation coefficient (K_d m^{-1}) calculated from PAR measurements within ±3 hours of solar noon from March 7 to May 15, 2018, near the center of the four large-scale transplant sites at Joemma Beach State Park. Data after April 9, delineated by the red shaded box, were considered not valid due to potential fouling of the sensors.

The total daily PAR measured from May 19 – June 4, 2018, ranged between 0.54 – 11.28 mol m^{-2} d^{-1} at the bottom sensor and 3.64 and 18.59 mol m^{-2} d^{-1} at the top sensor (Figure 14). The average PAR measured at the bottom sensor, indicating the minimum light eelgrass received, was 3.48 ± 0.71 mol m^{-2} d^{-1} (average ± se). The bottom sensor appeared fouled from June 4 through June 12, 2018, and data from June 13-17 was omitted from analyses due to exposure during periods of extreme low tides (Table 11).

With the exception of June 19, PAR data collected from June 18 – July 4 appeared uncompromised due to fouling or sensor malfunction and ranged between 2.22 – 15.70 mol m^{-2} d^{-1} at the bottom sensor and between 3.08 and 21.19 mol m^{-2} d^{-1} at the top sensor (Figure 14). The bottom PAR sensor on June 19 appeared fouled and recorded low PAR (1.23 mol m^{-2} d^{-1}) and high attenuation (4.24 K_d m^{-1}). The average PAR measured at the bottom sensor from June 18 – July 4 (omitting June 19) was 9.46 ± 0.95 mol m^{-2} d^{-1} (mean ± SE). The PAR data from July 11-15 was omitted because the top sensor was exposed to air during the spring low tide series (Table 11). And, although the sensors were cleaned during the spring low tide series, data from July 16 through August 9 were also omitted based on evaluation of the attenuation coefficients during this period (Figure 15).

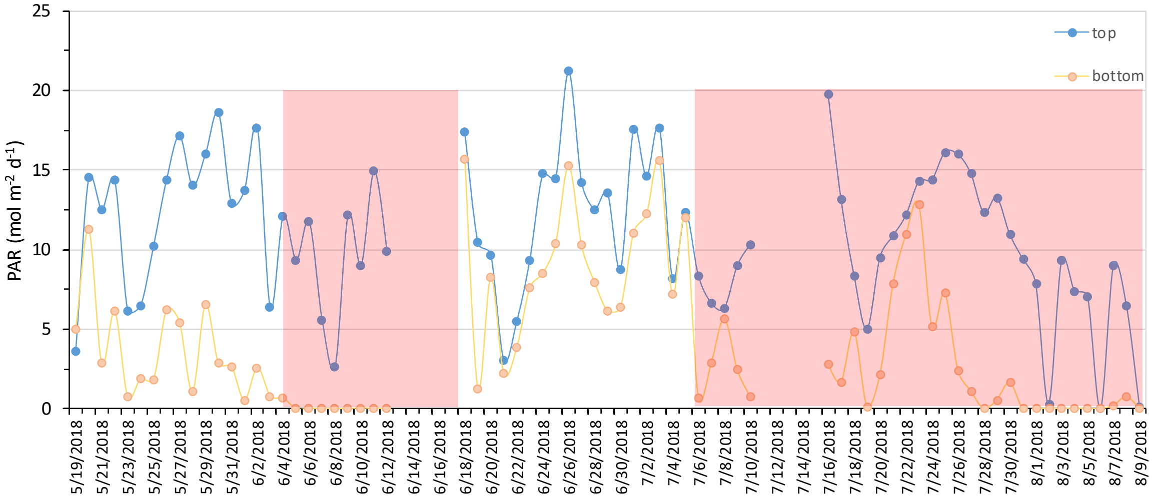


Figure 14. Total daily Photosynthetically Active Radiation (PAR) measured 15 cm (bottom) and 65 cm (top) above the sediment surface between May 19 and August 9, 2018. The sensors were deployed near the center of the four large-scale transplant sites at Joemma Beach State Park. Data from June 4 – 17, July 6-August 9, delineated by the red shaded box, were considered not valid due to exposure of the top sensor spring low tides (Table 11) and potential fouling of the sensors.

The calculated light attenuation coefficient (K_d m^{-1}), amount of light reduction relative to the depth of the water column, from May 19 – June 4 ranged between -2.02-9.84 K_d m^{-1}, with an average of 2.92 ± 0.62 (mean ± SE) for the period from May 19 – June 4, 2018. For the period from June 18 – July 4, the calculated light attenuation ranged between -0.04 and 1.73 K_d m^{-1}, with an average of 0.55 ± 0.11 (mean ± SE) (Figure 15).

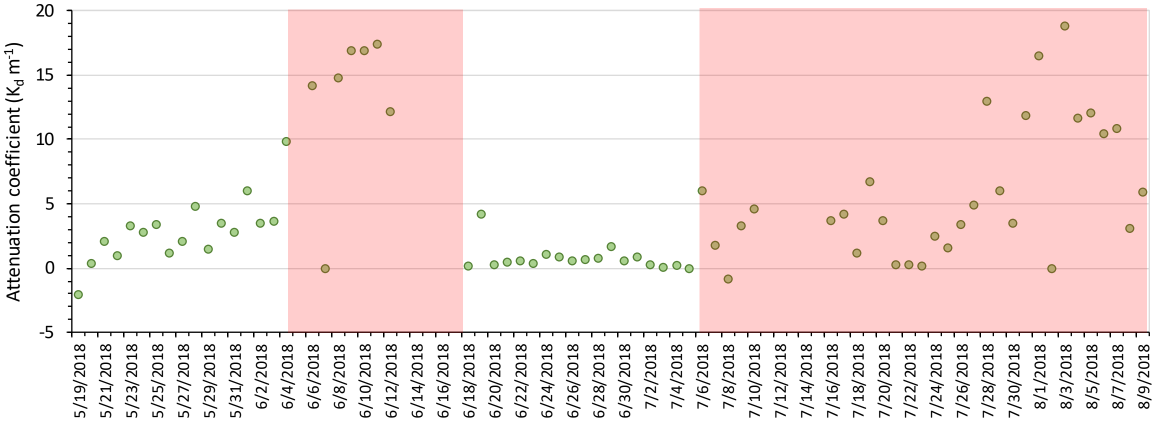


Figure 15. Attenuation coefficient (K_d m^{-1}) calculated from PAR measurements within ±3 hours of solar noon from May 19 to August 9, 2018, near the center of the four large-scale transplant sites at Joemma Beach State Park. Data from June 4 – 17, July 6 - August 9, delineated by the red shaded box, were considered not valid due to exposure of the top sensor spring low tides (Table 11) and potential fouling of the sensors.

3.3 *Eelgrass test-transplant enhancement*

The 2017 test-transplants at Fudge Point sites 1, 2 and 3 did not survive (Table 5). These test-transplants were planted with small, short canopy height (~ 30 cm) eelgrass from Rocky Bay (Figure 1). On June 12, 2018, larger eelgrass from DuPont Wharf (approximately 50-75 cm in canopy height) was transplanted in three 0.25 m^2 patches at Fudge Point 1 and 2 (Figure 16 is an example of a 0.25 m^2 transplant patch). Each patch was planted with three 50 cm lengths of metal rod with 25 eelgrass shoots attached using hemp cord for a total of 75 shoots 0.25 m^{-2} (density = 300 shoots m^{-2}). The total number of eelgrass transplanted at each Fudge Point site, 1 and 2, was 225 shoots; 450 total shoots for both sites.

Figure 16. Eelgrass test-transplant at Fudge Point planted on June 12, 2018. Each Fudge Point site, 1 and 2, was planted with three replicate 0.25 m^2 patches of eelgrass. Each replicate had 75 eelgrass shoots for a total of 225 shoots per site. Transplanted eelgrass was harvested from DuPont Wharf on June 12, 2018 (Figure 1).

Two months later on August 10, 2018, snorkelers counted eelgrass shoots in each of the 0.25 m^2 test-transplant plots at Fudge Point 1 and 2. The number of shoots counted at the Fudge Point 2 site decreased to 180 shoots from 225 shoots that were initially transplanted on June 12, 2018, and the number of shoots at the Fudge Point 1 site increased to 299 shoots. Overall, there were 29 more shoots counted in August at the two sites than originally planted on June 12, 2018 (Table 10).

Table 10. Total eelgrass shoot counted at Fudge Point 1 and 2 test-transplant sites. Eelgrass was planted on June 12, 2018 and monitored on August 10, 2018.

SITE	YEAR PLANTED	AREA	TOTAL SHOOT COUNT	TOTAL SHOOT COUNT
		(m^2)	June 12, 2018	August 10, 2018
Fudge Point 1	2018	0.75	225	180
Fudge Point 2	2018	0.75	225	299

Eelgrass from DuPont Wharf was also added to South Head test-transplant sites 1 and 2 on June 28, 2018, to enhance existing eelgrass at the two test-transplant sites (Figure 1, Table 5). Three 0.25 m^2 plots were planted with 75 shoots in each for a total of 225 shoots (Table 11). On August 12, 2018, snorkelers counted a total of 285 eelgrass shoots at both South Head sites 1 and 2 (Table 11). Snorkelers experienced poor visibility during monitoring on August 12, 2018.

Table 11. Total eelgrass shoot count at South Head 1 and 2 test-transplant sites. An additional 225 eelgrass shoots were added on June 28, 2018.

SITE	YEAR PLANTED	AREA	TOTAL SHOOT COUNT	TOTAL SHOOT COUNT
		(m^2)	May 30, 2018	August 12, 2018
South Head 1 & 2	2017 & 2018	2.25	308	285

4 Discussion

4.1 *Eelgrass*

Eelgrass at Joemma Beach State Park – 1, the large-scale transplant site planted in 2016 performed well over the last two years. Shoot density was similar to donor site density (~1,400 shoots m^{-2}) measured during harvest in 2016 (Shannon et al. 2018). There was also evidence of transplanted patches coalescing to form a larger, more contiguous bed at the site (Appendix B). The other three large-scale sites at Joemma Beach State Park, sites 2 – 4, still have eelgrass present but density and overall abundance was low. The density at Joemma Beach State Park site 2 was approximately 70%, site 3 was ~40%, and site 4 was ~75% of what was originally planted in 2017. Although eelgrass shoot density was low, the remaining eelgrass could still expand and colonize the available habitat at the sites.

Shoot density measured at the four large-scale sites at Joemma Beach State Park in May 2018 (Table 4) was low compared to densities measured in July 2017 (Shannon et al. 2018) and in August and September 2018 (Tables 6 and 7). The difference in shoot density between July 2017 and May 2018 could be due to how eelgrass responded to annual (2017-18) and seasonal (May vs. July) drivers (Sand-Jensen 1975). Water temperatures increase in the spring from winter lows and initiates lateral shoot production in eelgrass (e.g., branching) during the April to May timeframe. Whereas, by late July, water temperatures tend to be near the seasonal maximum and shoot densities are more stable. Another factor to consider was the limited experience the divers had sampling eelgrass shoot densities which could lead to low and skewed density estimates during the May 2018 effort. Later in the season shoot density estimates by snorkelers and divers, more experienced with eelgrass surveys, were found to be not significantly different (Tables 6 and 7, Figures 3 and 4).

Low survival of eelgrass at the Joemma Beach State Park sites 2 – 4 could be explained by the method by which the eelgrass was transplanted. Eelgrass at these sites was transplanted in turfs, groups of 5 – 15 shoots anchored with a 30 cm landscape staple (Shannon et al. 2018). Although this method has been successful elsewhere (Derrenbacker and Lewis 1982, Fonseca et al. 1982, Fonseca et al. 1998), it was possible site specific conditions at Joemma Beach State Park made the method less suitable. Joemma Beach State Park has high water currents that may have prevented shoots from maintaining contact with the sediment driving transplant success down. The high water current could have also caused drift algae to catch on the groups of shoots and tear them from the sediment.

The two large-scale transplant sites on the south end of Anderson Island, Anderson Island South 1 and 2, performed poorly since transplanted in 2017. Two factors likely played a role in the decline in eelgrass at these sites. First, the transplants were covered with green algae during a routine qualitative monitoring in August 2017 (Shannon et al. 2018). In this case the green algae competed with the transplanted eelgrass for light, added extra hydrodynamic drag on the plants that caused some of the transplants and landscape staples to be pulled from the bottom and may have smothered the transplants and caused anoxic conditions. The second factor that may have caused transplant failure could have been the donor source. The eelgrass transplanted at Anderson Island South 1 and 2 was from Rocky Bay (Figure 1). Although eelgrass is morphologically plastic and, therefore should adapt to conditions at a transplant sites, the process may have been too slow for the Rocky Bay plants to have modified their leaf length for successful establishment at the restoration sites. It may have been more favorable to have planted taller eelgrass, similar to the plants that grow in Thompson Cove on the southeast corner of Anderson Island or even eelgrass from the DuPont Wharf donor site (Figure 1). Future test-transplants should explore using eelgrass from Thompson Cove or another donor site with tall, more robust eelgrass, than found at the Rocky Bay donor site.

Overall, eelgrass survival at the test-transplant sites was poor with only one site from the 2017 transplant effort that had eelgrass present in 2018. Although eelgrass densities at South Head 1 and 2 were low, the presence of eelgrass was encouraging as this site historically supported eelgrass (Thom and Hallum 1991). As a result, additional plants were transplanted during the 2018 season to enhance the existing surviving shoots. The shoot density measured in August 2018 was much lower than expected but this was likely due to poor water quality. Snorkelers faced turbid waters and poor visibility during sampling at low tide in August 2018. For future monitoring, South Head 1 and 2 may be a site more suited for divers to sample than snorkelers.

The remaining test-transplant sites failed from 2017 to 2018. A few possible reasons for the poor eelgrass transplant success observed in 2018 included: green algae (ulvoids), burrowing organisms, unconsolidated/shifting sediments, and unsuitable donor source. Fudge Point 1 and 2 were sites that failed possibly due to a donor site issues. Therefore, in June 2018, additional eelgrass was transplanted at Fudge Point 1 and 2 to determine if conditions were suitable for larger eelgrass harvested from the DuPont Wharf donor site (Figure 1). The eelgrass at the South Head and Fudge Point test-transplant sites will be monitored in the future to determine transplant success and persistence.

4.2 *Water Quality*

Overall, the pH sensors performed well with values that were no more than 10% different between paired sensors in eelgrass and slightly more than 10% from sensors deployed on unvegetated, bare substrate (Figure 8). The greater difference in values from paired sensors on the unvegetated substrate was possibly due to fouling by macroalgae. Sensors deployed on unvegetated substrate were exposed to drift algae that floated through the site on ebb and flood tides, whereas the sensor arrays in eelgrass were somewhat protected by the eelgrass canopy (Figure 7).

As hypothesized, sea water pH values tended to be higher in eelgrass than unvegetated substrate, with a more consistent daily pattern measured in the older eelgrass transplant sites (Figures 9 and 10), compared to the eelgrass transplanted in 2017 (Figure 11). The 2017 large-scale eelgrass transplants did not perform well, resulting in more unvegetated substrate compared to areas with eelgrass. Again, the lack of the eelgrass canopy and exposure of the sensor arrays to excessive drift algae may have jeopardized the data recorded by these sensors.

Dissolved oxygen (DO) was collected at each sensor array for a different study, however, these sensors were more sensitive to subtle changes in sea water oxygen concentrations. Interestingly, DO was consistently higher in older eelgrass transplant areas (Figures C-1 and C-2) compared to DO measured in unvegetated substrate and younger eelgrass transplant areas (Figure C-3). The high DO measured in the 2015 and 2016 large-scale eelgrass transplant sites was evidence that eelgrass increases oxygen concentrations in nearshore systems relative to unvegetated substrate. There was no DO signal that differentiated 2017 large-scale eelgrass transplants from adjacent bare substrate (Figure C-3). These results suggest the transplants were less established and did not provide the ecosystem services that an older transplant bed may provide (Figures C-1 and C-2).

Fouled sensors seemed to be the cause for poor PAR data too. The PAR sensors were positioned on a post at 15 and 65 cm above the sediment surface leaving the bottom sensor susceptible to fouling by drift algae. Only portions of the PAR data were suitable for interpretation and analyses. The attenuation coefficients from March 7 to April 9 were similar to previous attenuations measured in Puget Sound (Thom et al. 1998), and within the biologically sustainable range for eelgrass (0.22 – 0.92 K_d m^{-2}, Dennison et al. 1993). These corresponded to average PAR values, measured at the bottom and top sensor, well above the 3 mol m^{-2} d^{-1} minimum required for eelgrass to survive (Thom et al. 2003). However, it was clear from the low PAR values (Figure 12) and the increased variability in the attenuation data (Figure 13) from April 10 on that sensor fouling occurred.

The next PAR sensor deployment from May 19 to August 9 seemed to be affected more by green algae and other drift algae based on the days of poor data quality. Sensors were deployed on May 18 with the first day of valid data acquired on May 19, and yet, an extremely low attenuation coefficient (i.e., -2.01) indicated the top sensor was fouled while the bottom sensor was not, or just less fouled (Figure 14). Drift algae, such as ulvoids, create a growing challenge for environmental sensors in marine systems. Mechanical wipers can reduce fouling by small epiphytic algae but large green algal blooms tend to entangle with sensors and diminish available light. Most of the suitable values for PAR between March and August were immediately after manual removal of macroalgae and sensor cleaning.

4.3 *Eelgrass test-transplant enhancement*

During the 2018 test-transplant monitoring, only one area, South Head 1 and 2, had eelgrass remaining from the 2017 test-transplant effort. However, there were other test-transplant sites where conditions appeared promising, but eelgrass transplants did not survive over the winter. Additional eelgrass test-transplants in 2018 provided an opportunity to enhance the density of eelgrass at the South Head 1 and 2 sites and test an alternate donor source at the Fudge Point 1 and 2 sites. The shoot count measured at the South Head 1 and 2 sites in August seemed low but these values could be a result of poor water quality and the challenge of counting all the eelgrass present at the site. The site will be monitored in the spring of 2019 to determine overwinter success of the 2017 test-transplants and the addition of the 2018 eelgrass. Similarly, the test-transplants at Fudge Point 1 and 2 will be monitored in the spring of 2019 to determine if the DuPont Wharf donor source was more suited for transplant at that site than Rocky Bay plants. During the 2018 planting and monitoring at Fudge Point 1 and 2 green algae was present but did not appear to be a major nuisance. However, conditions can change and cause algae to pile up on transplants causing physical damage and leading to competition for light.

5 Conclusion

The performance of the 2016 large-scale transplant at Joemma Beach State Park carries the overall success of the project into the future. At this point, the 2016 large-scale transplant site supports more eelgrass (~169,200 shoots) than the original project proposed to transplant (152,740 shoots, sum of eelgrass shoot transplant objectives from Tables 6 and 7, Shannon et al. 2018). Eelgrass at the 2017 large-scale transplant sites 2 – 4 at Joemma Beach State Park and the test-transplant at South Head 1 and 2 continue to survive and add to the success of the project, but the overall addition of shoots is small. Future monitoring of all four successful large-scale and two test-transplant sites will provide insight on eelgrass donor source performance, transplant site development and expansion over time.

The project also demonstrated that eelgrass modified sea water pH relative to different age eelgrass transplant sites at Joemma Beach State Park. Challenges related to measuring water parameters and minimizing the effects of fouling were still present but duplicate sensors and regular cleaning improved data quality. Furthermore, the utilization of dissolved oxygen sensors, albeit not a specific part of the project, demonstrated the daily oxygen production from eelgrass and the potential eelgrass has to alter water chemistry parameters. The greatest challenge for data acquisition in the future will be the in situ sensor maintenance and minimization of fouling by macroalgae, epiphytes, and other fouling organisms such as barnacles.

The test- and large-scale transplant sites will be monitored beyond the project scope and timeline by the Eelgrass Stressor-Response Program (Nearshore Habitat Program, Aquatic Resources Division). Eelgrass transplant performance will be documented and maintained in an eelgrass restoration database to support future restoration efforts and advance eelgrass restoration science in Puget Sound.

6 References

Aston LA, AB Borde and J Vavrinec. 2015. Final Summary Report Eelgrass Restoration in Puget Sound Project Summary. Pacific Northwest National Laboratory, Sequim. Report #: PNNL-24445. Pp. 40.

Astronomical Applications Department. 2018. U.S. Naval Observatory, Washington, DC. https://aa.usno.navy.mil/cgi-bin/aa_rstablew.pl?ID=AA&year=2018&task=0&state=WA&place=Olympia (accessed November 2018)

Dennison WC, RJ Orth, KA Moore, JC Stevenson, V Carter, S Koller, PW Bergstrom and RA Batiuk. 1993. Assessing water quality with submersed aquatic vegetation. BioScience 43:86-94.

Derrenbacker JA and RR Lewis. 1982. Seagrass habitat restoration in Lake Surprise, Florida Keys. Pp. 132-154. In: Stoval RH (ed.) Proceedings Ninth Annual Conference on Wetlands Restoration and Creation, May 20-21, Hillsborough Community College, Tampa, FL.

Fonseca MS, WJ Kenworthy and GW Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the Unites States and adjacent waters. National Oceanic and Atmospheric Administration, Coastal Ocean Office (NOAA Coast Ocean Program Decision Analysis Series No. 12), Silver Spring, Maryland.

Fonseca MS, WJ Kenworthy and GW Thayer. 1982. A low cost transplanting procedure for sediment stabilization and habitat development using eelgrass (*Zostera marina*). Wetlands 2:138-151.

Gaeckle JL. 2017. Quality Assurance Project Plan – Eelgrass Restoration in Puget Sound. Nearshore Habitat Program, WA State Department of Natural Resources, Olympia. WDFW 14-02072, DNR 15-110. Pp 33.

Sand-Jensen K. 1975. Biomass, net production and growth dynamics in an eelgrass (*Zostera marina* L.) population in Vellerup Vig, Denmark. Ophelia 14. 185-201.

Shannon J, J Blanchette and J Gaeckle. 2018. Eelgrass (Zostera marina) restoration in Puget Sound, WA. Restoration and Monitoring Report prepared for the EPA. Hart Crowser Report No. 12059-05, Edmonds, WA. Pp 131.

Thom RM and L Hallum. 1990. Long-term changes in the areal extent of tidal marshes, eelgrass meadows and kelp forests of Puget Sound. EPA 910/9-91-005, Final Report to Office of PS, Region 10, U.S. Environmental Protection Agency.

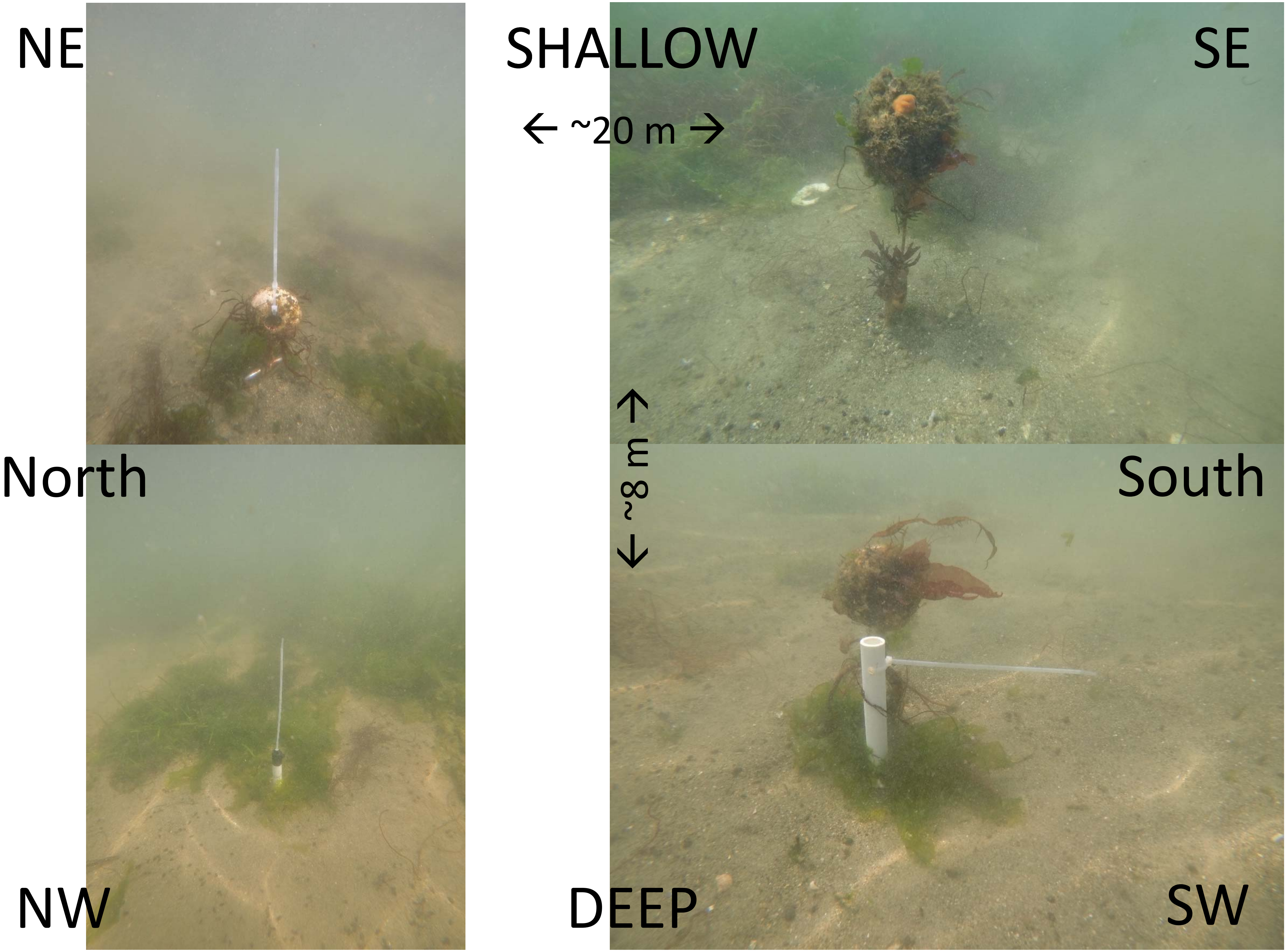
Thom RM, LD Antrim, AB Borde, WW Gardiner, DK Shreffler, PG Farley, JG Norris, S Wyllie-Echeverria and TP McKenzie. 1998. Puget Sound's eelgrass meadows: factors contributing to depth distribution and spatial patchiness. Proceedings of Puget Sound Research 1998. Seattle, WA. Pp. 363-370.

