2023

SeagrassNet Monitoring in the Great Bay Estuary, NH/ME Field Season 2022

Kalle Matso
Piscataqua Region Estuaries Partnership (PREP), UNH

Lara Martin
UNH Jackson Estuarine Laboratory

Trevor Mattera
Piscataqua Region Estuaries Partnership (PREP), UNH

Tom Gregory
UNH Jackson Estuarine Laboratory

David M. Burdick
UNH Jackson Estuarine Laboratory, david.burdick@unh.edu

SeagrassNet Monitoring in the Great Bay Estuary, NH/ME
Field Season 2022

Kalle Matso[1], Lara Martin[2], Amanda Giacchetti[2], Trevor Mattera[1], Tom Gregory,[2] David Burdick[2],

[1] Piscataqua Region Estuaries Partnership (PREP); [2] UNH Jackson Estuarine Laboratory

This report was funded by a grant from the Piscataqua Region Estuaries Partnership, as authorized by the U.S. Environmental Protection Agency pursuant to Section 320 of the Clean Water Act, and in part, by NOAA's Office for Coastal Management under the Coastal Zone Management Act in conjunction with the NH Department of Environmental Services Coastal Program.

Funding was also provided by the NH Department of Environmental Services (DES) as well as the City of Portsmouth, NH.

Introduction

Eelgrass (*Zostera marina* L.) forms a critical habitat in the Great Bay Estuary and is valued not only for the functions it provides but also as an indicator of water quality. A global monitoring protocol called SeagrassNet was started in 2001 by Dr. Fred Short and designed to scientifically detect and document seagrass habitat change (Short et al. 2015). Since Dr. Short's retirement, SeagrassNet (seagrassnet.org) is currently in the process of being transferred to the Smithsonian Institution. Annual monitoring (3-4 times a year) of eelgrass in the Great Bay Estuary using the SeagrassNet protocol was conducted in Portsmouth Harbor between 2001 and 2009 (Short et al. 2006; Rivers and Short 2007). This site was discontinued after eelgrass failed to recover from grazing by Canada Geese in the winter of 2003. SeagrassNet monitoring in Great Bay started in 2007 (Short et al. 2009); that site is referred to as "NH 9.2, Great Bay". In July 2019, a new site was established in Portsmouth Harbor, approximately 1,000 meters from the previous site and designated "NH 9.3, Fort Foster". Results from SeagrassNet 2022, conducted in Great Bay and at Fort Foster, are described in this report.

Sites

The two survey sites were established following the standard SeagrassNet protocol (Short et al. 2015) used worldwide. Details are noted in "Methods" and further details and context can be found in the Quality Assurance Project Plan for the Great Bay Estuary (Matso and Short 2019). For SeagrassNet, a "site" consists of three permanent, parallel, 50 m transects, referred to as A, B, or C. For all SeagrassNet sites, transect A is closest to shore and shallowest; C is furthest from shore and deepest (Figures 1 through 4). See figure captions for water depths at each transect.