Thom RM, GD Williams and AB Borde. 2003. Conceptual model as a tool for assessing, restoring and managing Puget Sound habitats and resources. Proceedings of Puget Sound Research 2003. Puget Sound Water Quality Action Team, Olympia, Washington.

Thom RM, JL Gaeckle, KE Buenau, AB Borde, J Vavrinec, L Aston and DL Woodruff. 2014. Eelgrass (*Zostera marina* L.) restoration in Puget Sound: development and testing of tools for optimizing site selection. Pacific Northwest National Laboratory, Sequim, WA. Pp 62.

Thom R, J Gaeckle, K Buenau, A Borde, J Vavrinec, L Aston, D Woodruff, T Khangaonkar and J Kaldy. 2018. Eelgrass (*Zostera marina* L.) restoration in Puget Sound: development of a site suitability assessment process. Restoration Ecology 26:1066-1074.

Appendix A Buoy System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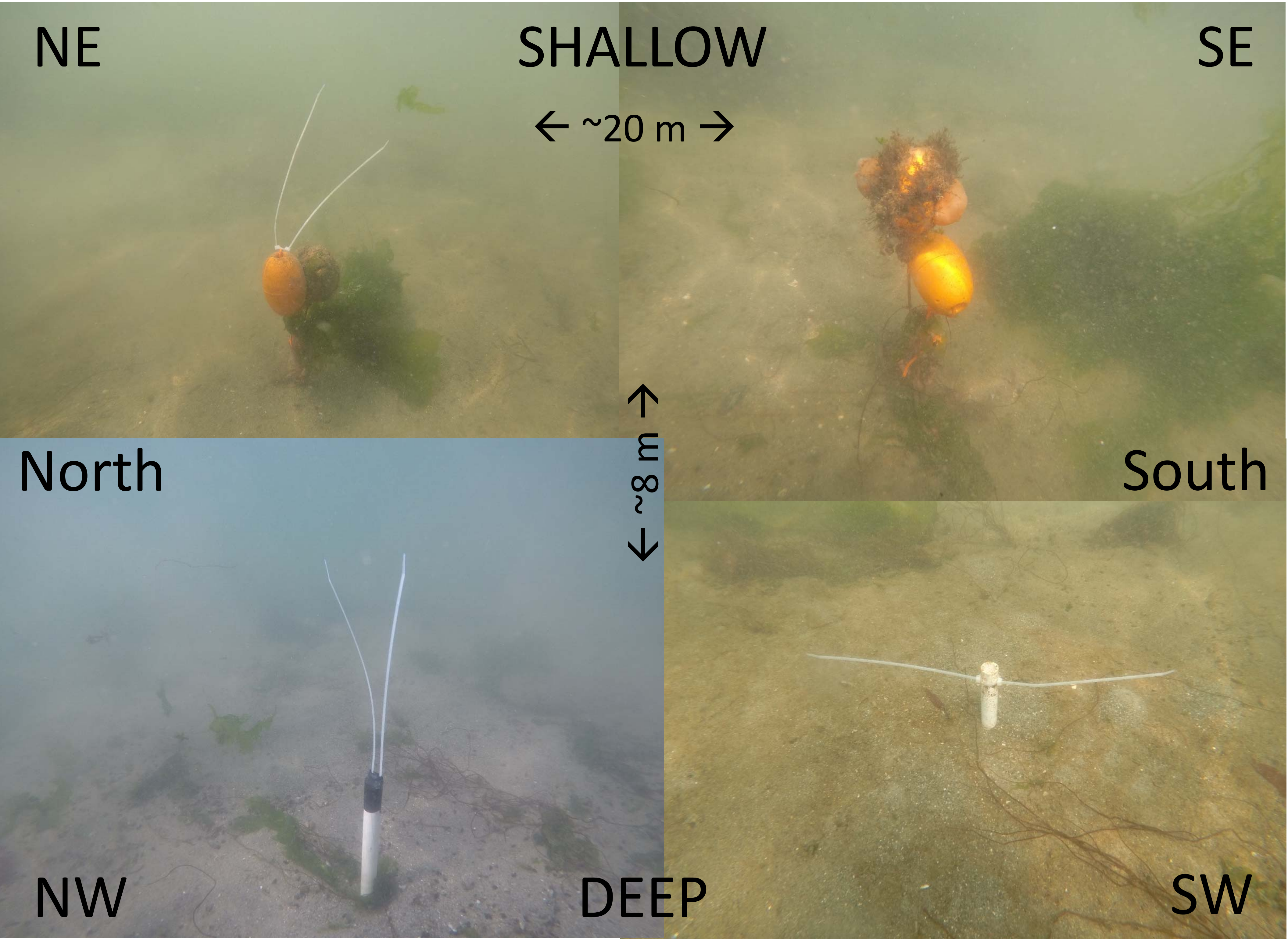
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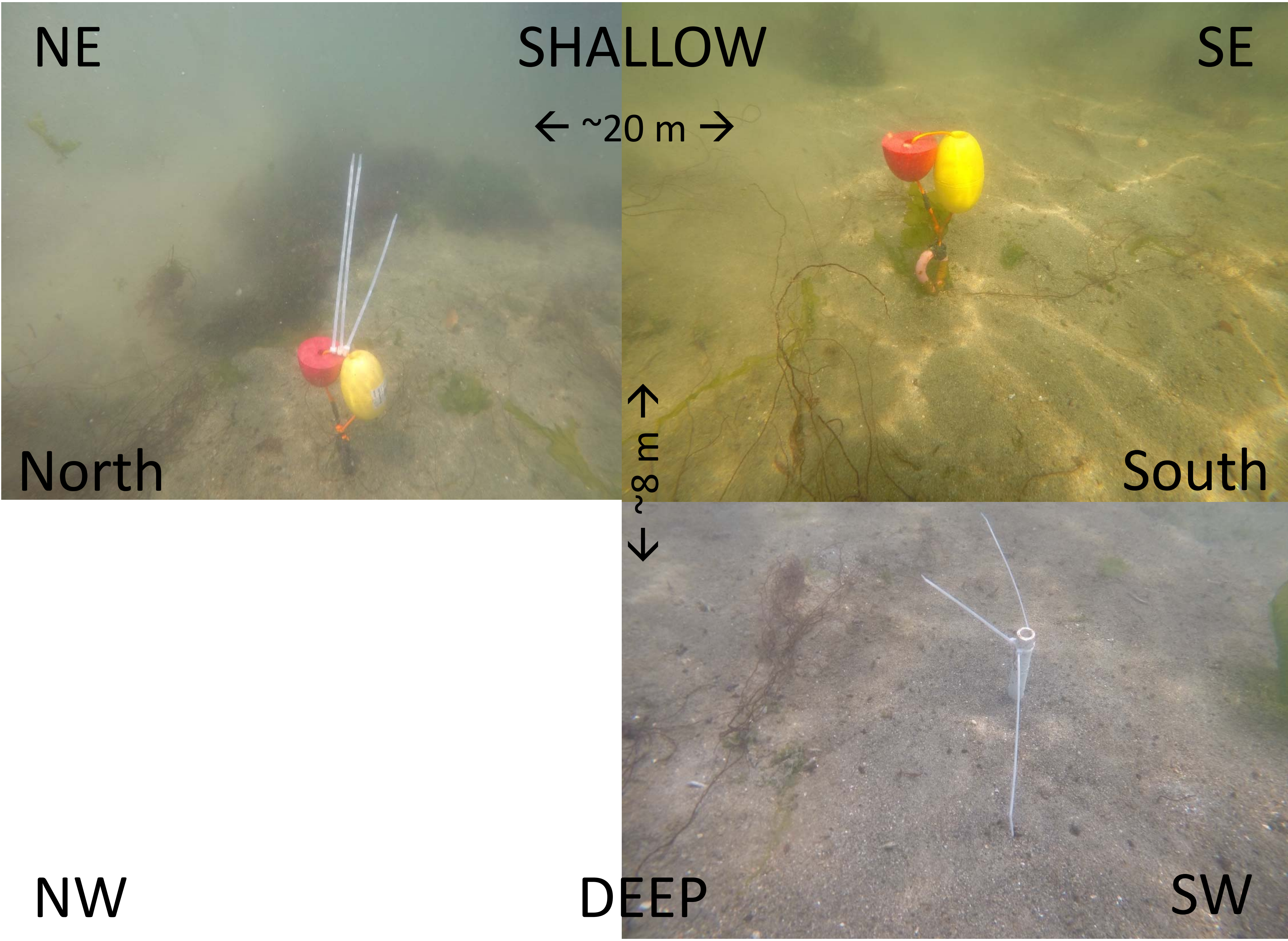
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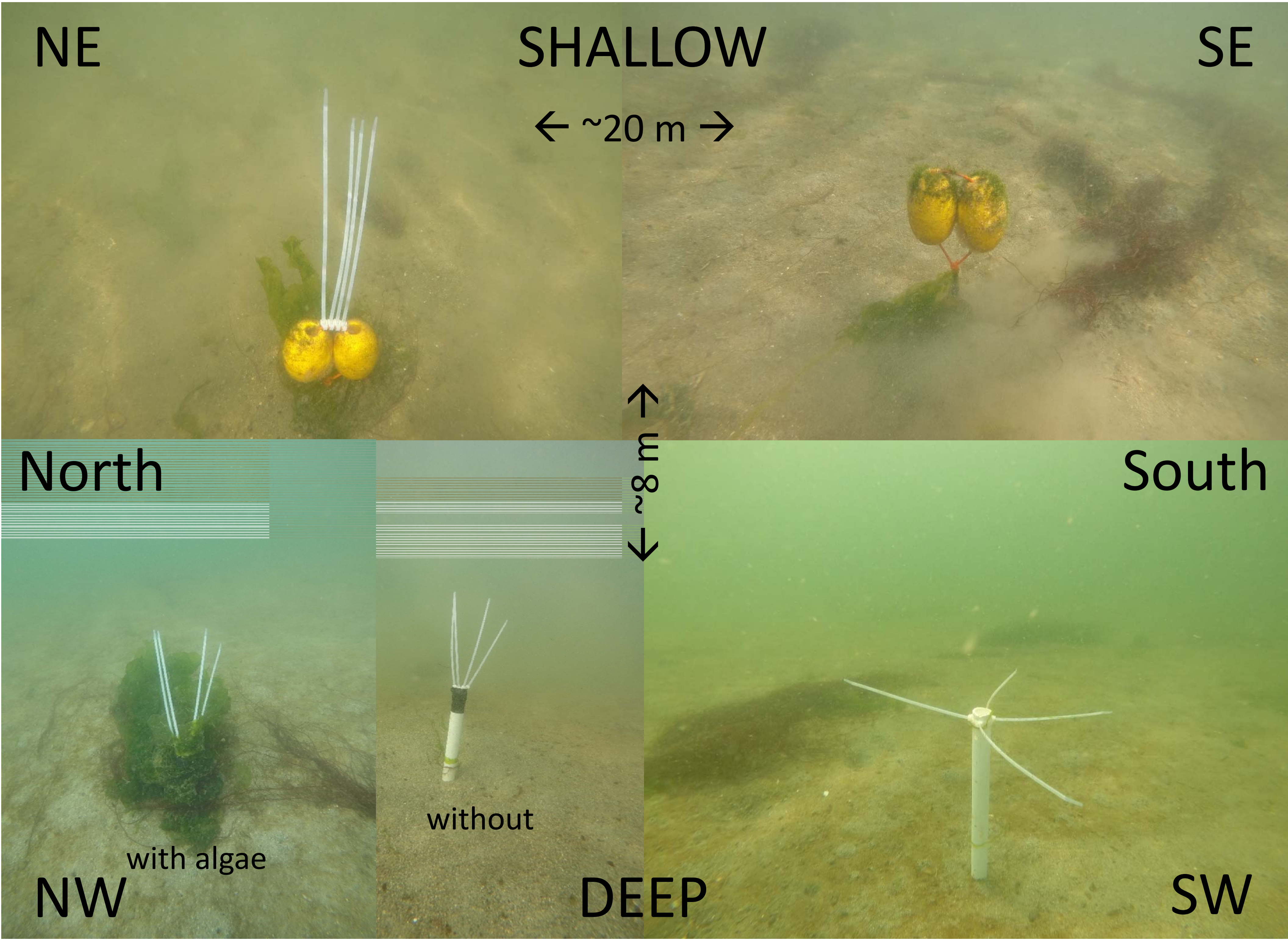
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with algae
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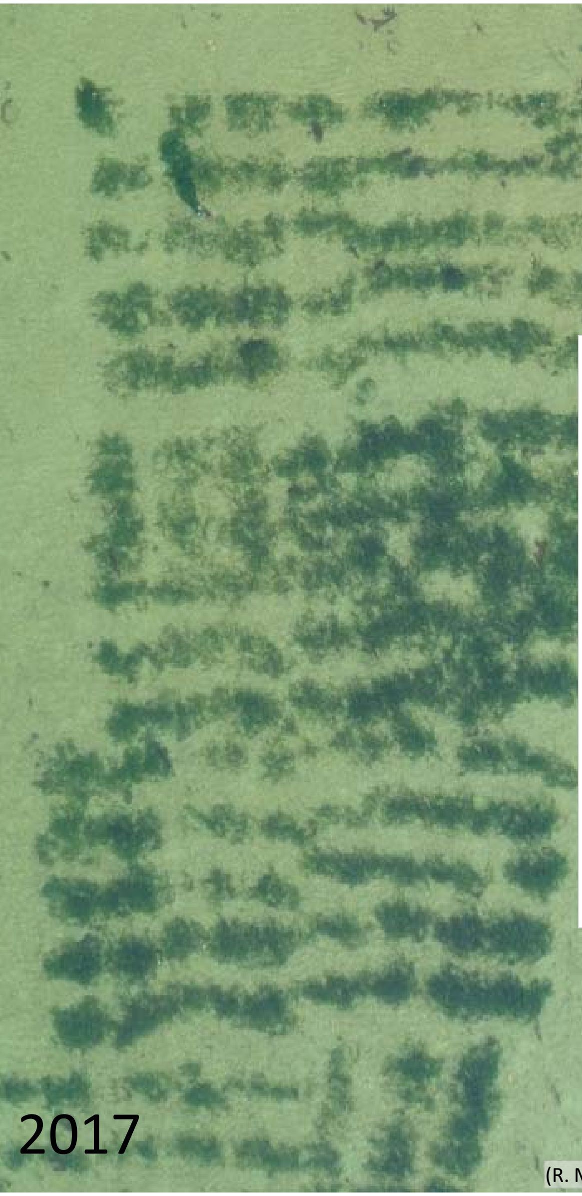
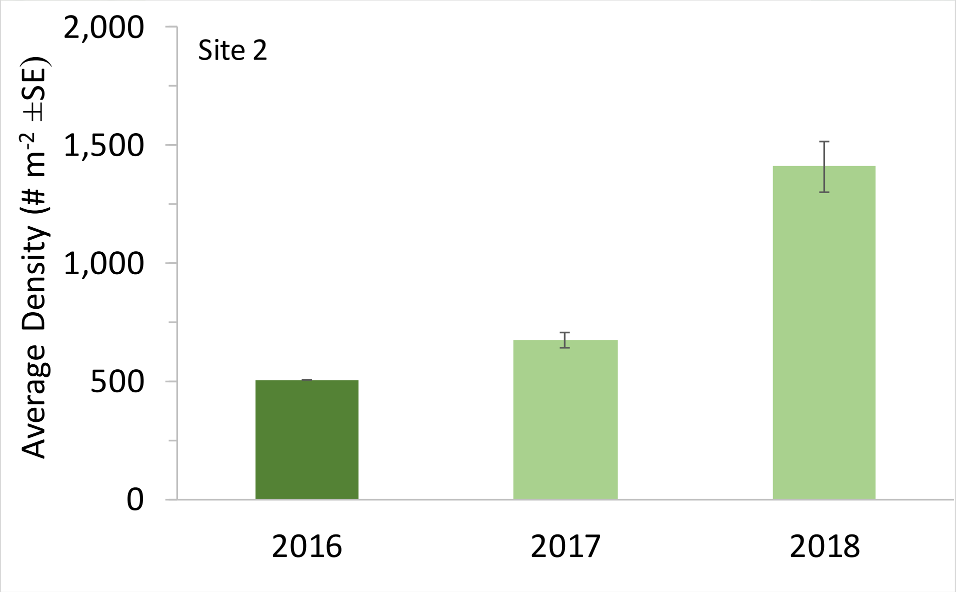
Appendix B Aerial Photo

Joemma Beach State Park
2016 large-scale



(R. McMillan 2017)



(R. McMillan 2018)

Appendix C Dissolved Oxygen

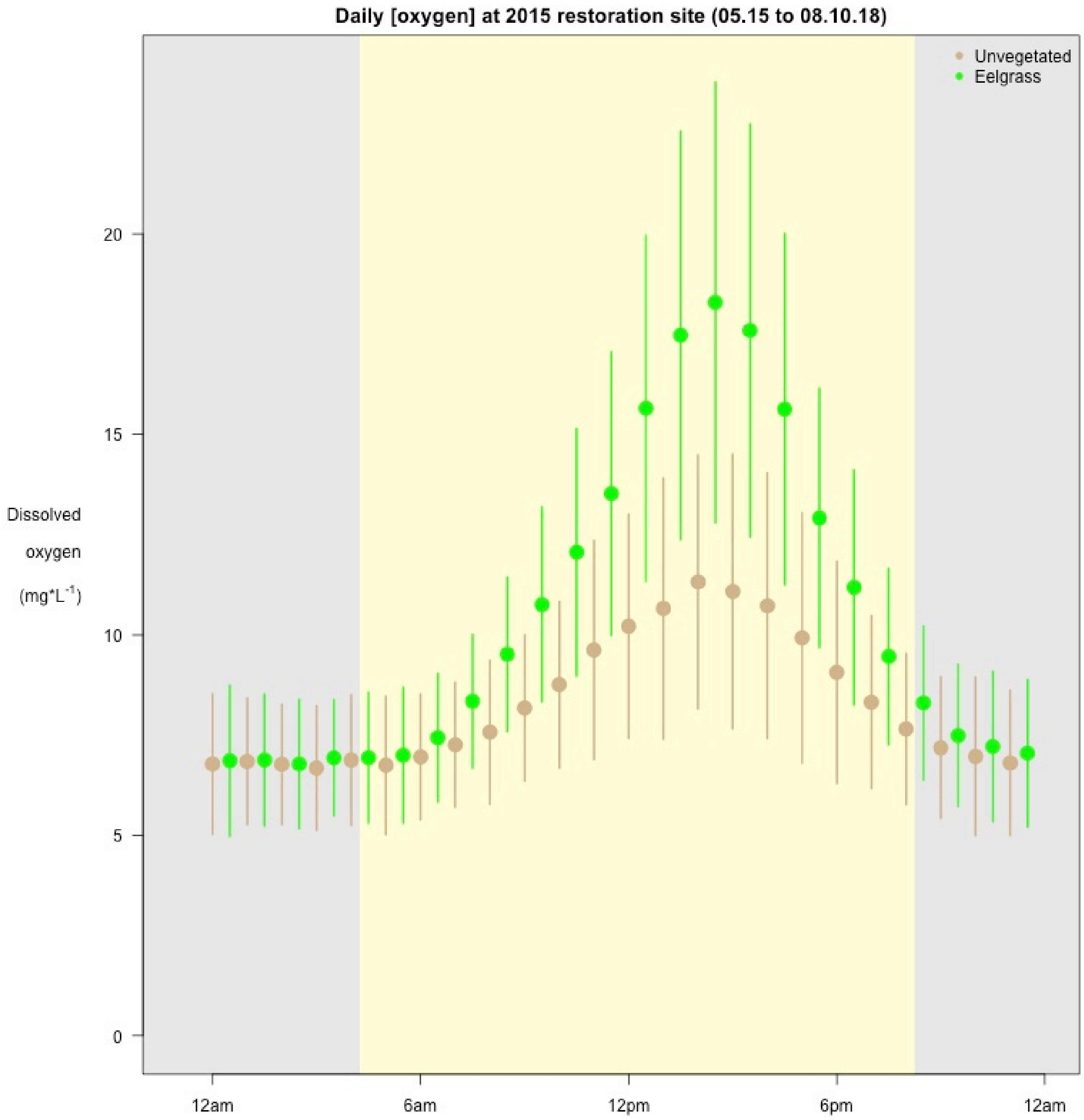


Figure C-1. Dissolved Oxygen (mg L^{-1}) measured in eelgrass and unvegetated substrate at the 2015 large-scale transplant sites at Joemma Beach State Park from May 15-August 10, 2018.

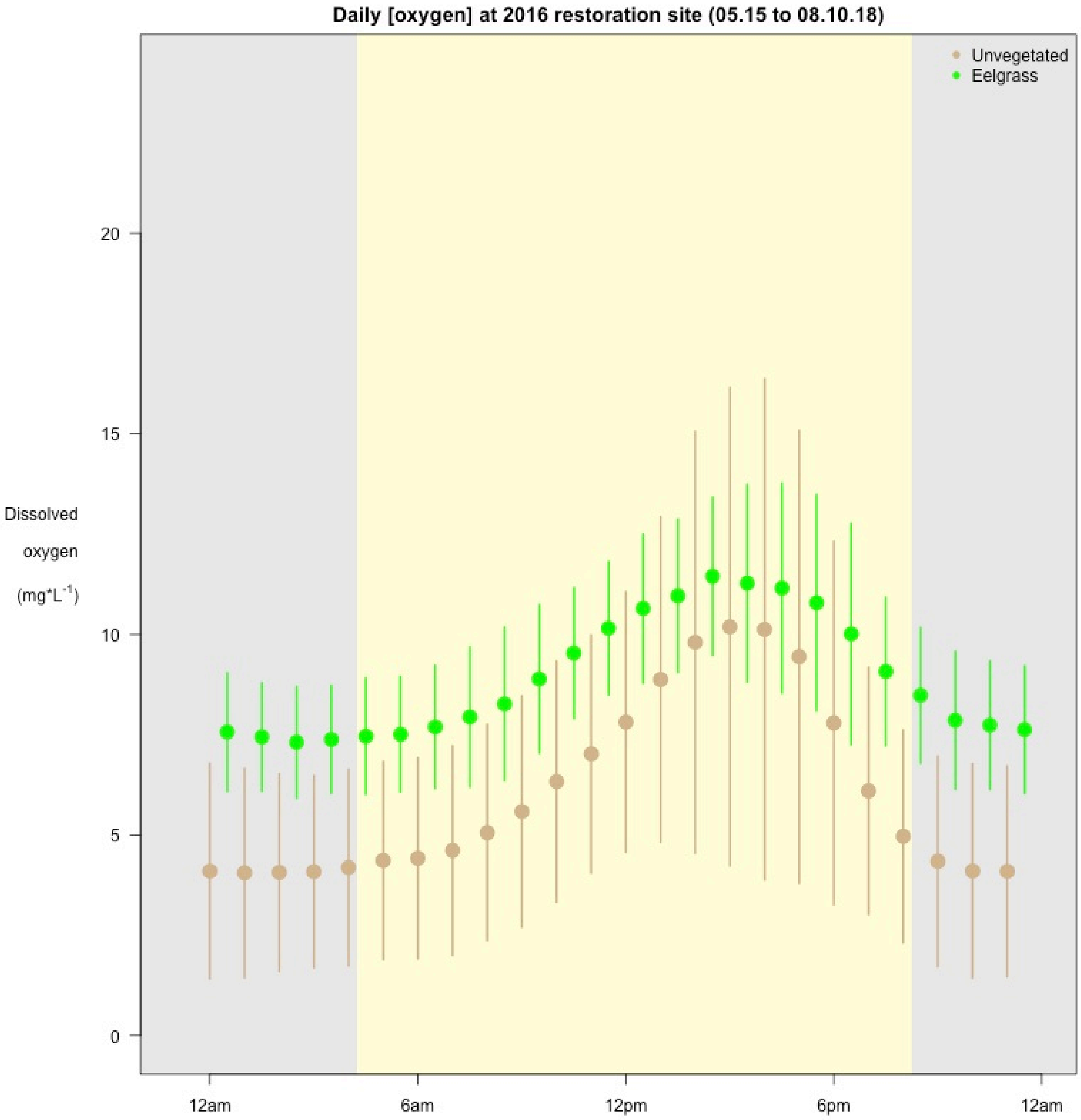


Figure C-2. Dissolved Oxygen (mg L^{-1}) measured in eelgrass and unvegetated substrate at the 2016 large-scale transplant sites at Joemma Beach State Park from May 15-August 10, 2018.

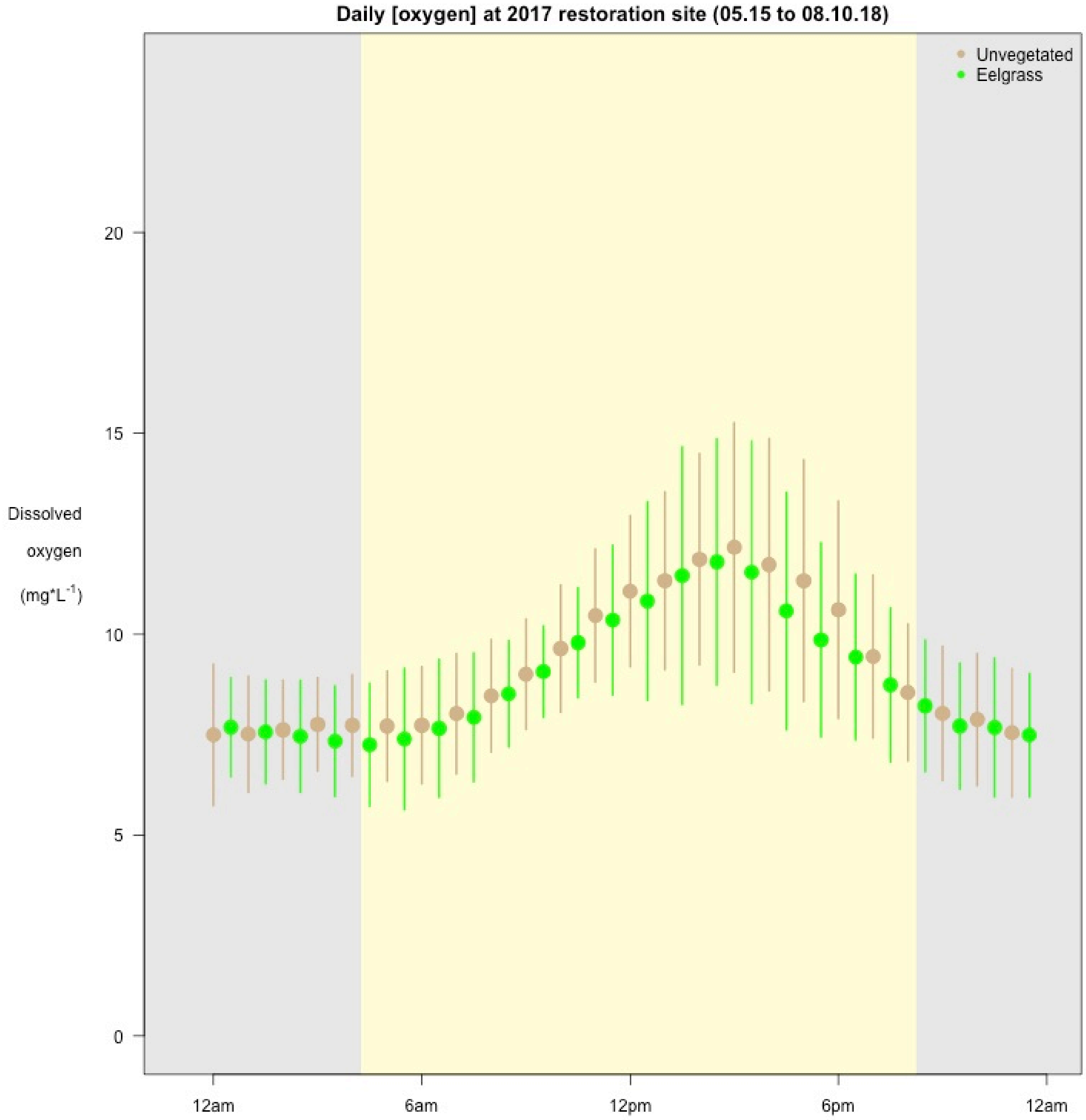


Figure C-3. Dissolved Oxygen (mg L^{-1}) measured in eelgrass and unvegetated substrate at the 2017 large-scale transplant sites at Joemma Beach State Park from May 15-August 10, 2018.

Appendix D South Sound Science Symposium (S^4) Presentation

Eelgrass restoration and its potential to counteract ocean acidification in South Puget Sound

Jeff Gaeckle
Nearshore Habitat Program

Micah Horwith
Aquatic Assessment & Monitoring

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
HILARY S. FRANZ | COMMISSIONER OF PUBLIC LANDS

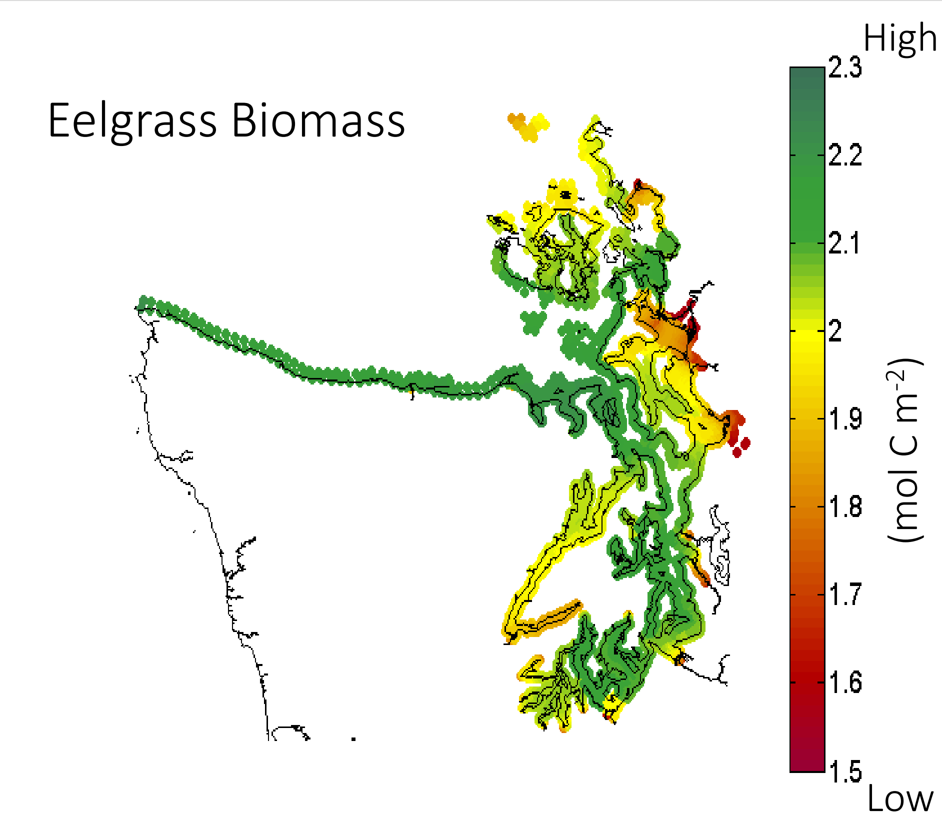
Restoration

- Eelgrass (*Zostera marina*) recovery goal established by the Puget Sound Partnership

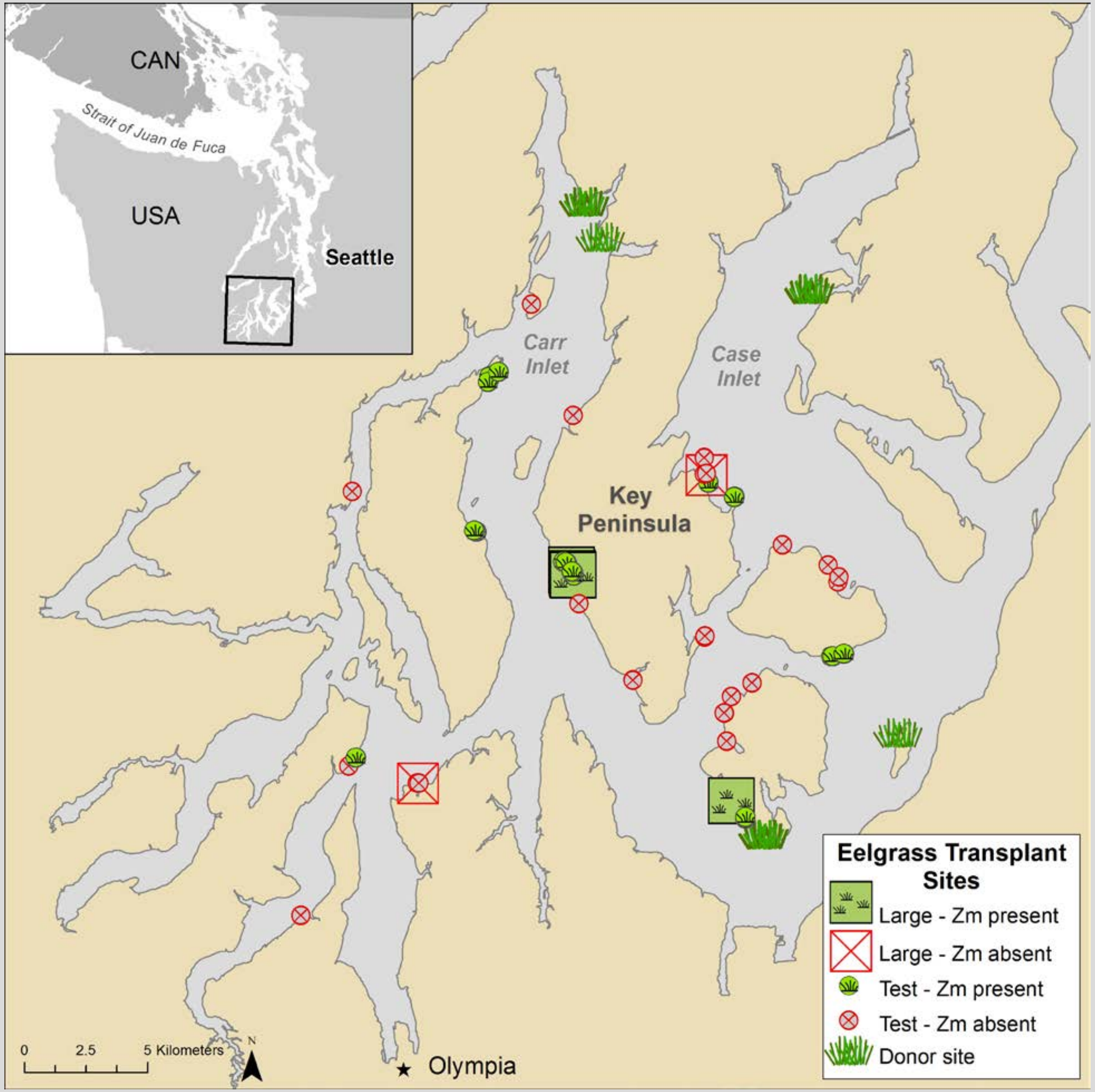
- 20% more eelgrass by 2020
  - 4,400 ha (relative to baseline of 22,000 ha)

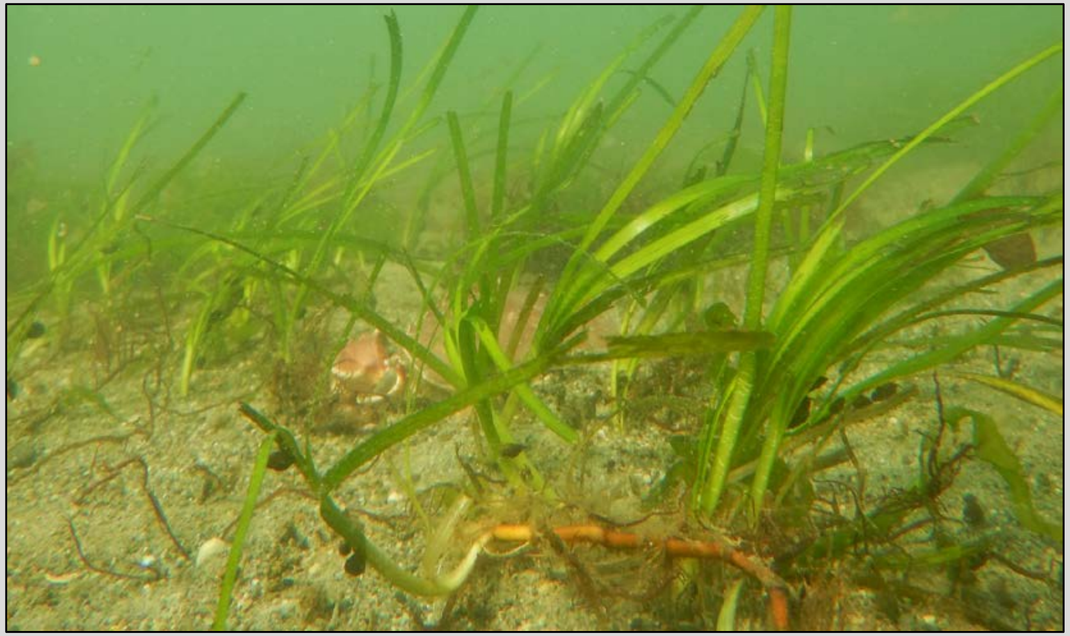
- Recovery Strategy
  - Stressor reduction
  - Restoration

- Multi-step adaptive process
  - model
  - test-transplants
  - evaluate
  - large-scale transplants