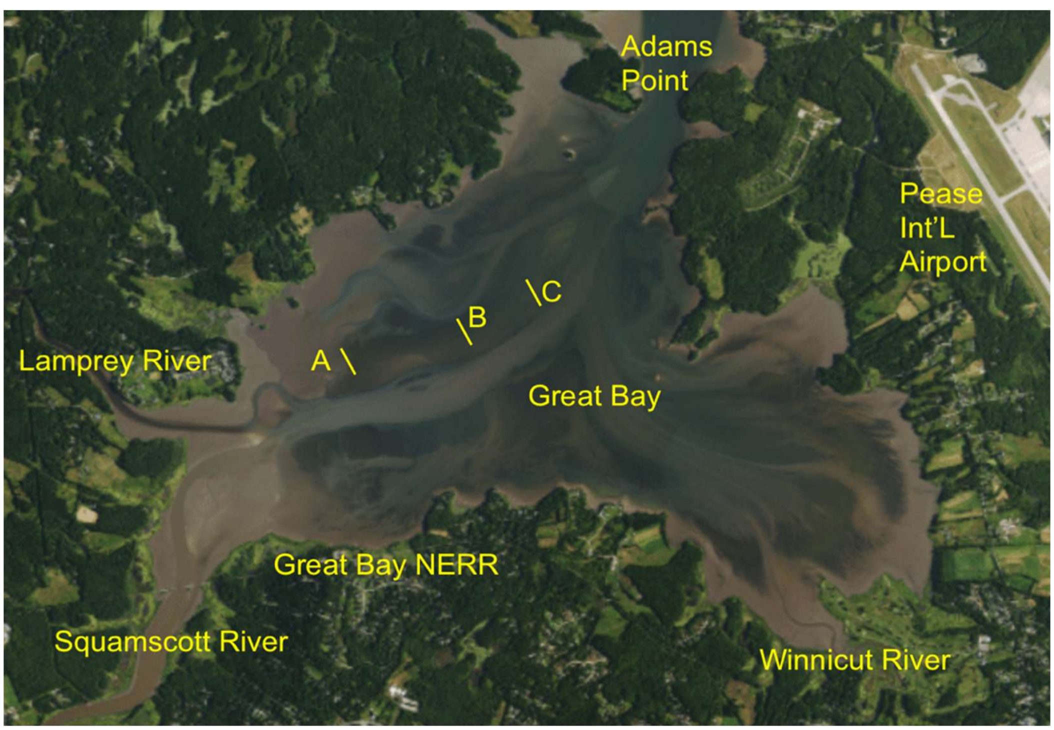


Figure 1. SeagrassNet monitoring site, NH 9.2, with Transects A, B, and C in Great Bay, New Hampshire. Baseline imagery taken in 2019 for eelgrass distribution monitoring and available via NH Coastal Viewer. Lines showing transects are not to scale. Transect depth estimates (Mean Low Lower Water): A = 0 m; B = 0.3 m; C = 0.6 m.

Figure 2. SeagrassNet monitoring transects, using GPS-identified points for each end and the midpoint of permanent Transects A, B, and C in Great Bay, New Hampshire. Baseline imagery taken in 2019 for eelgrass distribution monitoring and available via NH Coastal Viewer. Distances between transect points are not to scale.

Figure 3. SeagrassNet monitoring site, NH 9.3, with Transects A, B, and C in Portsmouth Harbor, NH/ME, at Fort Foster. Baseline imagery taken in 2019 for eelgrass distribution monitoring and available via NH Coastal Viewer. Distances between transect points are not to scale. Transect depth estimates (Mean Low Lower Water): A = 1.2 m; B = 1.8 m; C = 3.7 m.

Figure 4. SeagrassNet monitoring transects, using GPS-identified points for each end and the midpoint of permanent Transects A, B, and C in Portsmouth Harbor, NH/ME, at Fort Foster. Baseline imagery taken in 2019 for eelgrass distribution monitoring and available via NH Coastal Viewer. Distances between transect points are not to scale.

Sampling

In 2022, SeagrassNet sites were sampled once in the summer. Prior to 2020, sampling occurred 3 to 4 times a year. However, PREP's Technical Advisory Committee agreed that the frequency should be reduced from 2020 forward so resources could be allocated to other seagrass monitoring priorities.

Great Bay Transect A was sampled on July 15 by a team that walked into the site which is exposed at low tide. Transects B and C were sampled on SCUBA on July 14 and 15. Fort Foster was sampled on August 2, 3, and 9 on SCUBA.

Quadrats are $0.25m^2$ and placed at specific random locations (Figure 5). SeagrassNet sampling parameters for each quadrat include: photographic record; percent cover of eelgrass; canopy height; biomass (above and below-ground combined); shoot density; and sexual reproduction (number of flowering shoots). Biomass assessments focus on the type of shoots (non-reproductive versus reproductive) that are dominant in the quadrat; this is almost always the non-reproductive shoots. Note that the biomass sampling procedure in the SeagrassNet Manual (Short et al. 2015) advises an alternative method for assessing biomass for "large seagrass species" like eelgrass. Instead of taking a core, the field team collects an individual shoot of similar height to representative plants in the quadrat, including at least 7 cm of rhizome, approximately 0.5 m landward of each quadrat. In the lab, the plant height is measured, and the shoot divided into leaf, sheath, and rhizome sections. The plant is dried for 24 hours at 60º C, and the total dried shoot weight is multiplied by density to obtain biomass. Seaweed percent cover is also assessed for each $0.25m^2$ quadrat.

The position of the quadrats (Figure 5) along each transect was assigned during the development of the SeagrassNet protocol using a random number generator and does not change, providing repeated measure assessment of specific parts of each eelgrass bed over time.