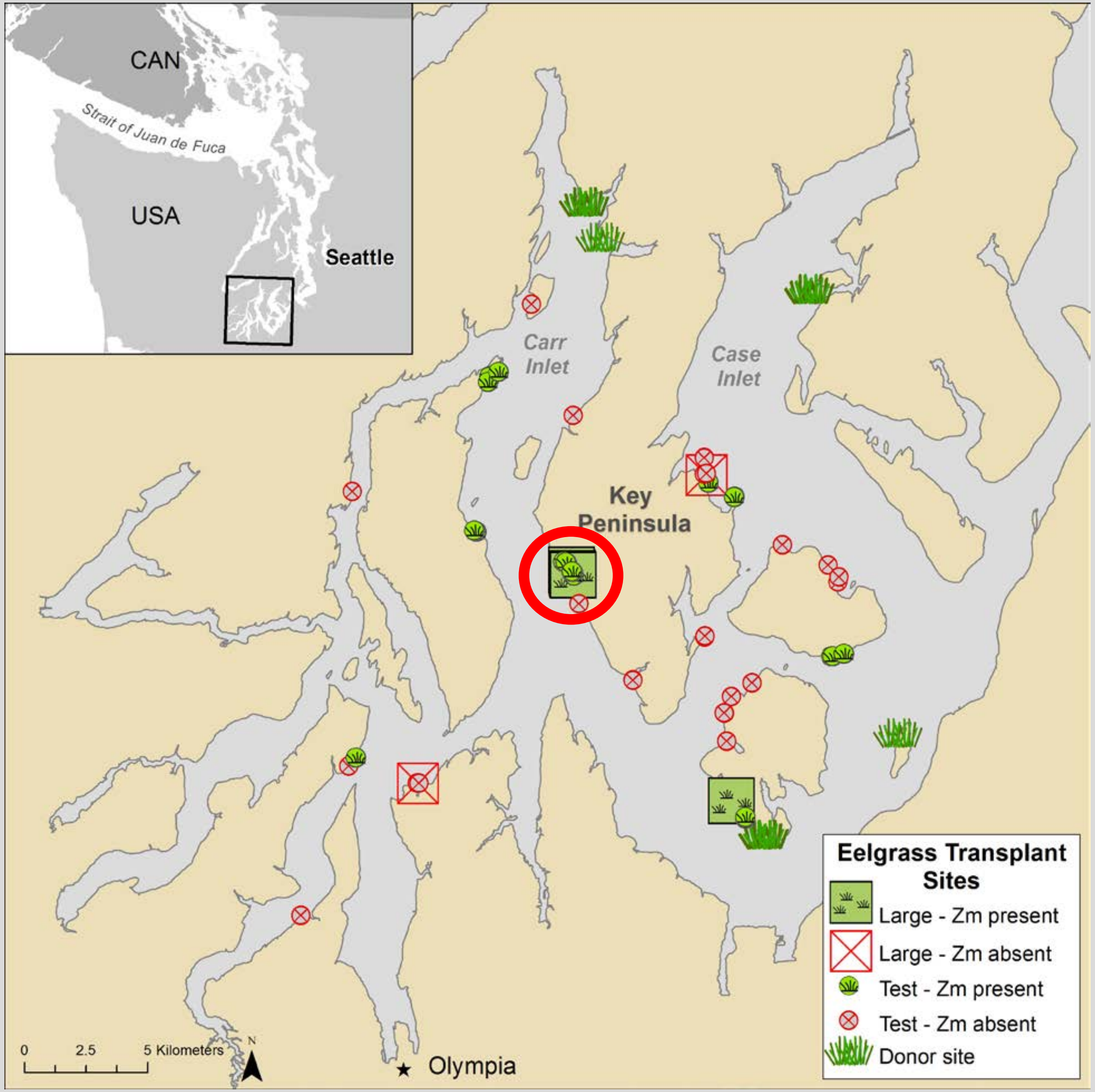


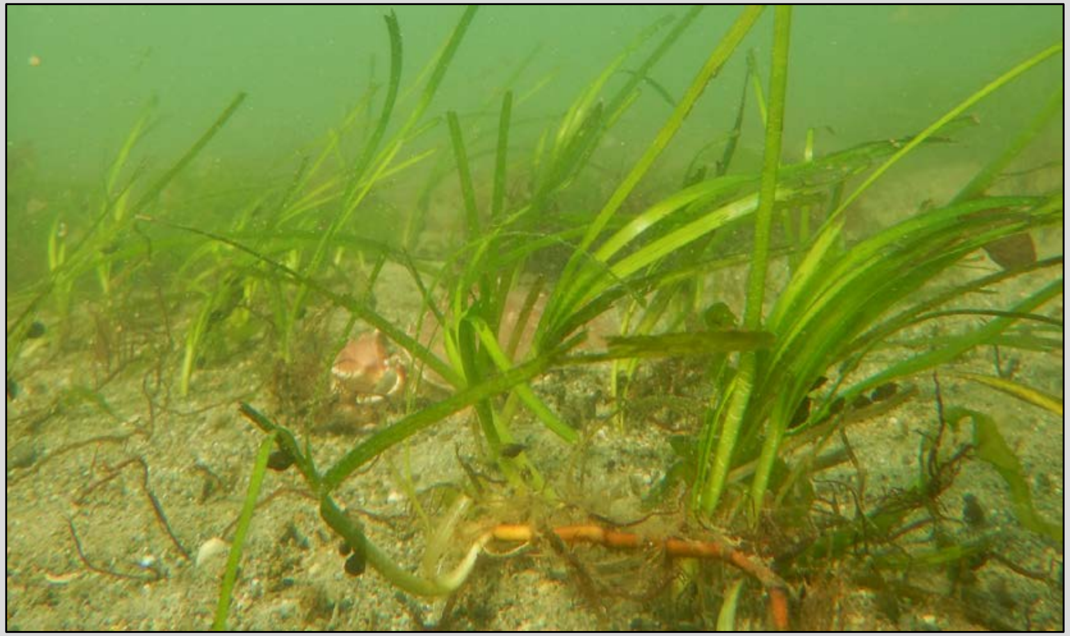
Restoration Sites 2013 - 2018





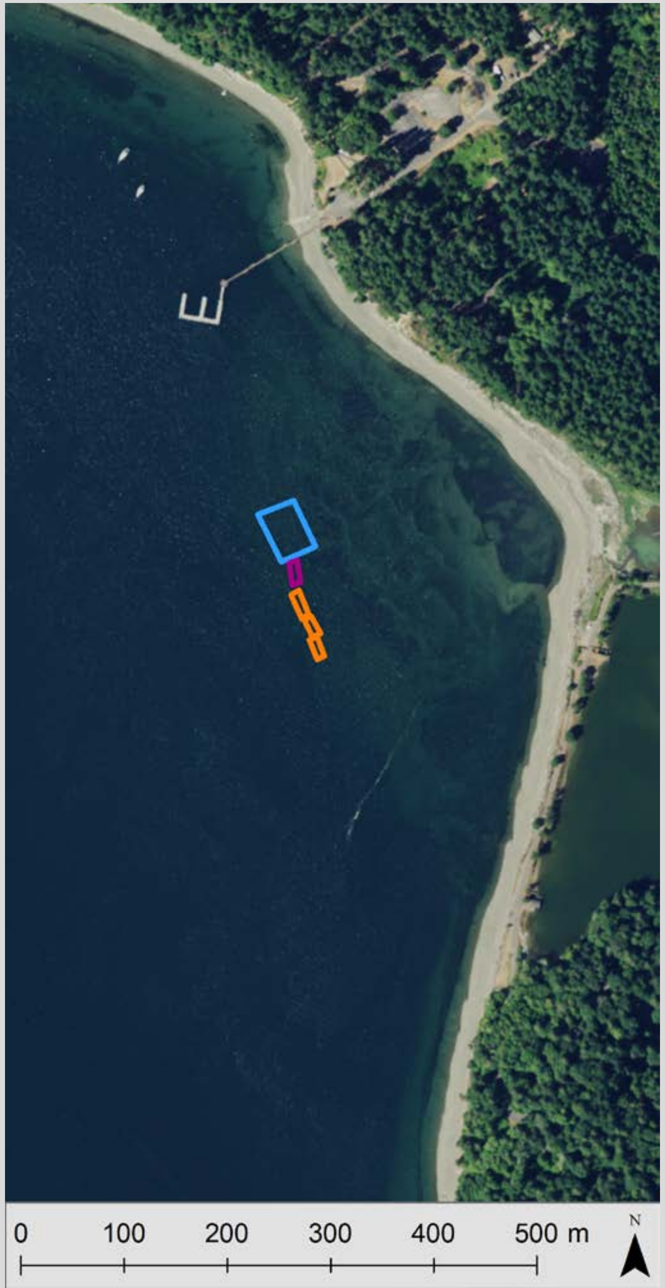
Restoration Sites 2013 - 2018



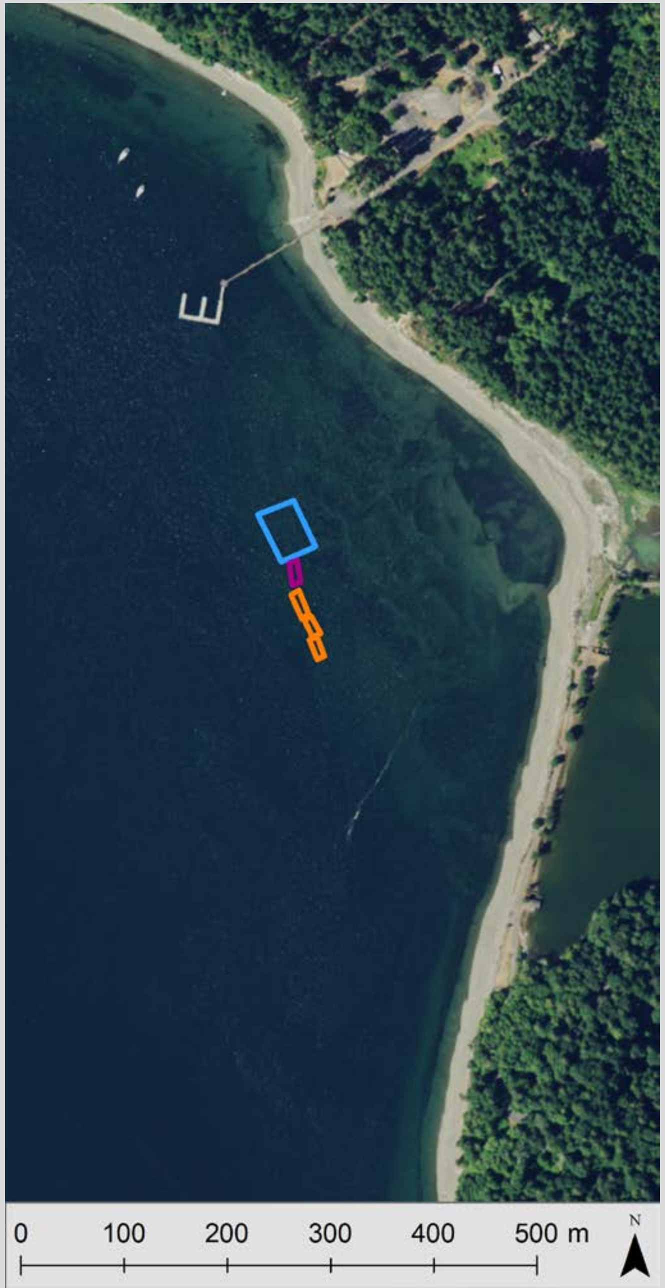


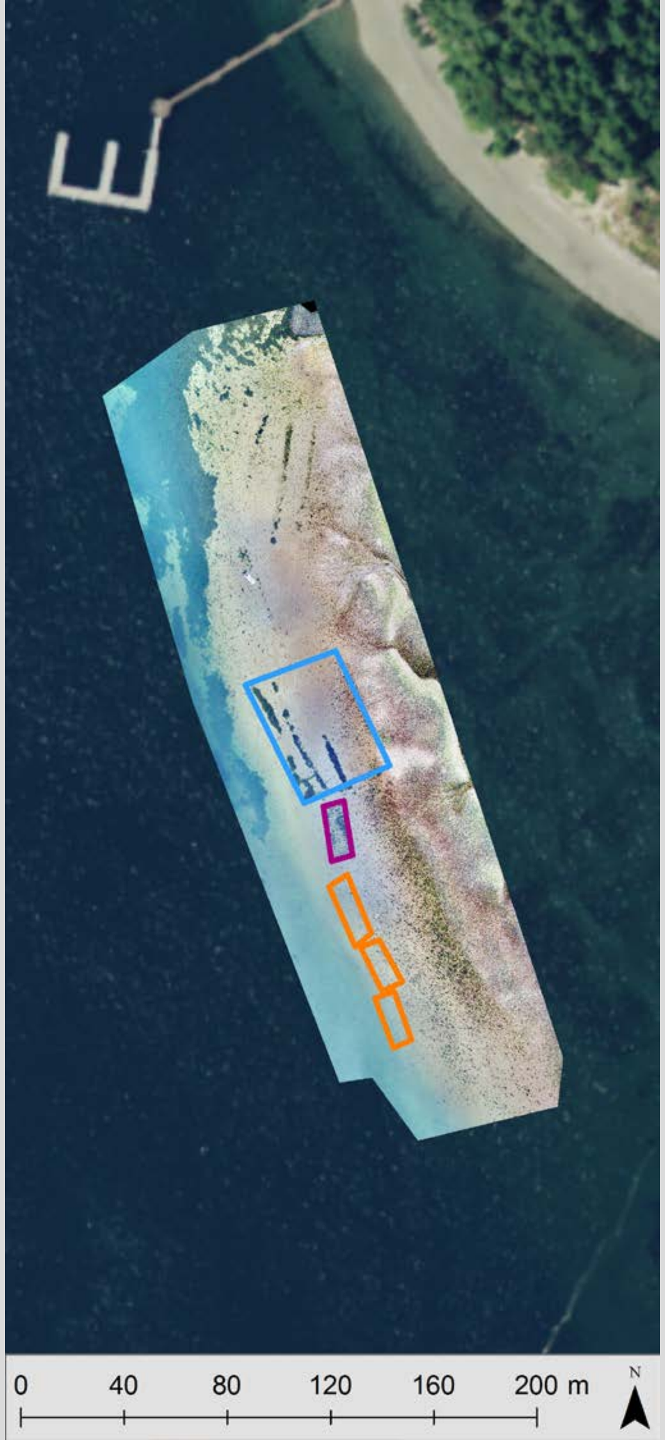
Joemma Beach State Park

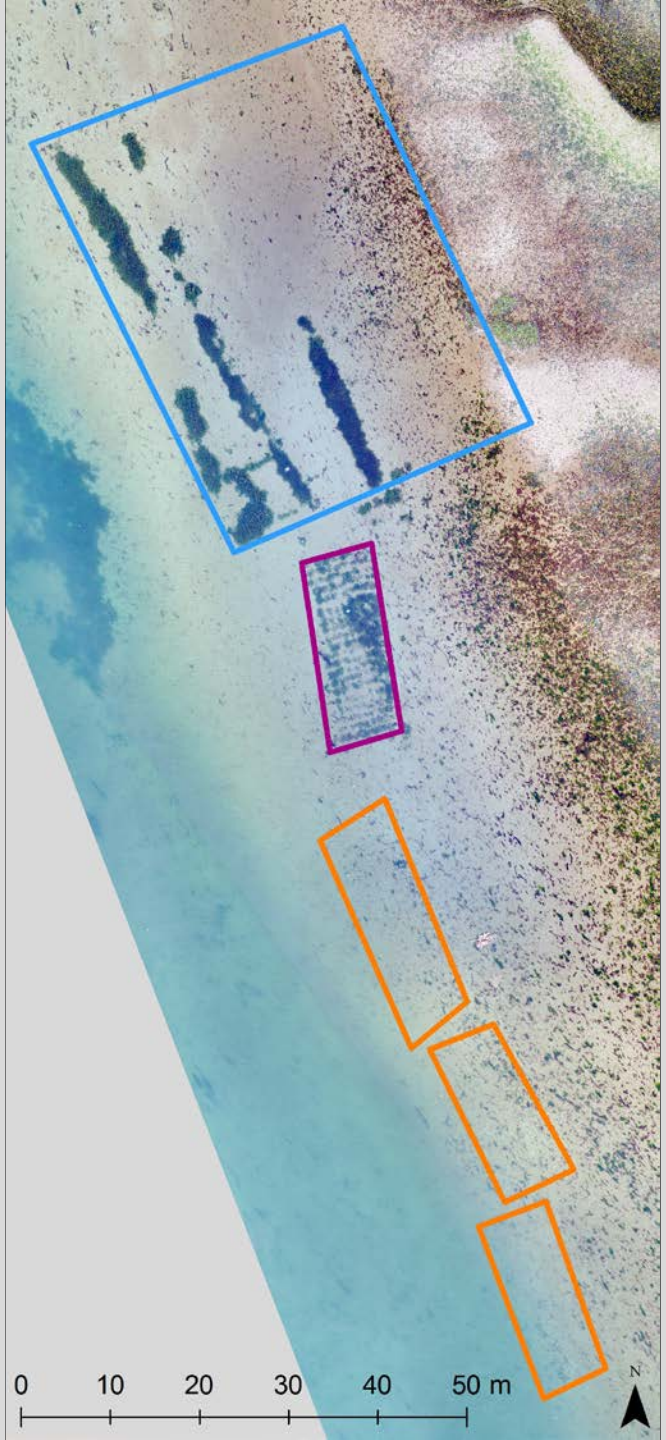
Joemma Beach State Park



Joemma Beach State Park







Joemma Beach State Park

1 – 2015

– staples w/ 4-5 shoots, 80 shoots m^{-2}

2 – 2016

– burlap w/ 21 shoots, 504 shoots m^{-2}

3-5 – 2017

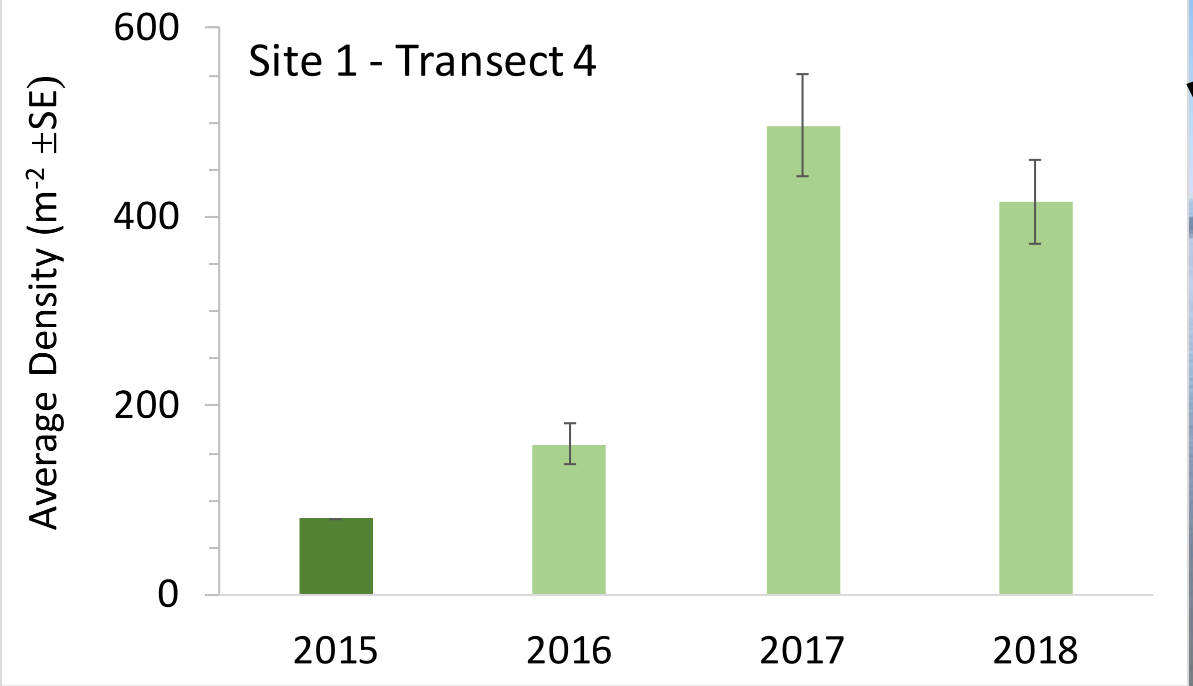
– staples w/ 10-15 shoots, 160 shoots m^{-2}

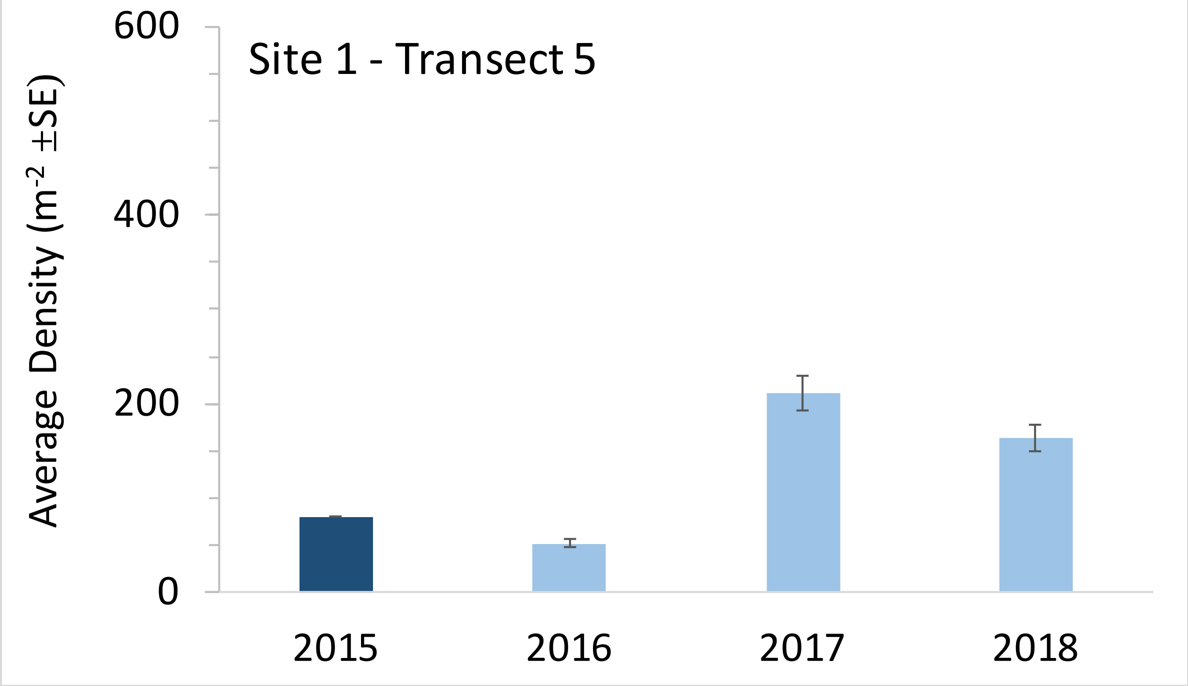

(L. Bryan)

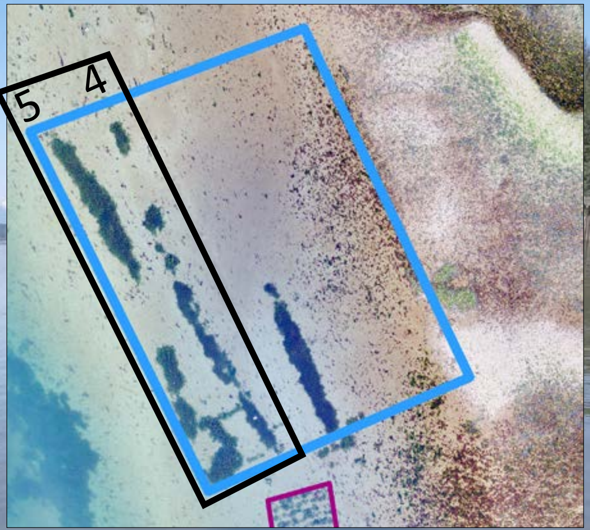
SITE 1

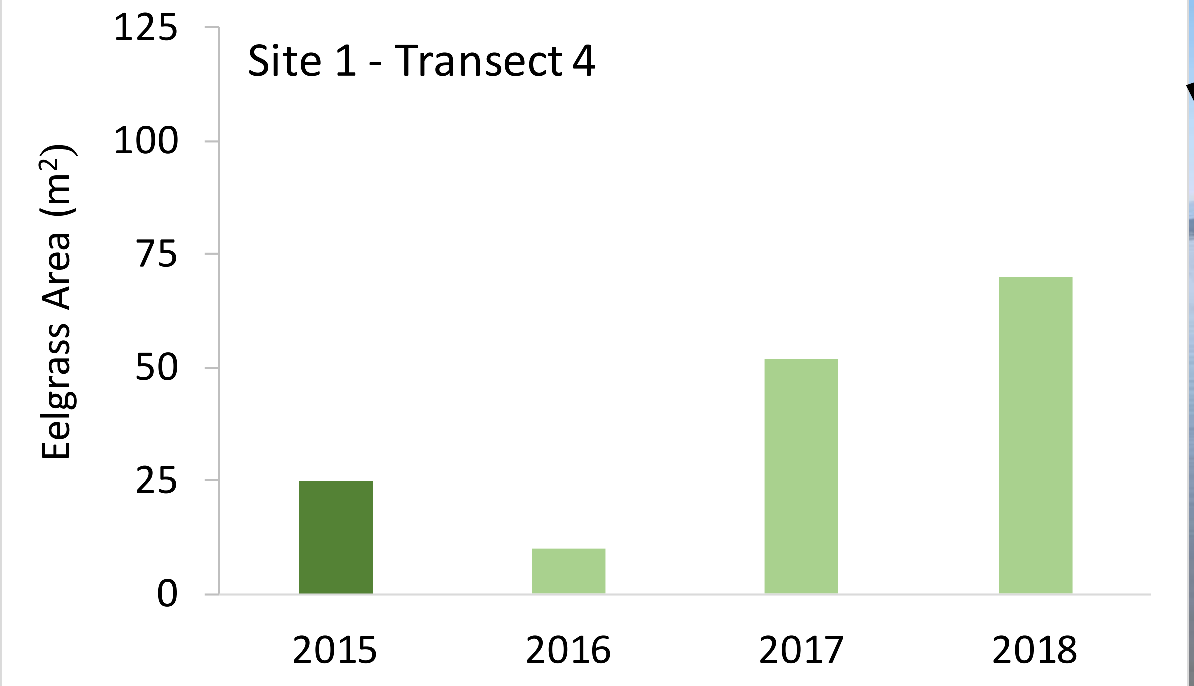
Planted in 2015

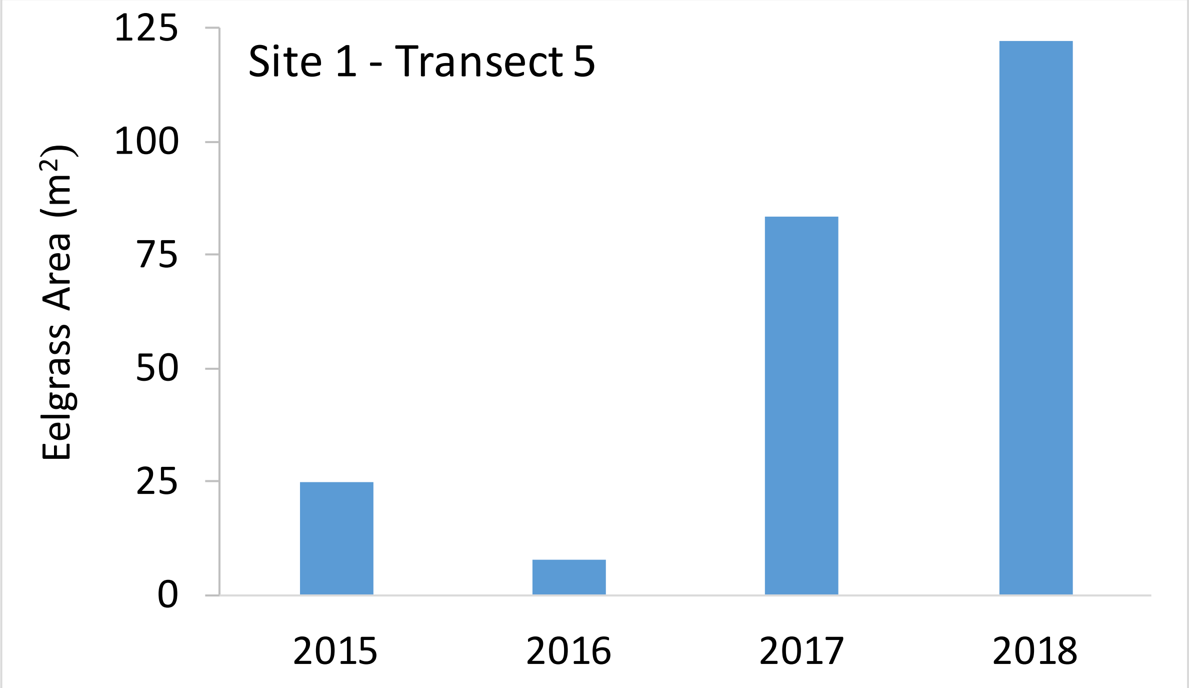
- 5 transects
- 80 shoots m^{-2}
- 125 m^2
- 10,000 shoots

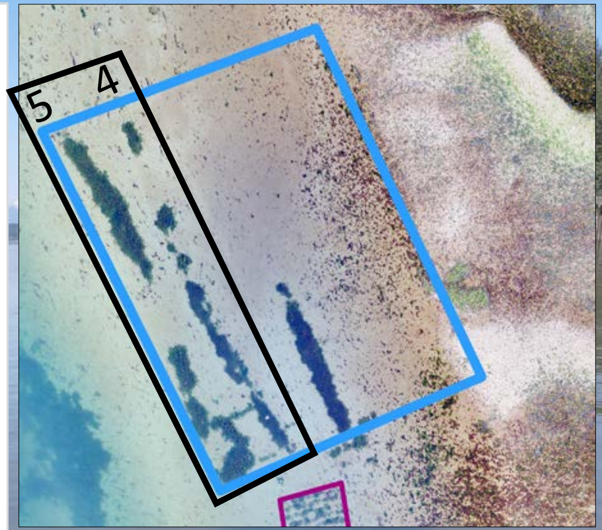

Site 1 - Transect 4
Average Density (m^{-2} ±SE)
600
400
200
0
2015
2016
2017
2018

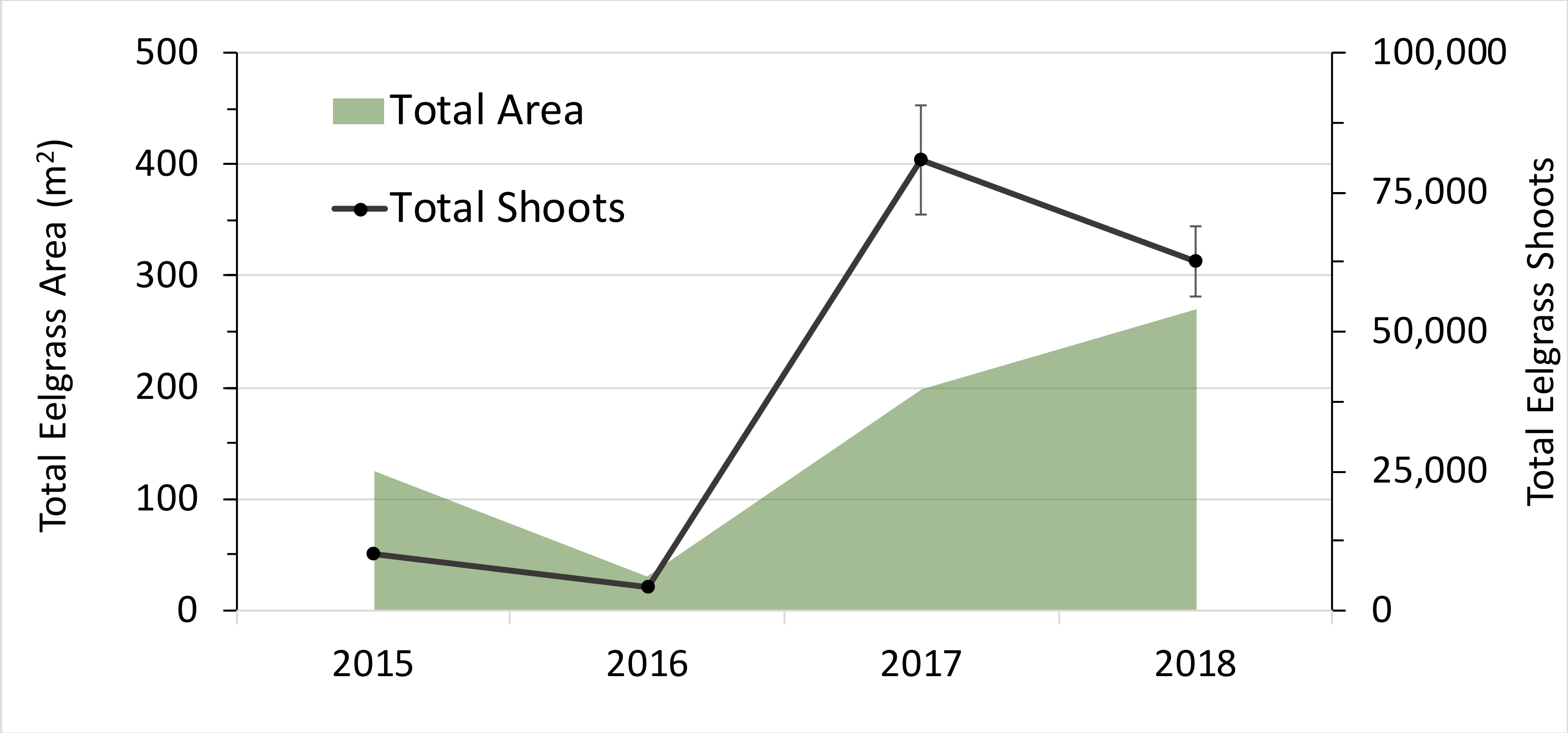

Site 1 - Transect 5
Average Density (m^{-2} ±SE)
600
400
200
0
2015
2016
2017
2018


5
4


Site 1 - Transect 4
Eelgrass Area (m^2)
125
100
75
50
25
0
2015
2016
2017
2018


Site 1 - Transect 5
Eelgrass Area (m^2)
125
100
75
50
25
0
2015
2016
2017
2018


5
4

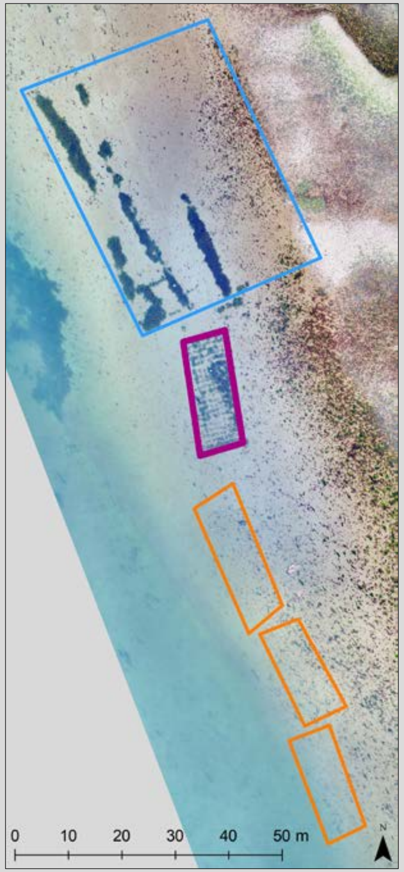


Total Area
Total Shoots
Total Eelgrass Area (m²)
Total Eelgrass Shoots
500
400
300
200
100
0
100,000
75,000
50,000
25,000
0
2015
2016
2017
2018

SITE 2


2017

(R. McMillan 2017)



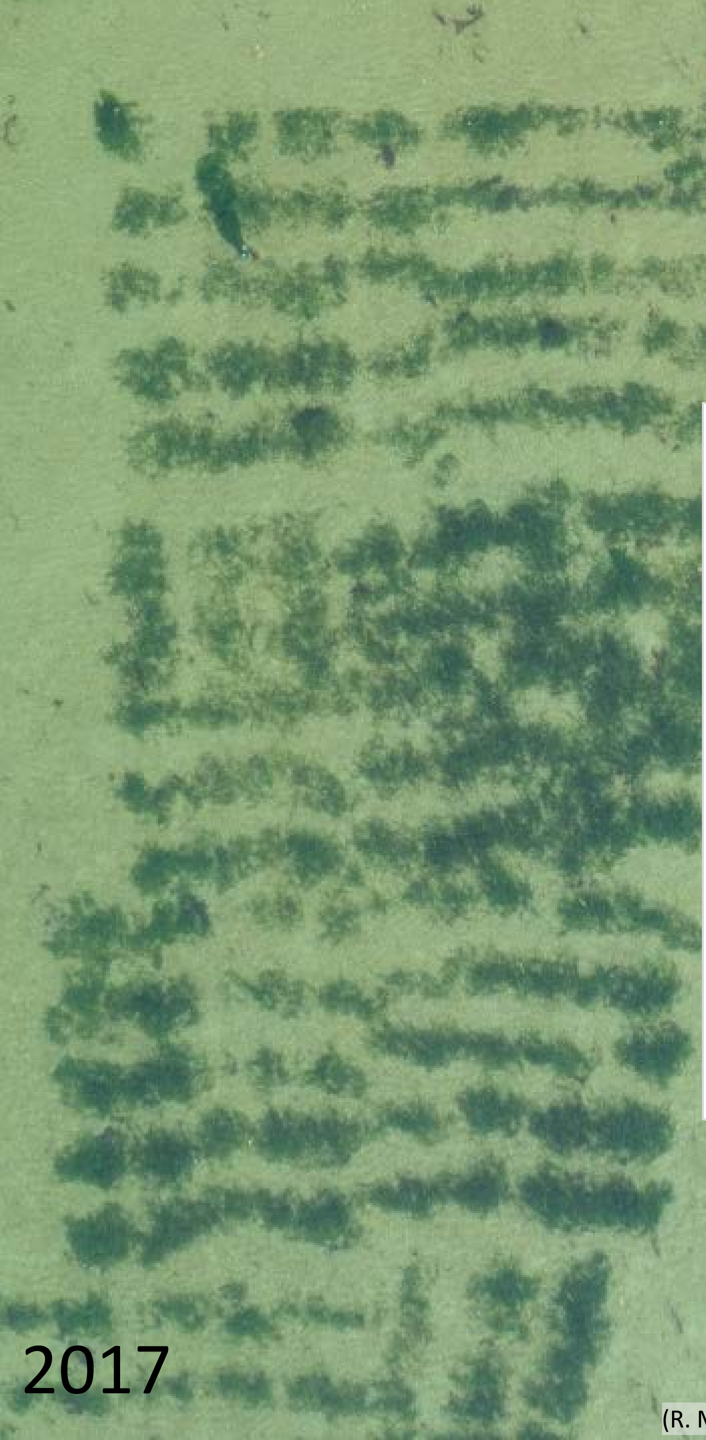
Planted in 2016

- 504 shoots m^{-2}
- 40 m^2 planted
- 20,160 shoots


2018

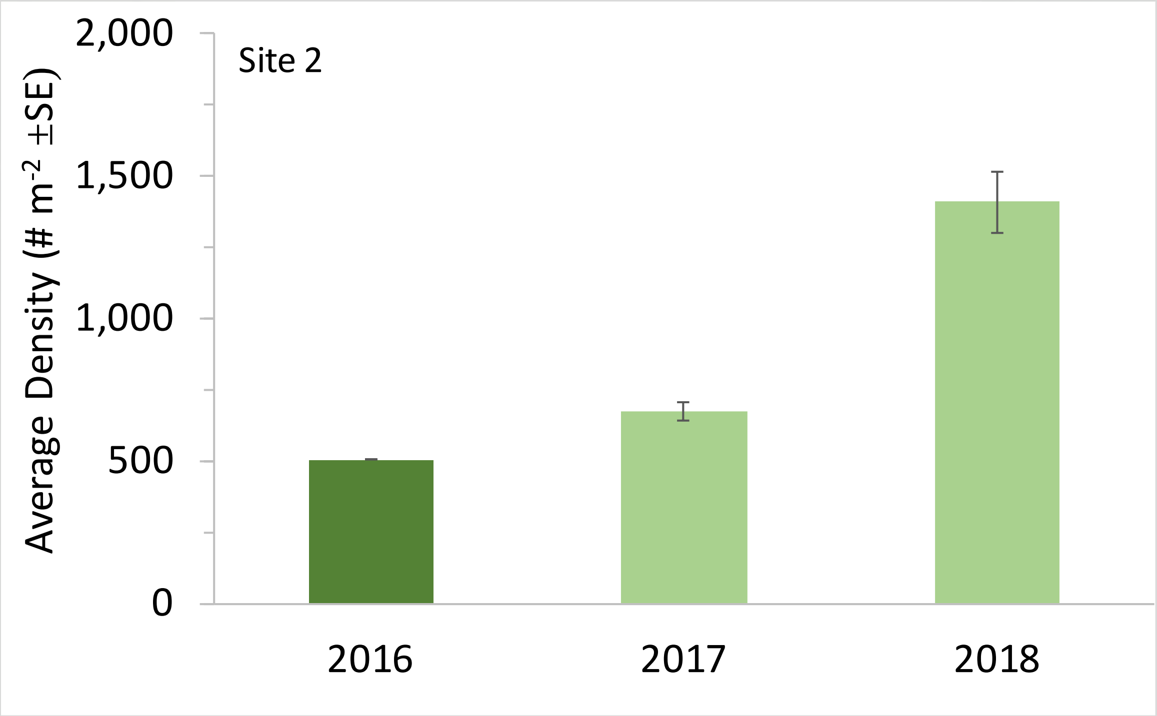
(R. McMillan 2018)

SITE 2



2017

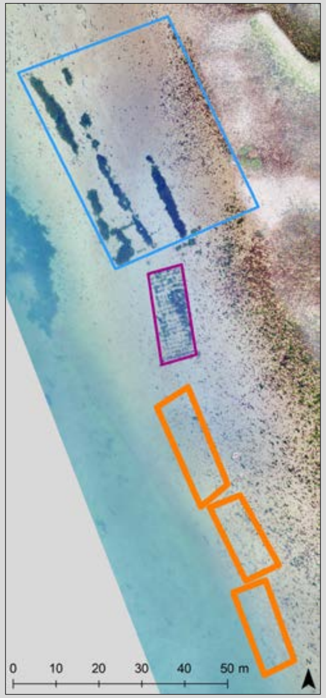
(R. McMillan 2017)



2018

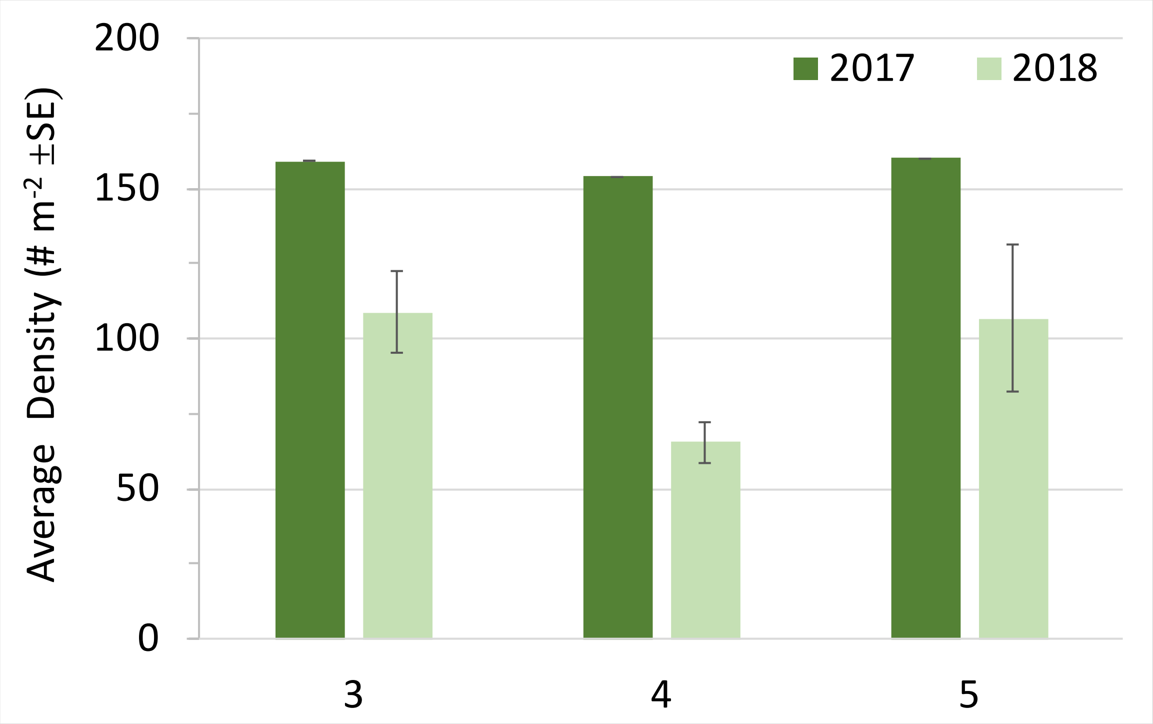
(R. McMillan 2018)

SITES 3 – 5



Planted in 2017

- ~ 160 shoots m^{-2}
- ~ 22,000 shoots

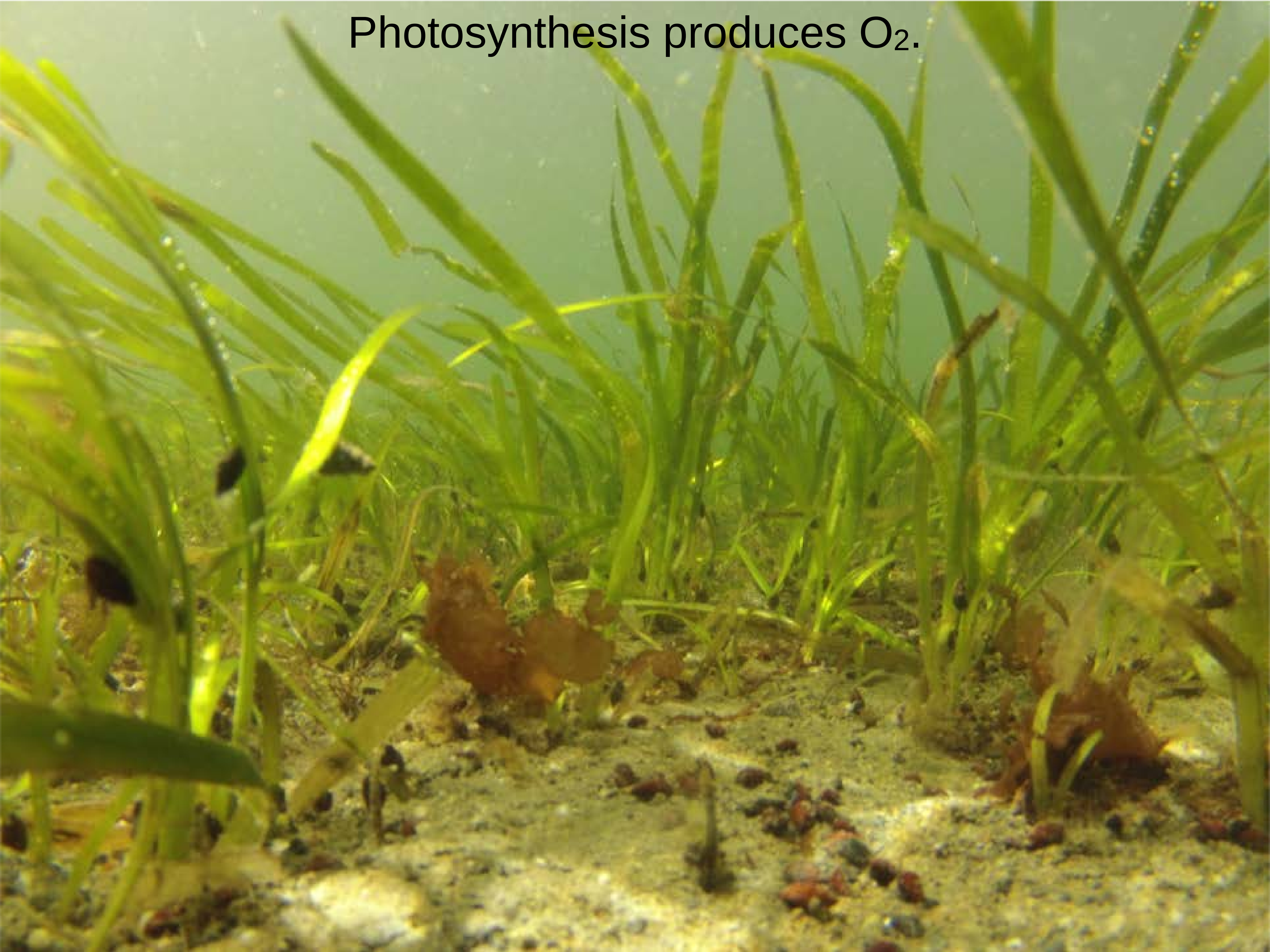


ANeMoNe sensors measure eelgrass effects on water quality.

Heat and low oxygen levels cause fish kills in South Sound.

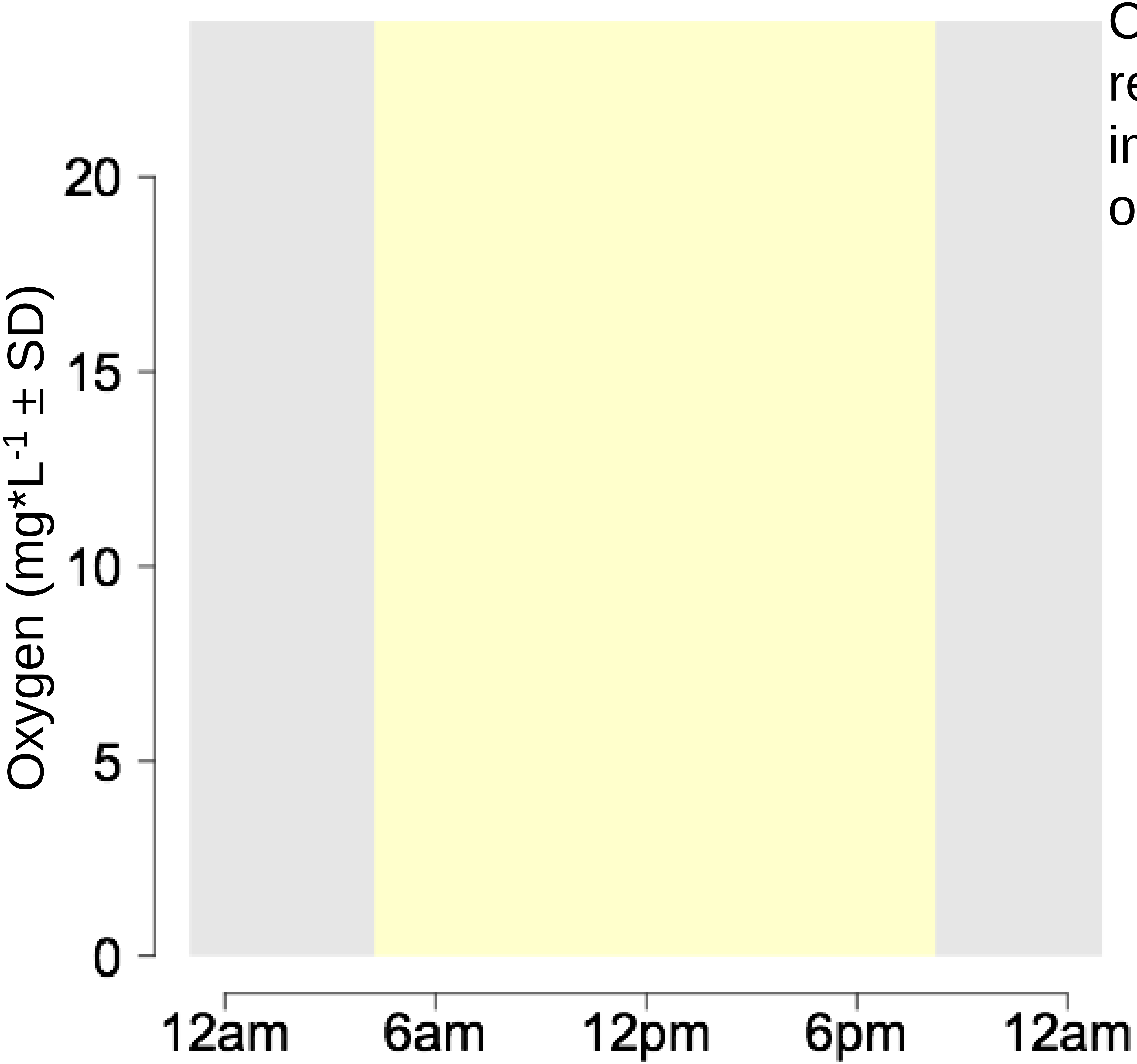
KOMO News 06.05.2017

Photosynthesis produces O_2.

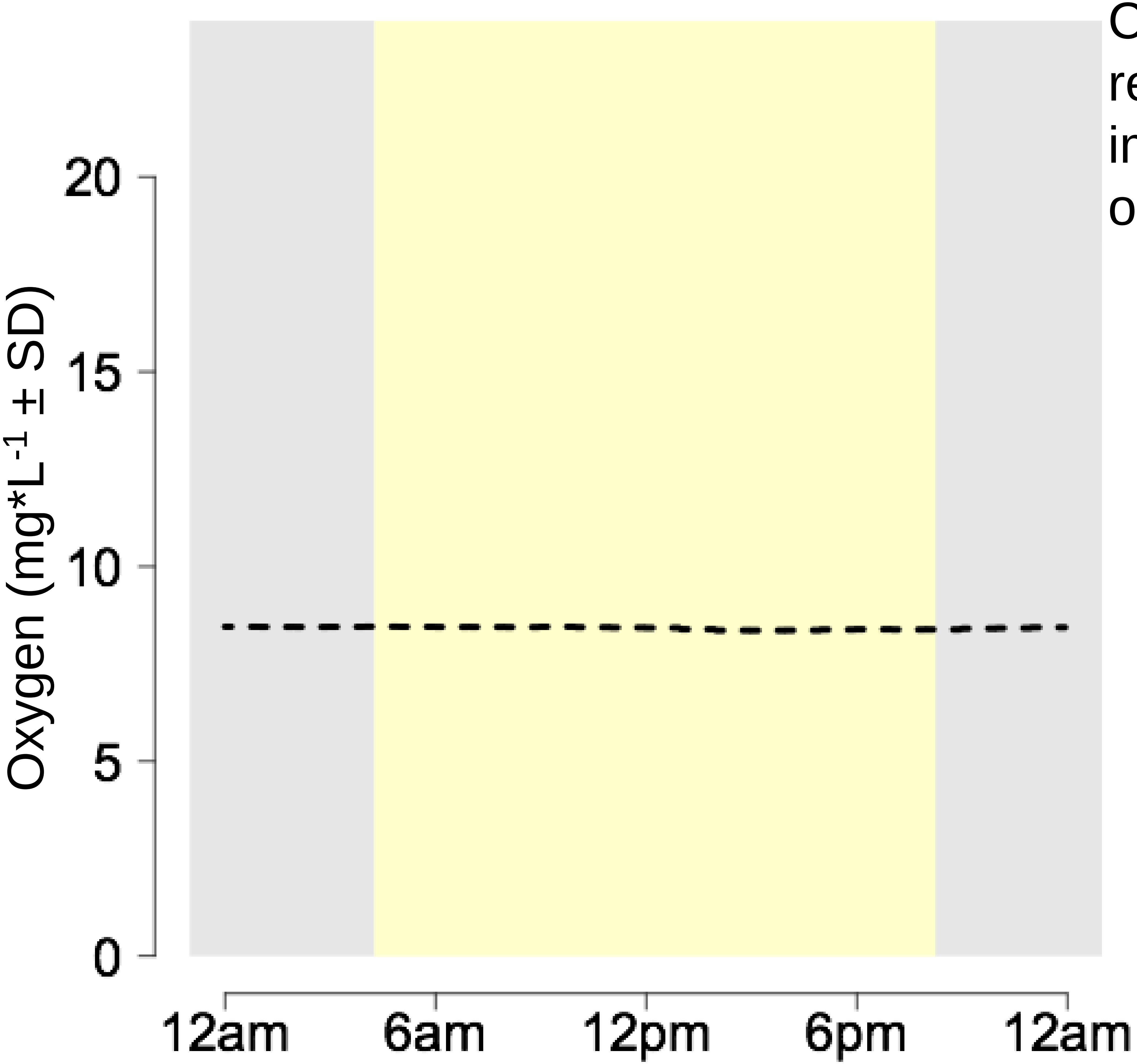


Can eelgrass restoration improve oxygen levels?

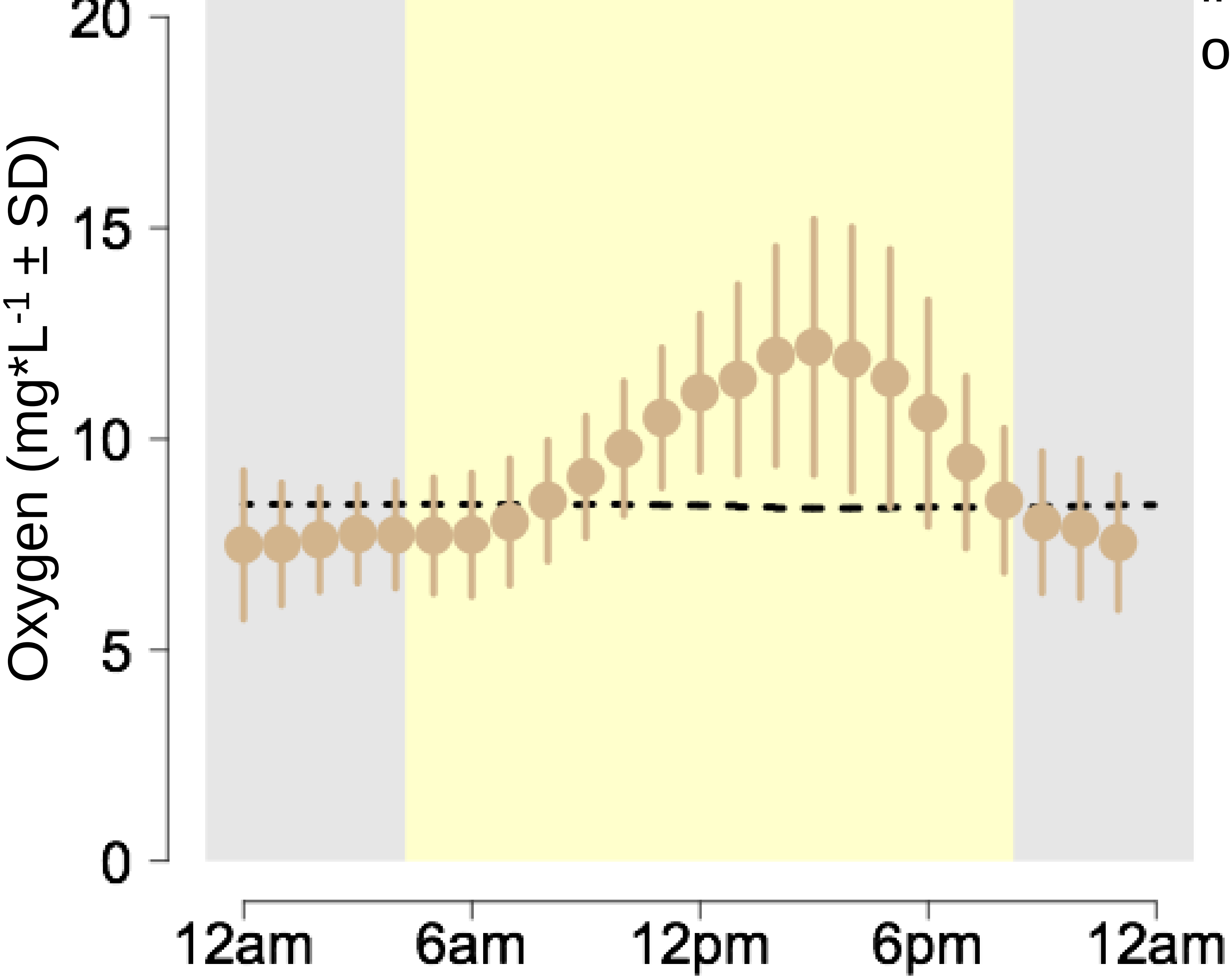
Can eelgrass restoration improve oxygen levels?



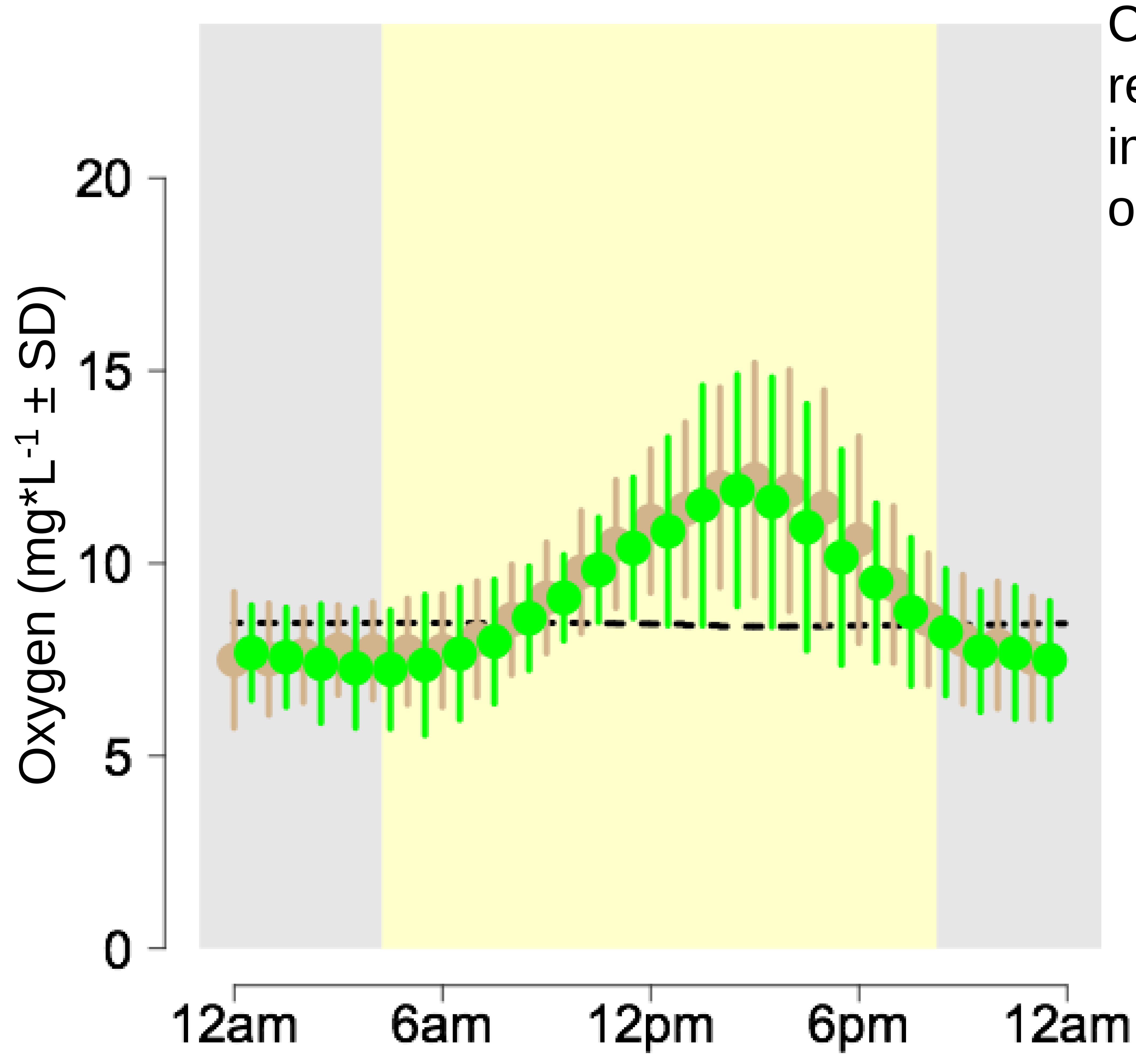
Can eelgrass restoration improve oxygen levels?

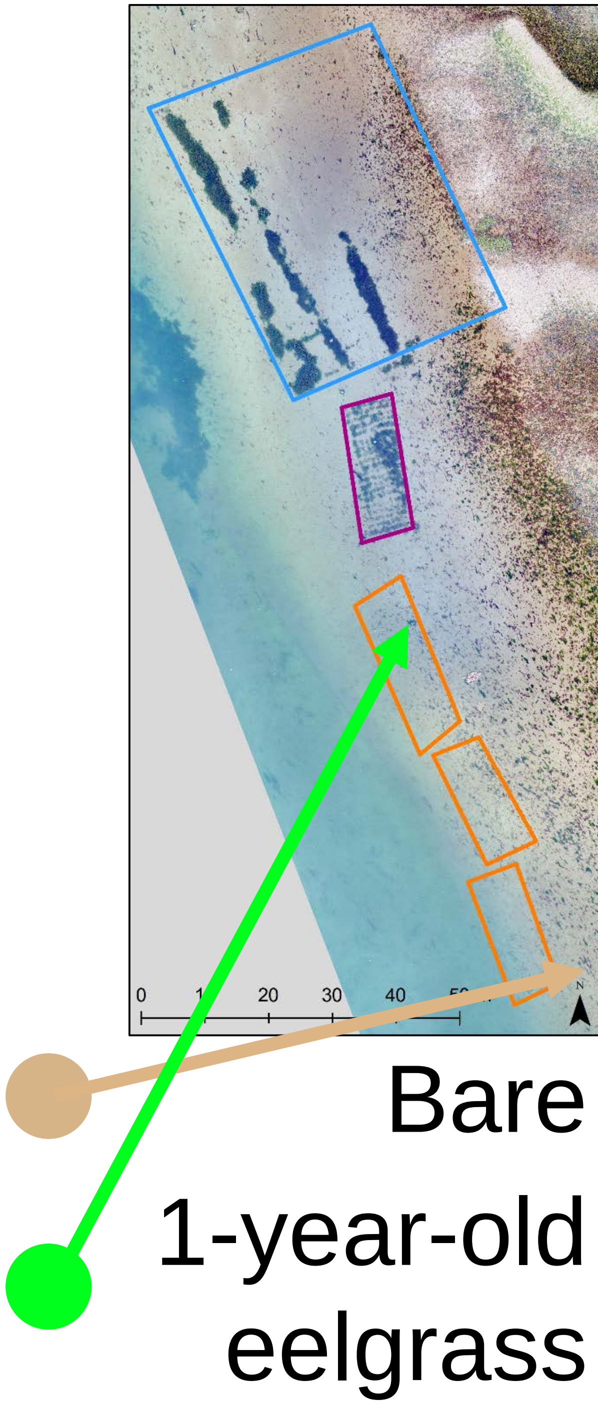


Can eelgrass restoration improve oxygen levels?

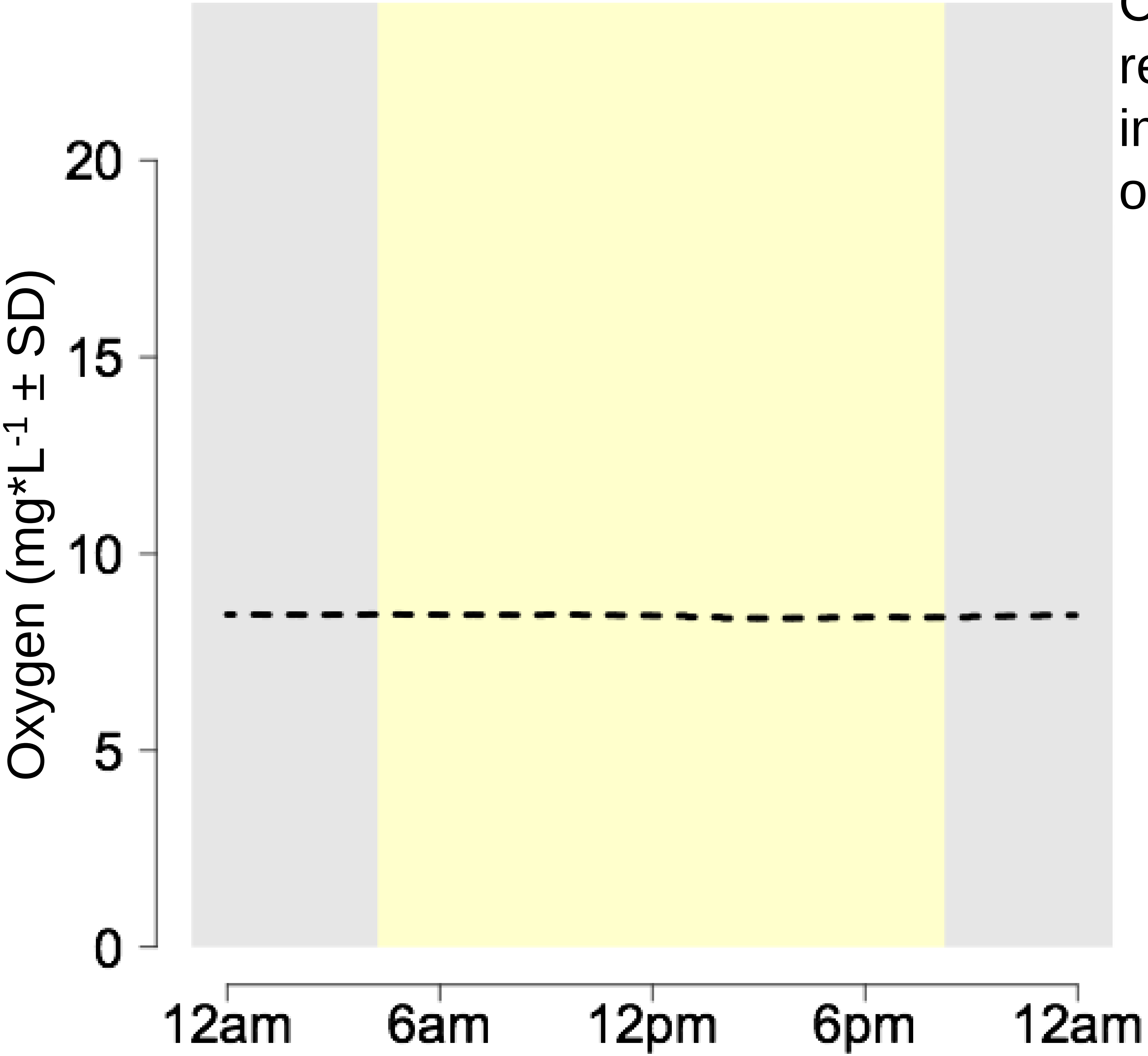


Can eelgrass restoration improve oxygen levels?

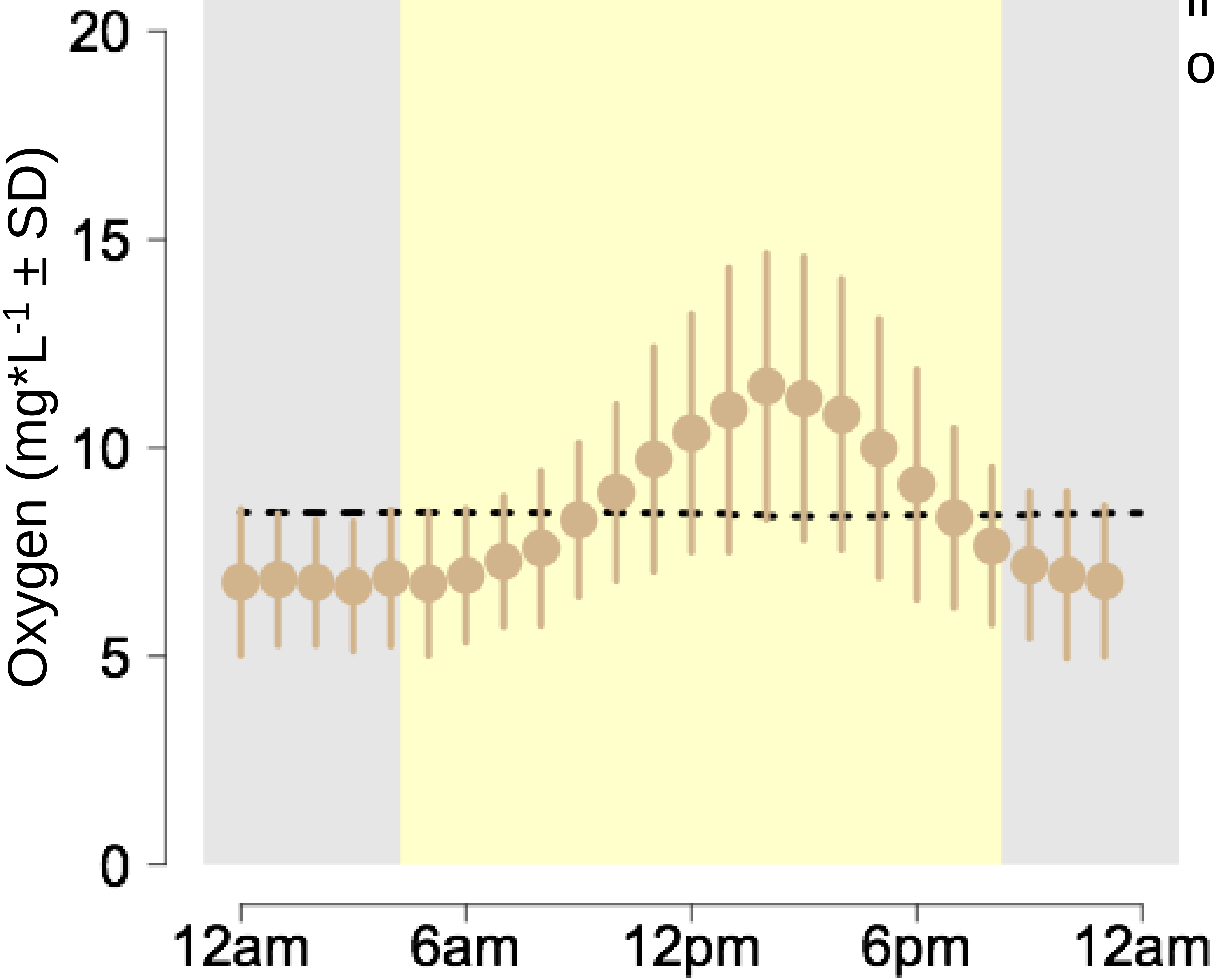




Can eelgrass restoration improve oxygen levels?

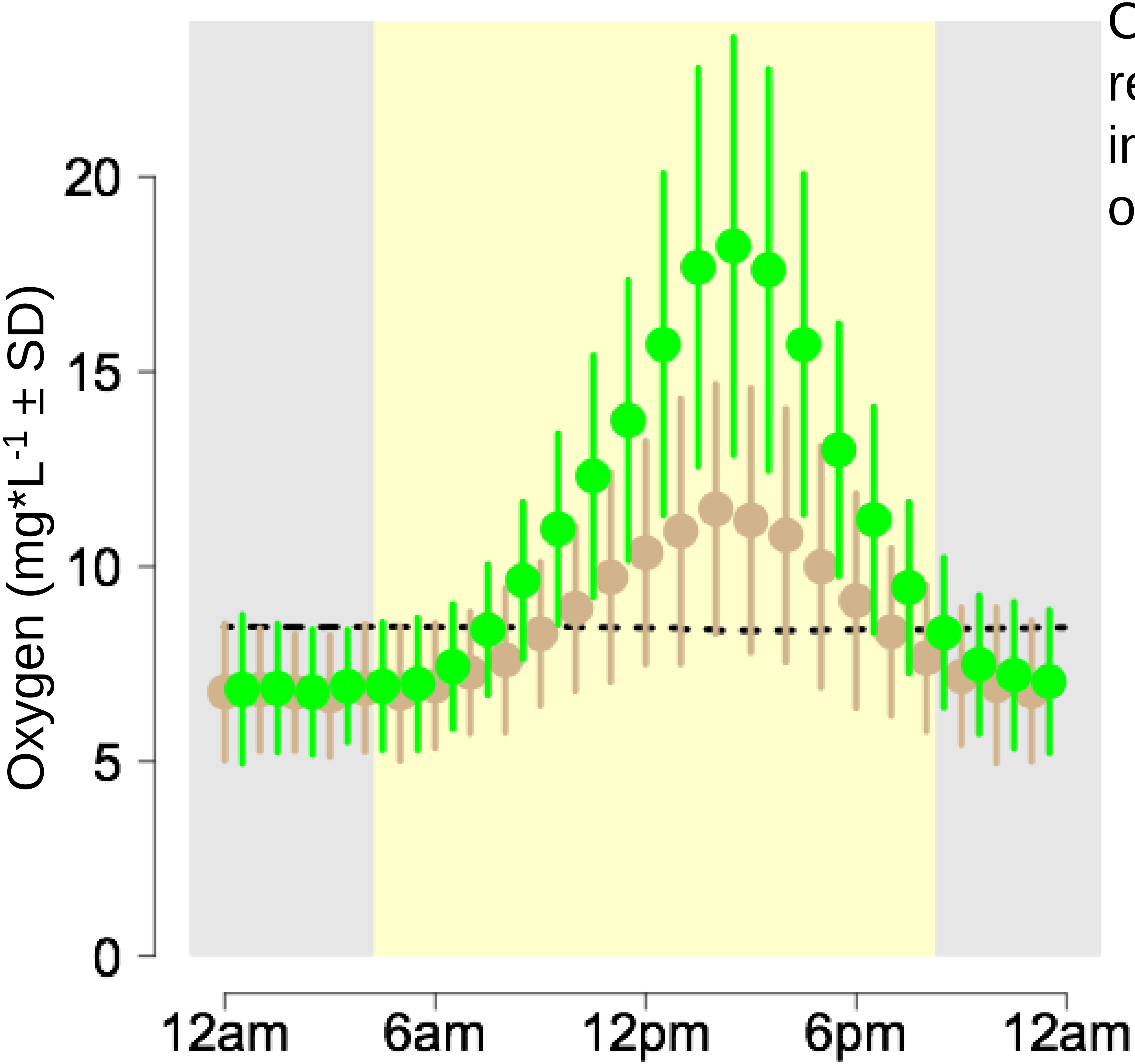


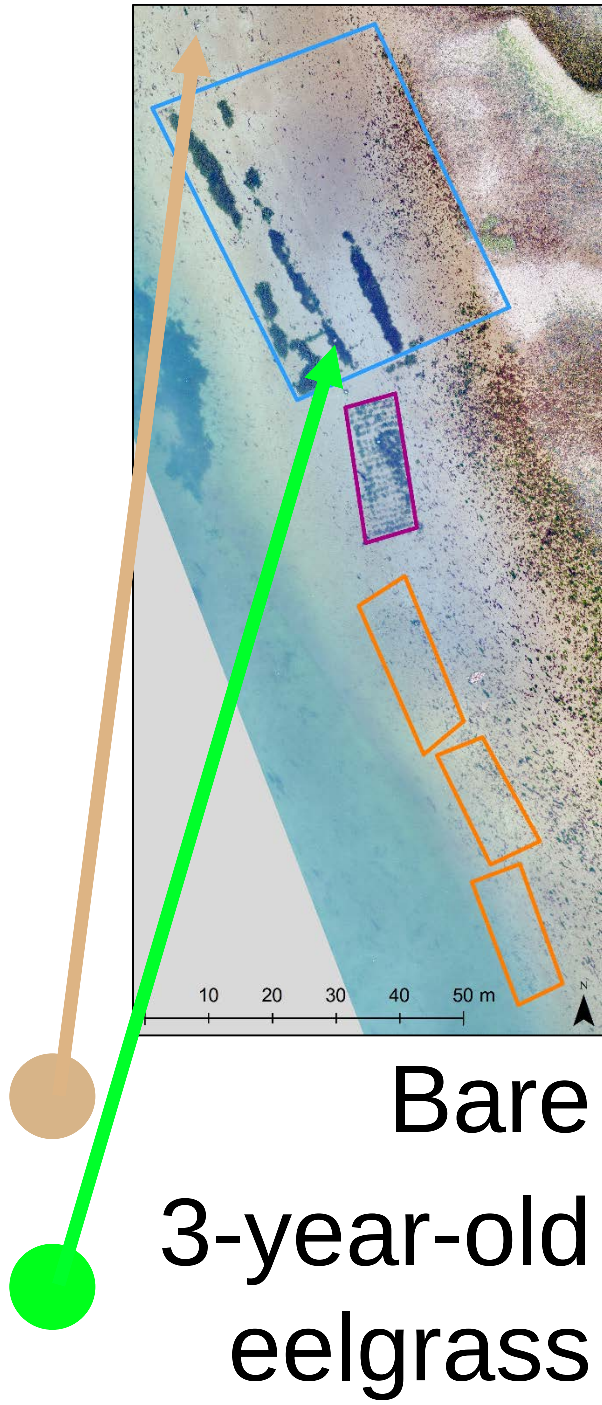
Can eelgrass restoration improve oxygen levels?



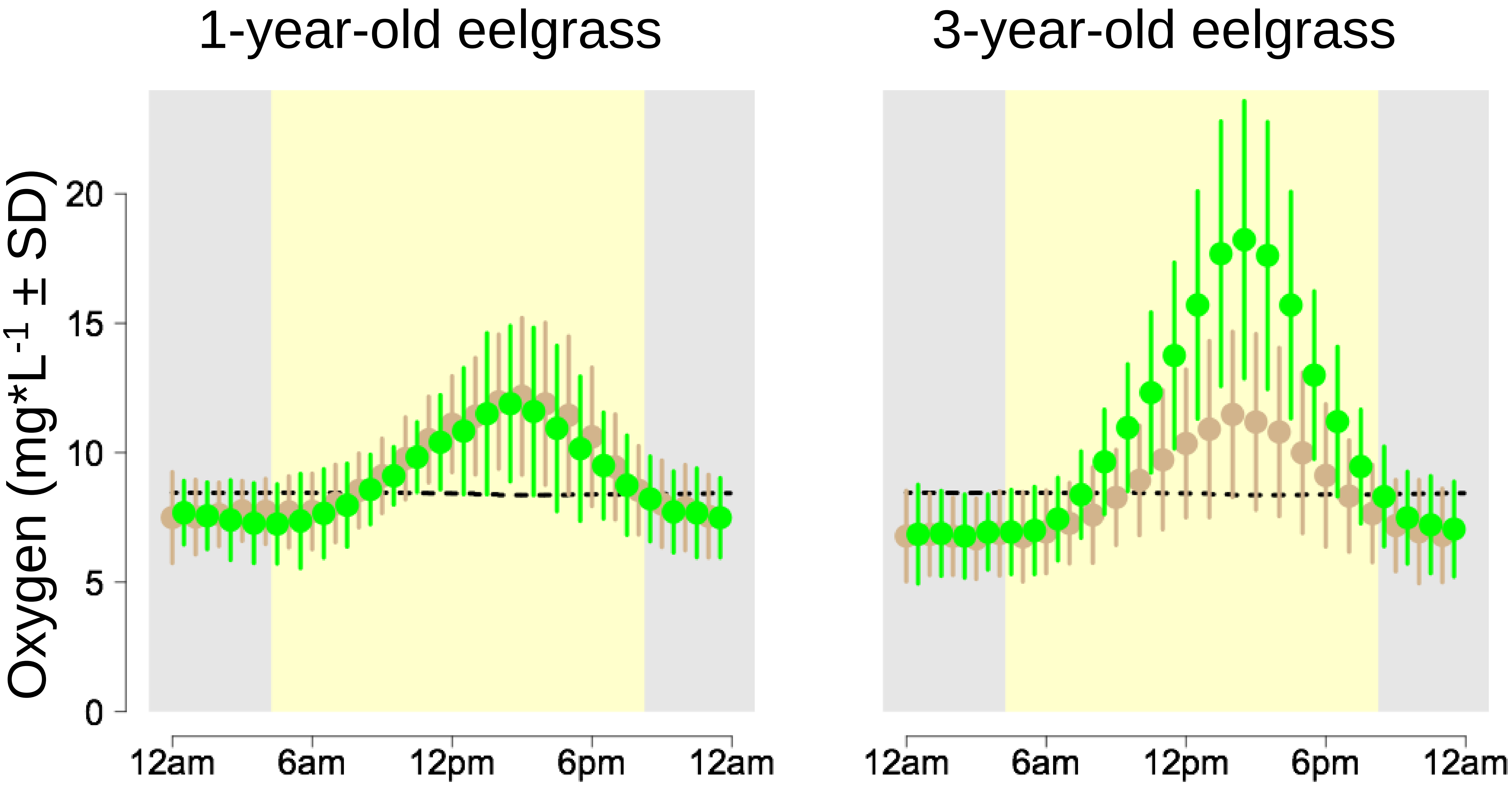
Bare

Can eelgrass restoration improve oxygen levels?



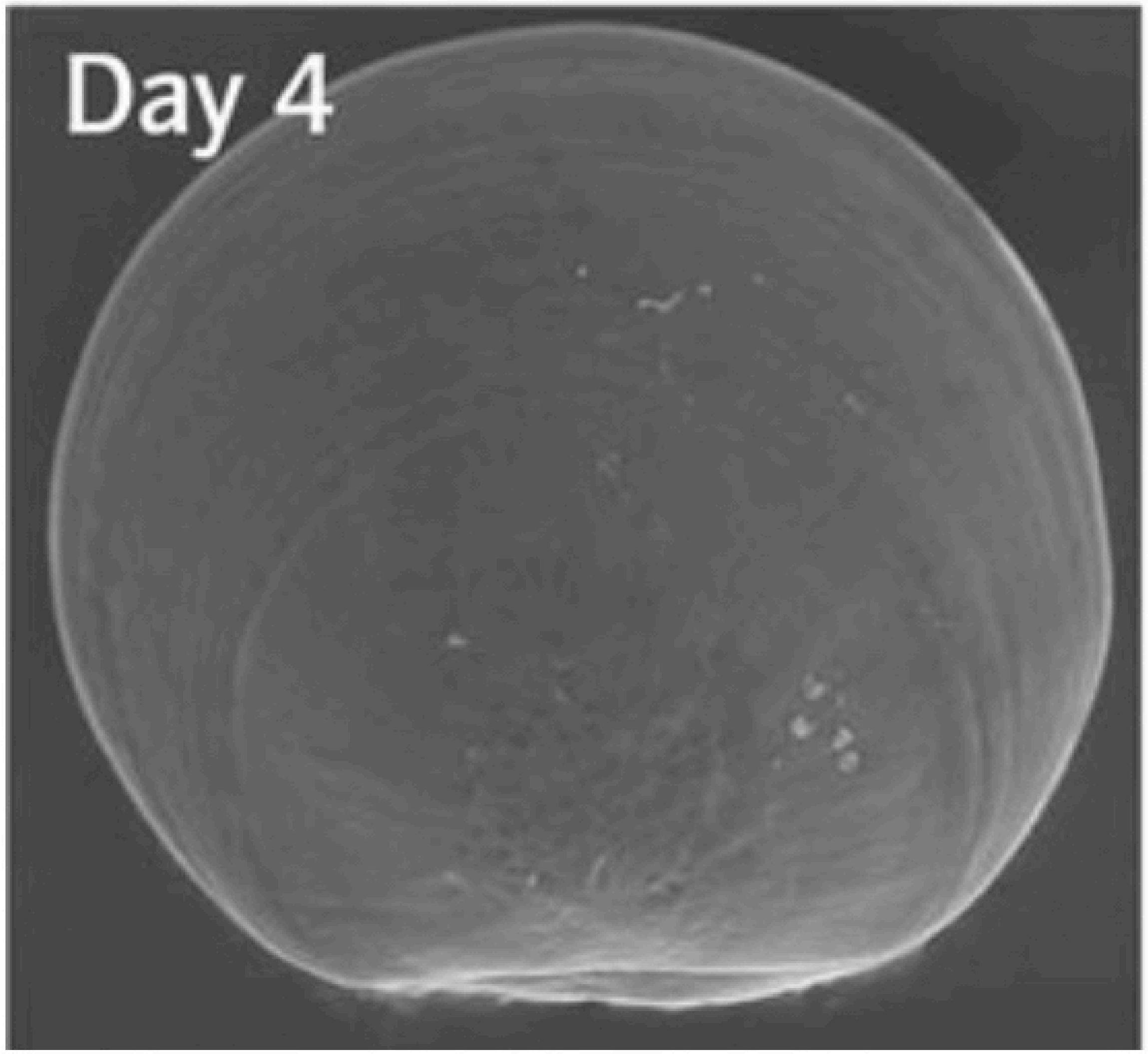


Can eelgrass restoration improve oxygen levels?

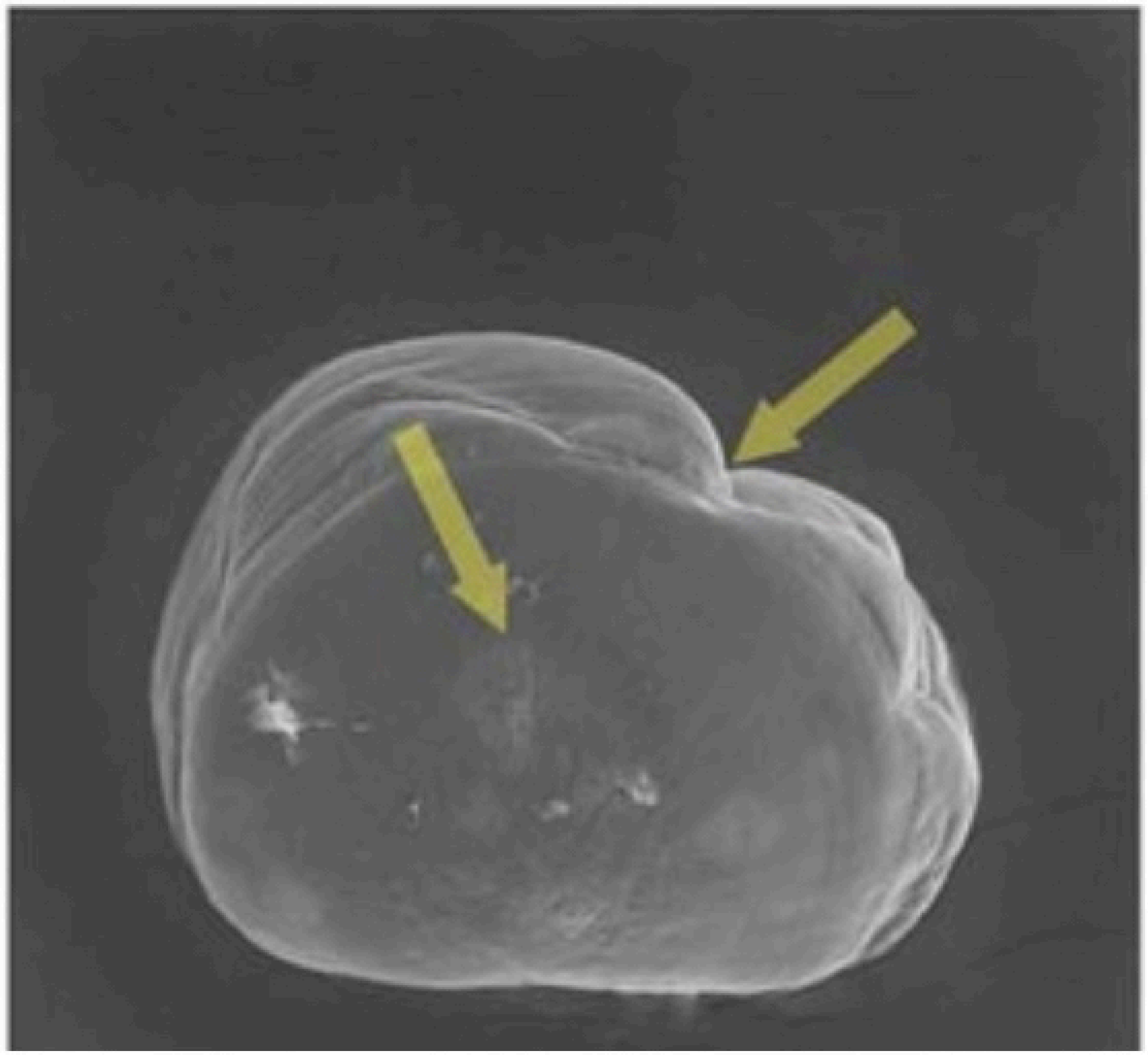


Mature eelgrass improved daytime oxygen; new grass did not.

CO_2 emissions cause ocean acidification, which could harm shellfish and other animals in South Sound.



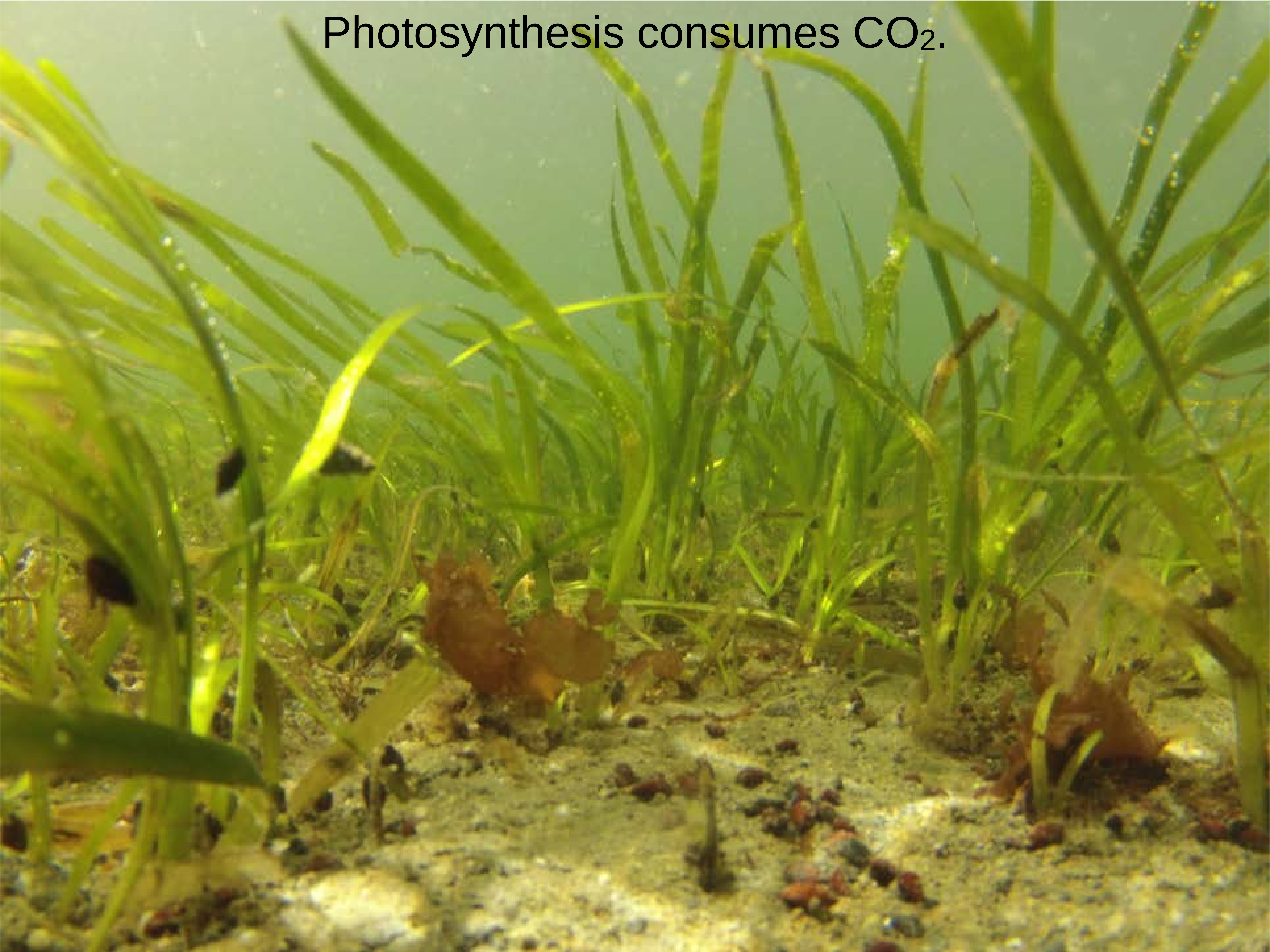
pH_T: 8.0



pH_T: 7.5

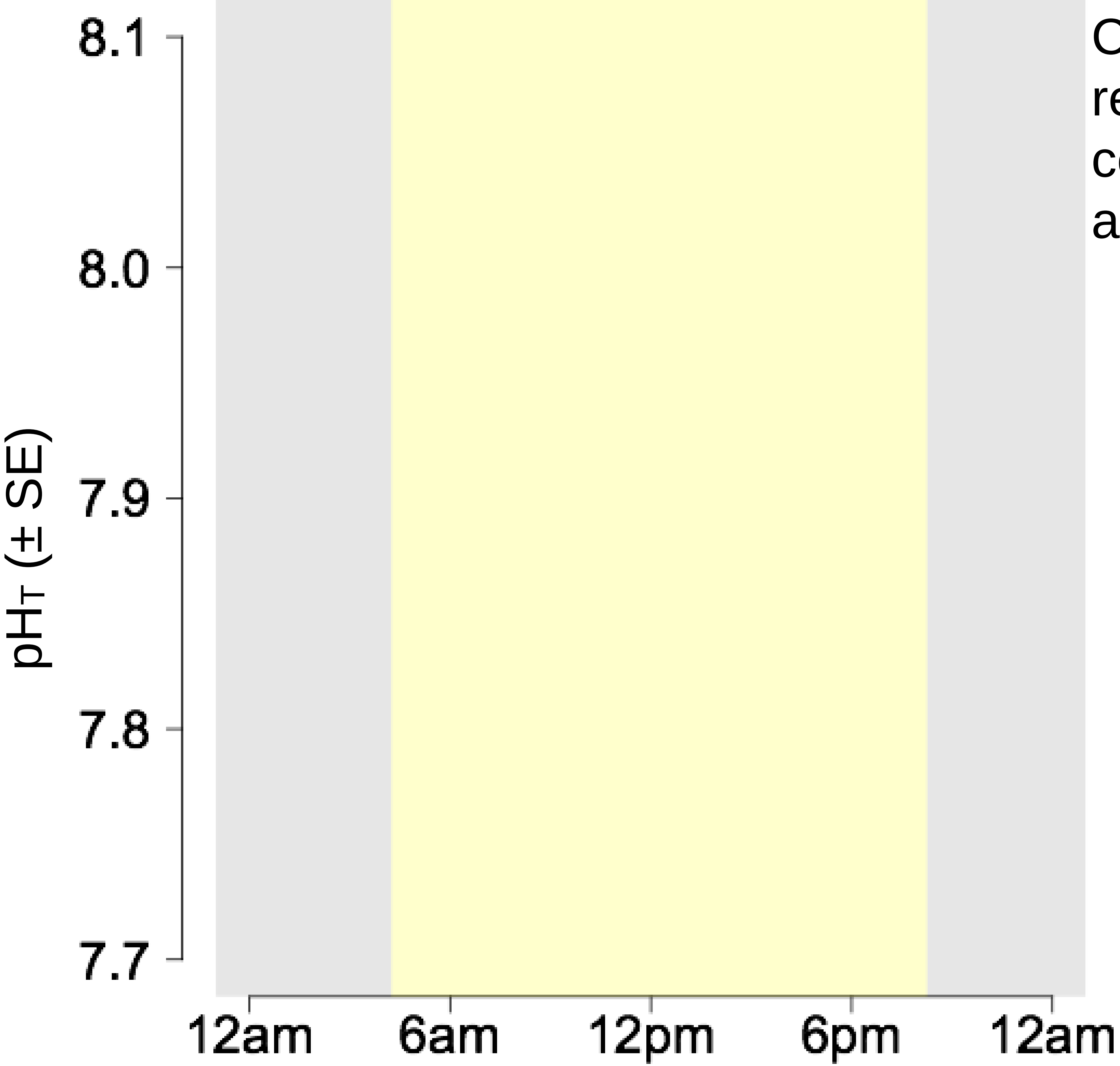
Barton et al. 2015

Photosynthesis consumes CO_2.

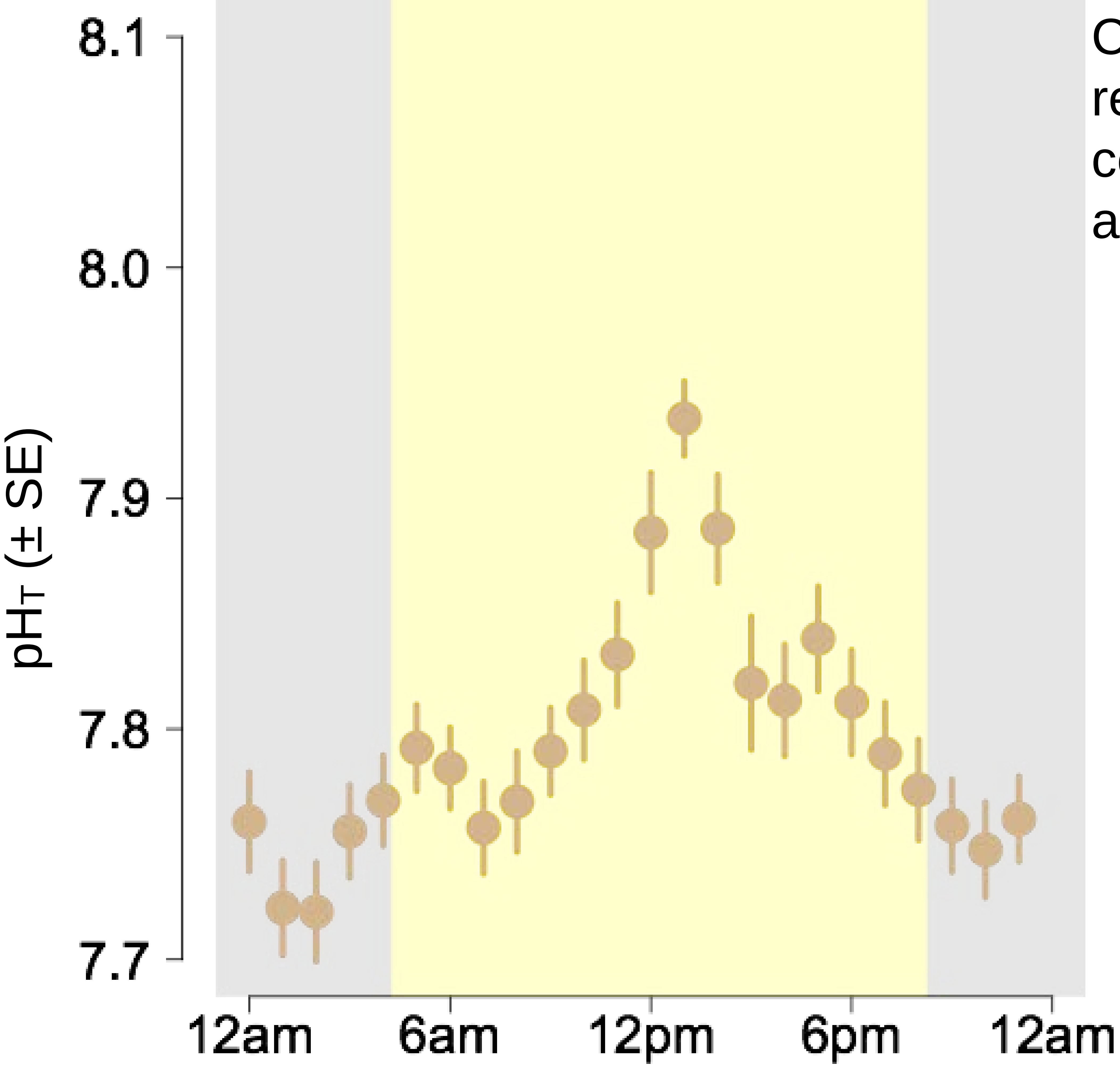


Can eelgrass restoration counteract acidification?

Can eelgrass restoration counteract acidification?

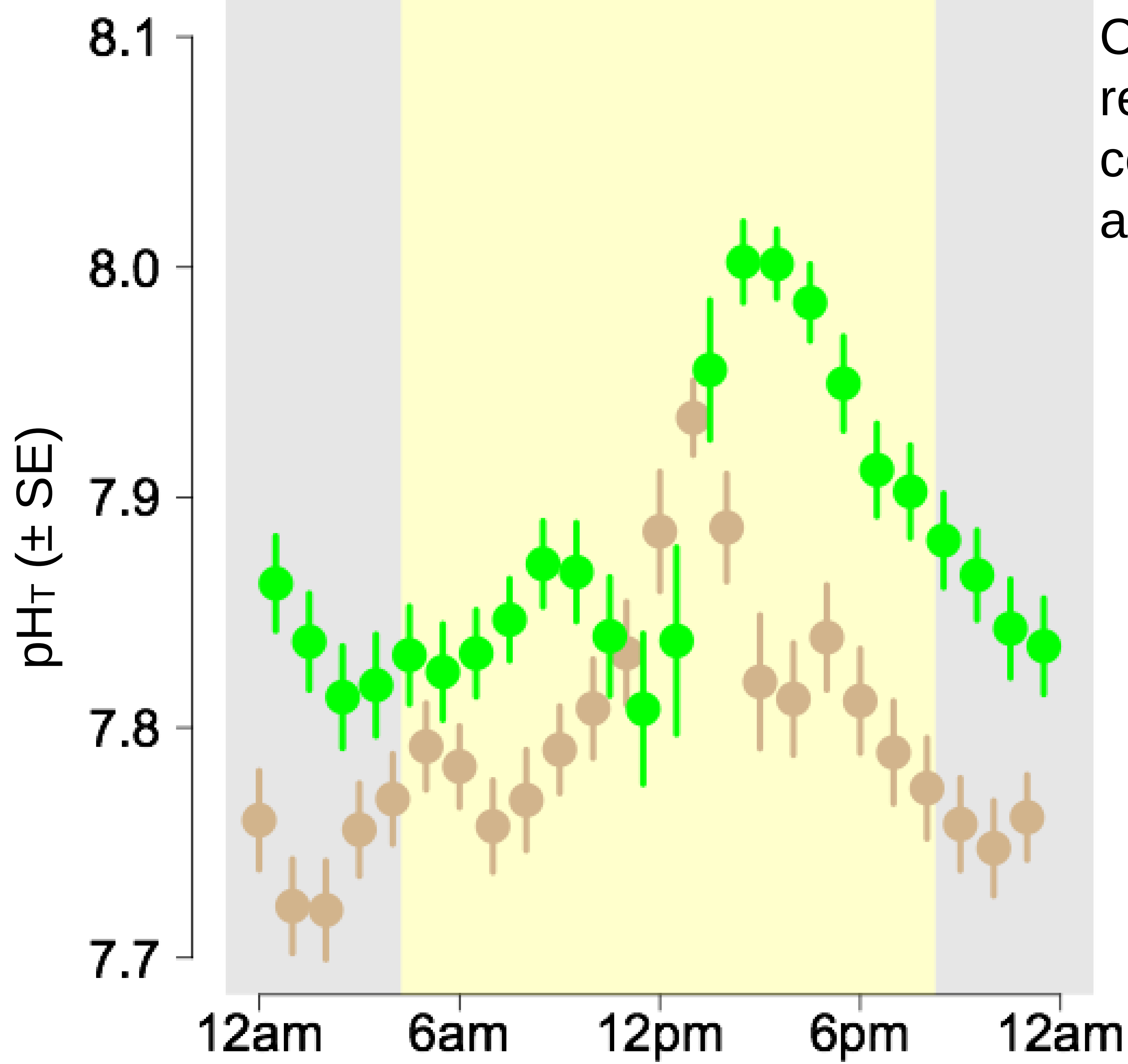


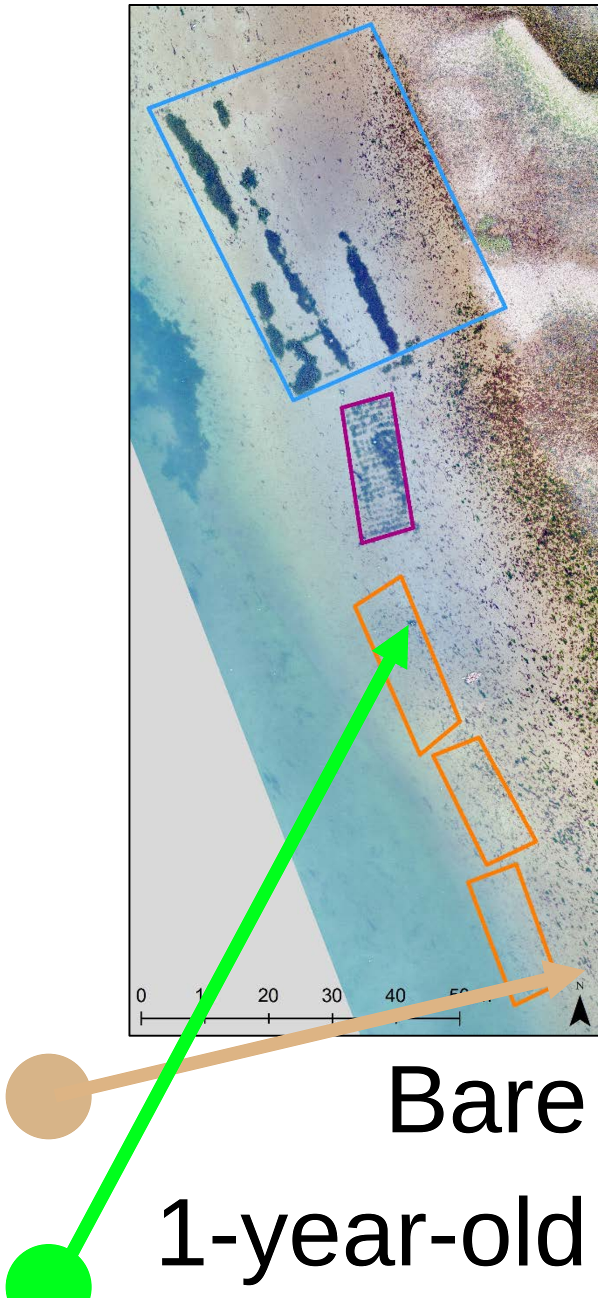
Can eelgrass restoration counteract acidification?



● Bare

Can eelgrass restoration counteract acidification?

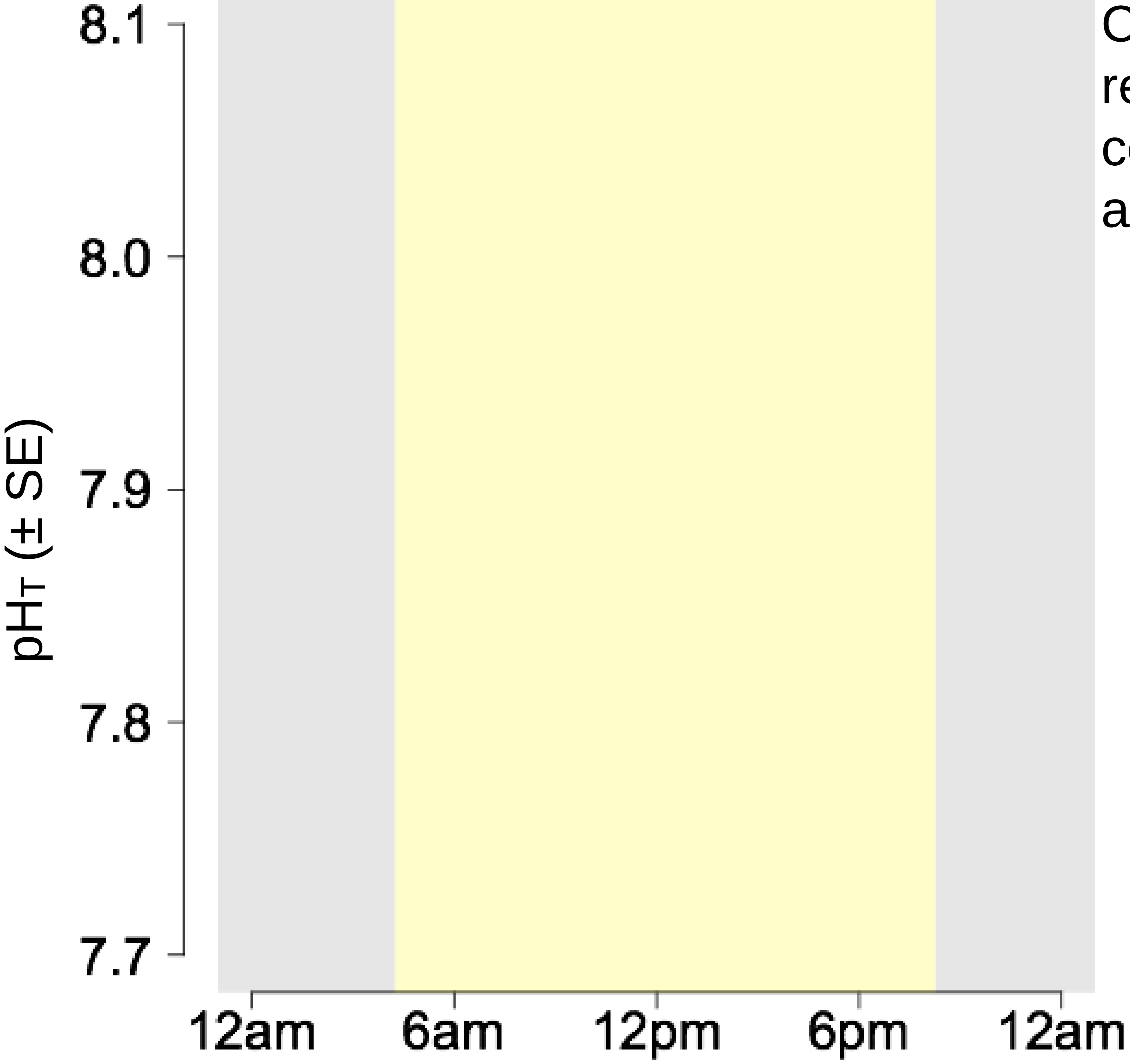




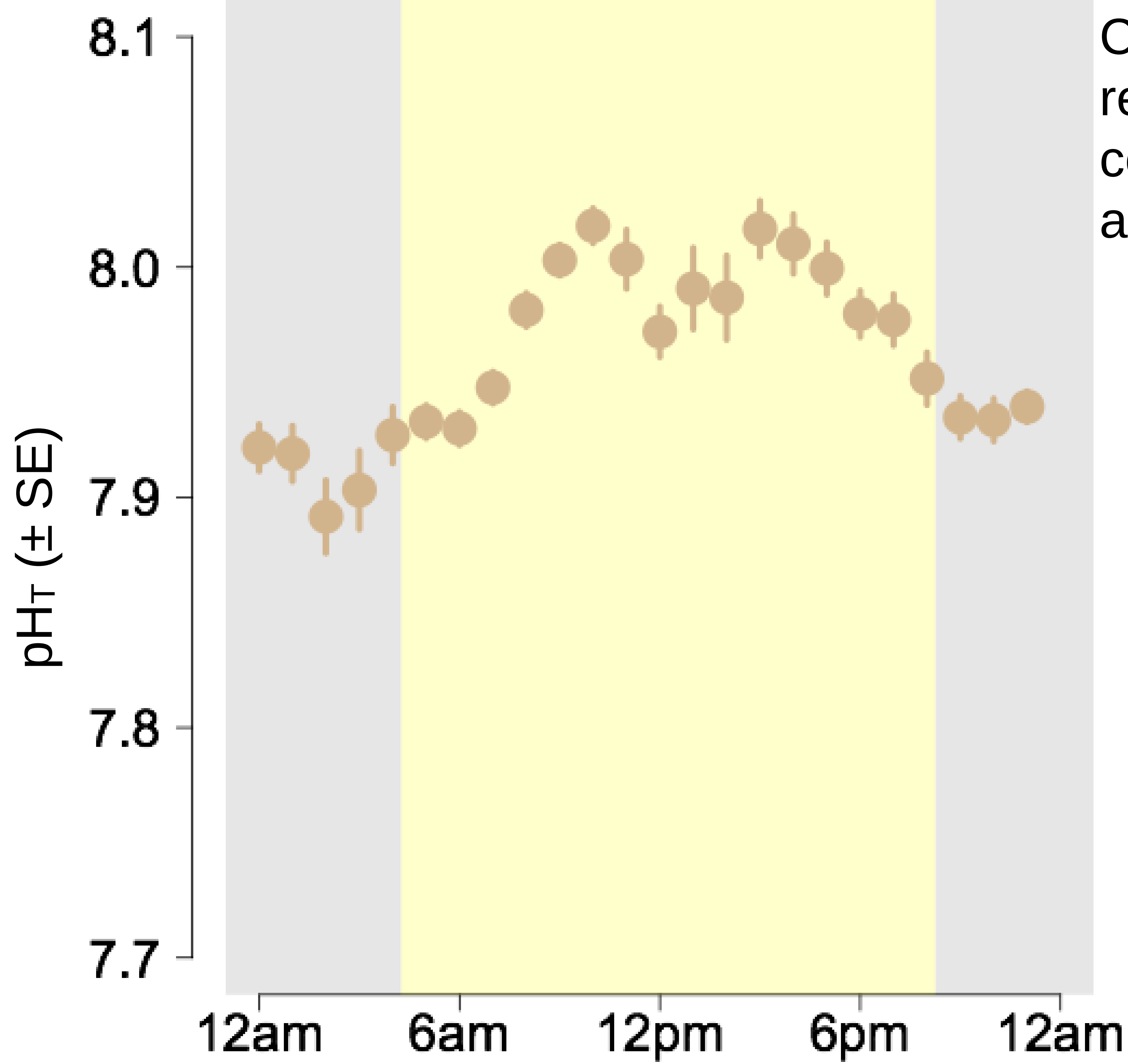
● Bare

● 1-year-old eelgrass

Can eelgrass restoration counteract acidification?



Can eelgrass restoration counteract acidification?



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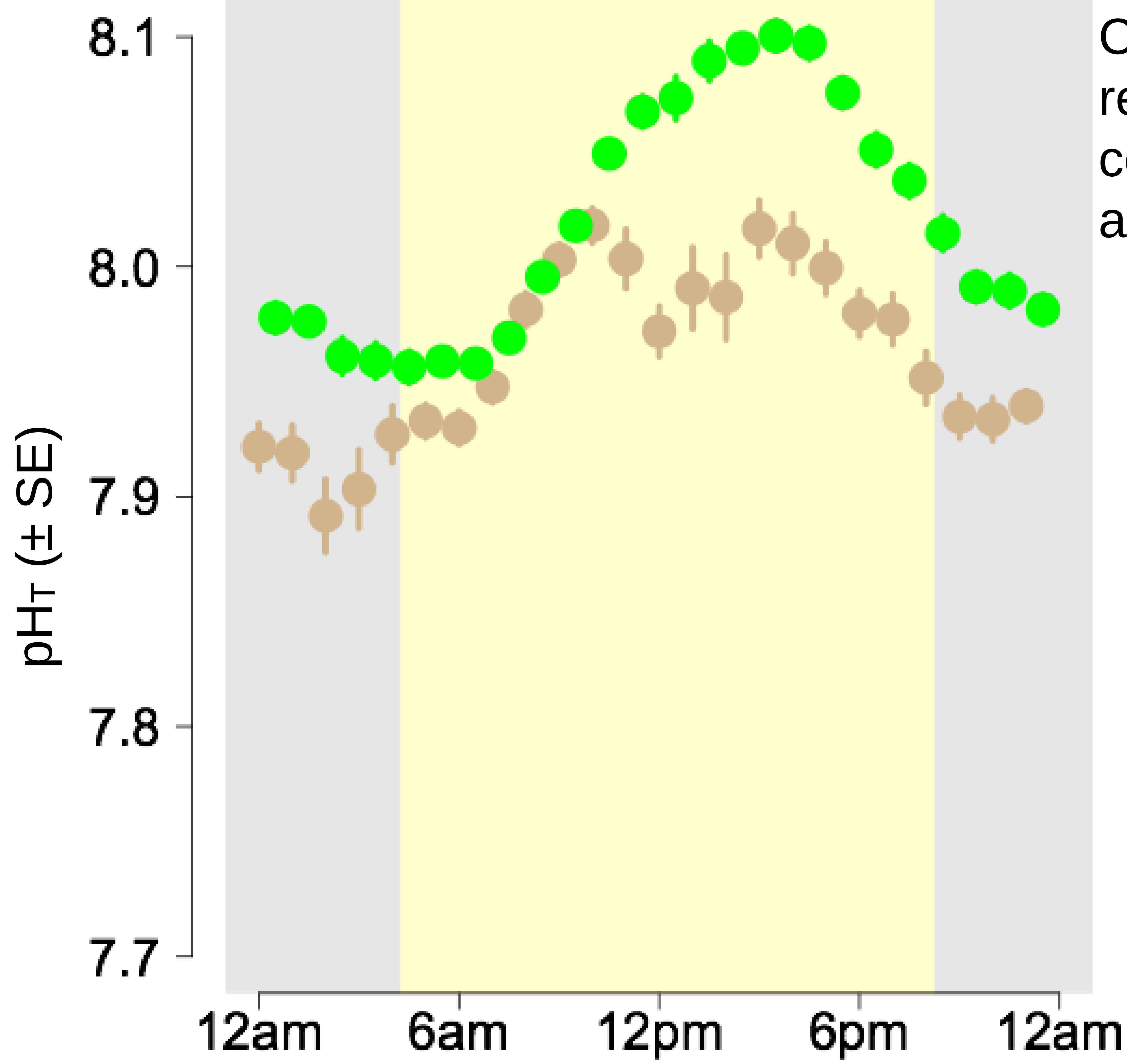
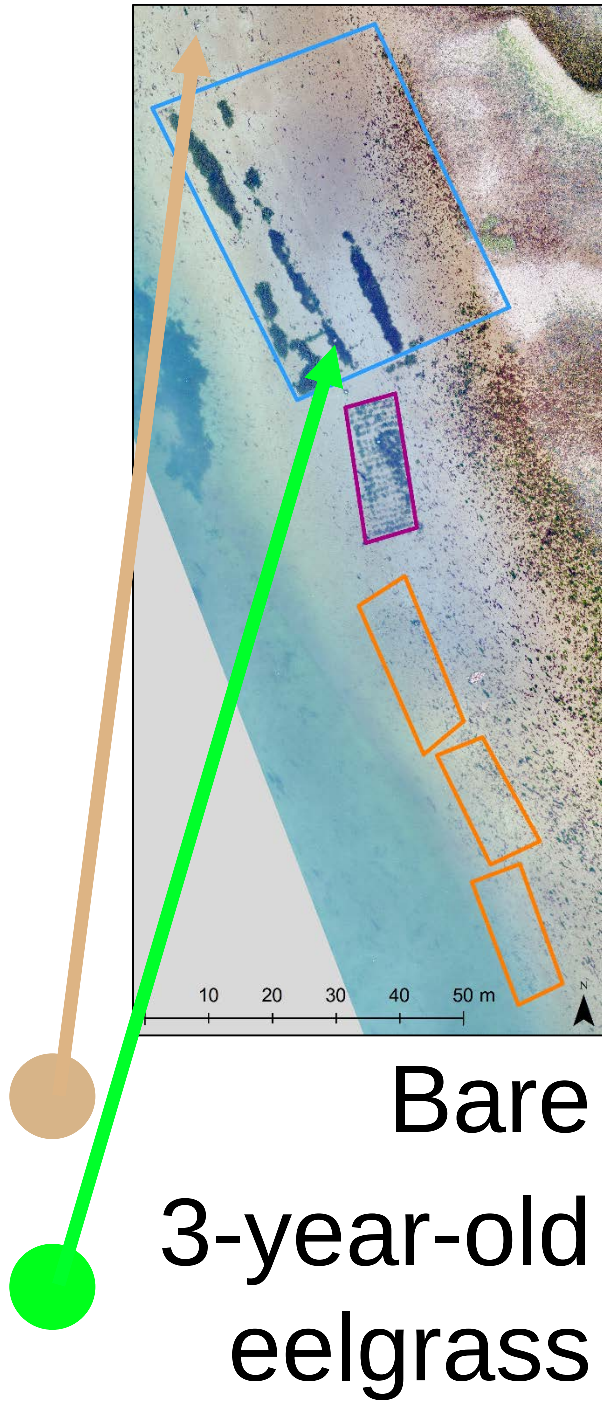
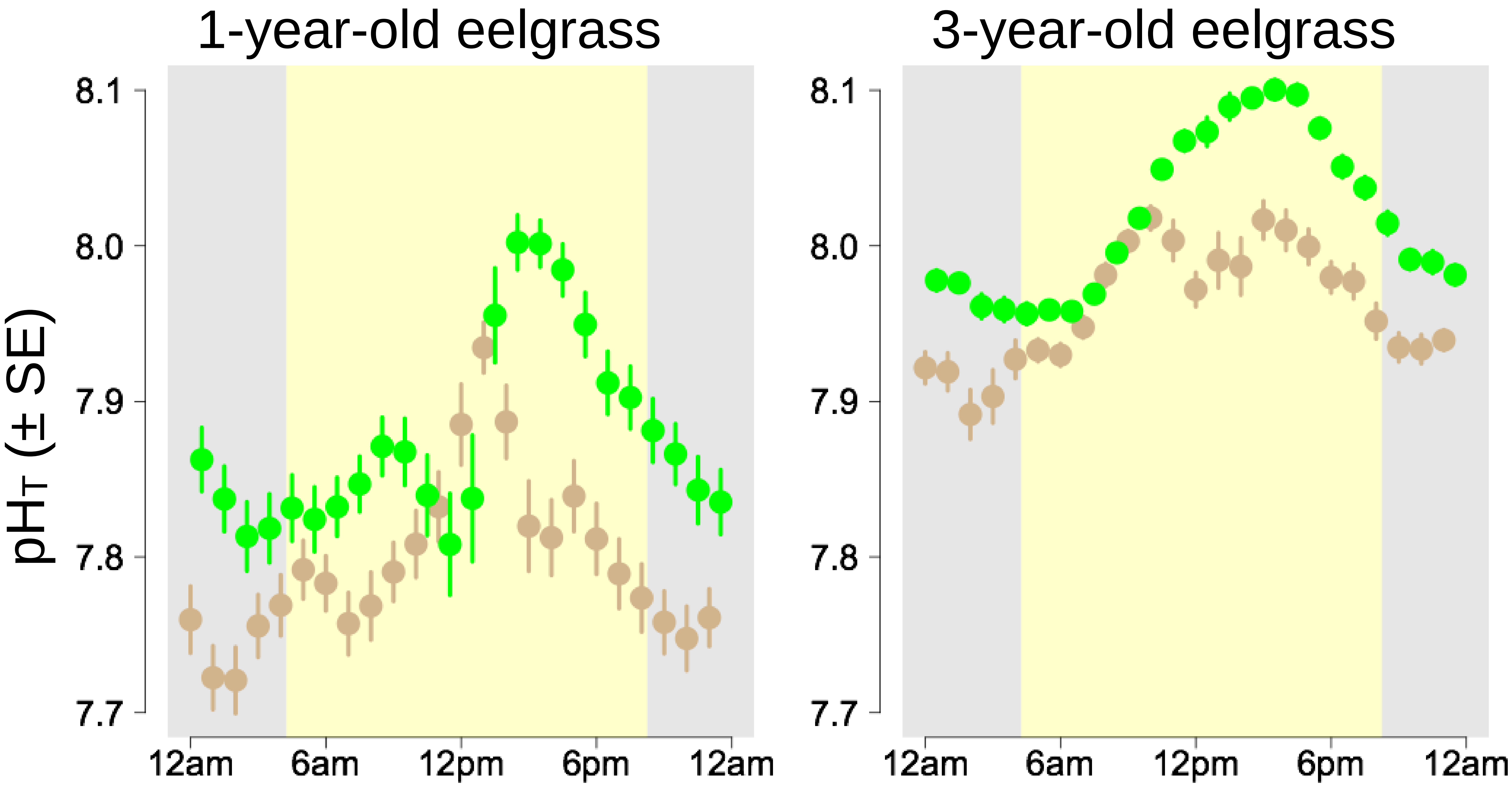
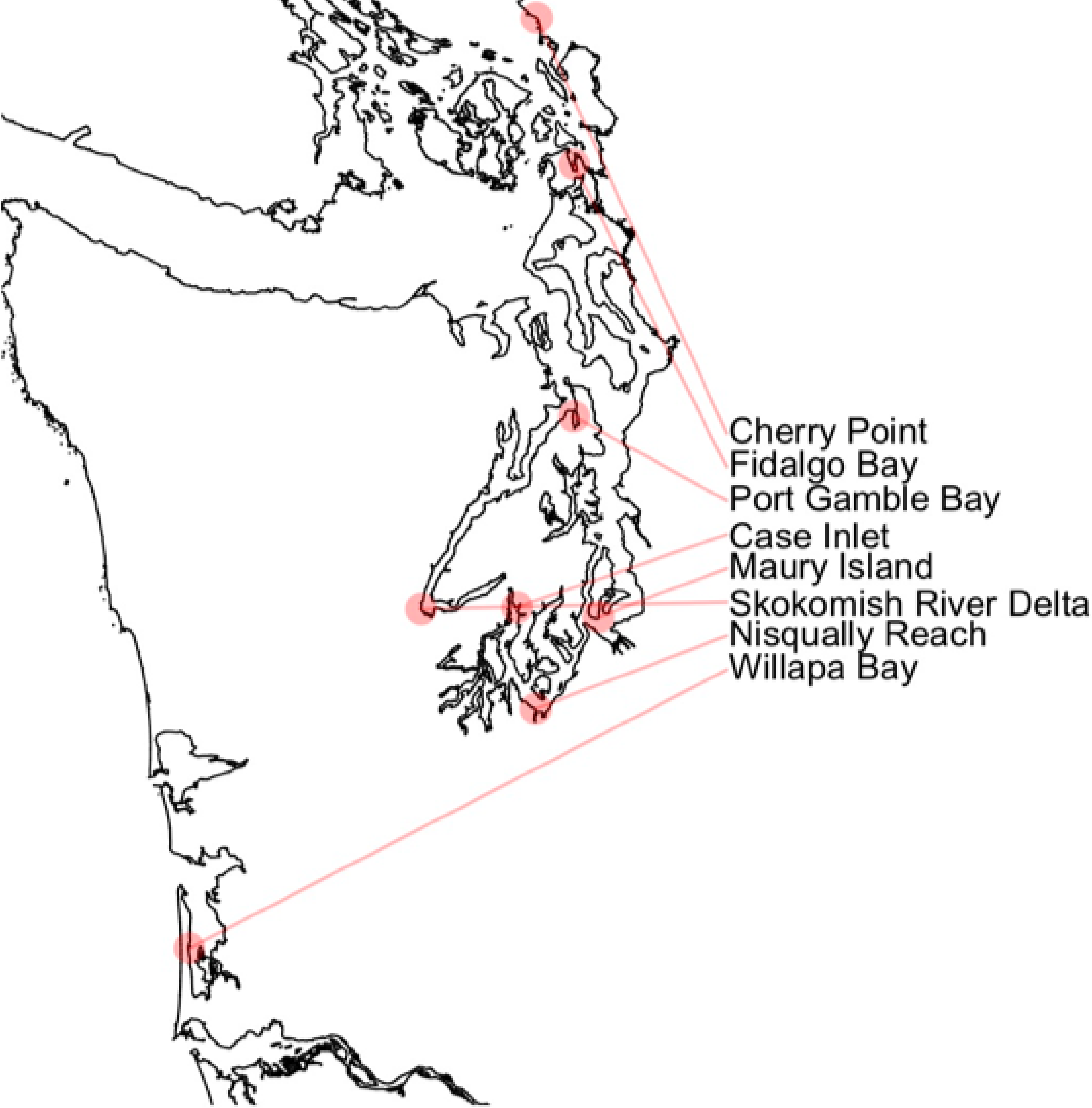




Can eelgrass restoration counteract acidification?



Mature and new eelgrass appear to improve daytime pH.



Acidification **Ne**arshore **Mo**nitoring **Ne**twork - ANeMoNe

ANeMoNe measures acidification and ocean warming, and tests practical solutions.

ANeMoNe Site Guardians participate in research, maintain data quality and assess ecosystem response.

Interested in becoming a Guardian? Contact Micah Horwith micah.horwith@dnr.wa.gov / 206.850.3505

Acknowledgements


(A. Barna 2016)

Nearshore Habitat Program colleagues
Aquatic Assessment and Monitoring Team

Aquatic Restoration Program and Aquatic Reserves Program
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U.S. Fish and Wildlife Service

WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES
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