The SeagrassNet protocol includes other parameters that are not quadrat specific, but rather apply to the site or to particular transects at the site; these include temperature, salinity, and light penetration. For light penetration, HOBO sensors (without wipers) from Onset (HOBO Pendant Temperature/Light 8K Data Logger; Model #UA-002-08) were deployed for at least two weeks as part of each sampling event. The sensors for light also measure water temperature. In Great Bay, the sensors were attached to a 0.5 m PVC pipe and placed one meter away from the end of the transects, ideally in an area not shaded by eelgrass. The loggers were about 0.25 m off the bottom. At Fort Foster, the light sensors were attached to the screw anchors marking the end of the transects at a height approximately 0.25 m off the bottom. For both sites, salinity was measured using a YSI EXO2 datasonde placed close to Transect C. In Great Bay, the sonde was attached to a mushroom anchor, 0.5 m off the bottom. At Fort Foster, the sonde was attached to a light array frame, approximately 1.5 m off the bottom.

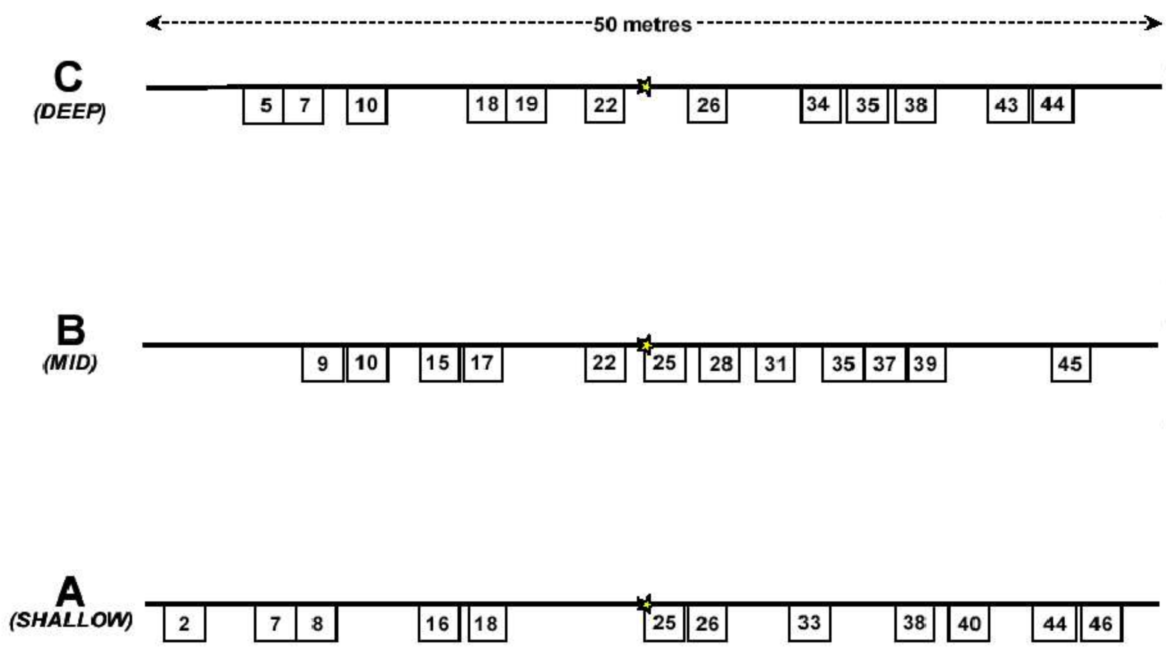


Figure 5. Location of the 12 SeagrassNet quadrats along the three 50 m transects. Each square represents a quadrat. Numbers indicate the meter distance along each transect where the quadrats are positioned for sampling (Distances are not drawn to scale). The stars represent the midpoint of each transect.

For the light analysis, only the data between 10 a.m. and 2 p.m. are analyzed in order to avoid the effects of low sun angle on the light data. Underwater values collected every 10 minutes during the 4-hour period are compared with land-based values to calculate percent light penetration. These values are then used to

produce a daily average. We define ‘Percent in situ surface light’ as the amount of light reaching the plants compared to the amount of light at the water surface. This is calculated by dividing the amount of light reaching the plants underwater by the amount of light at the water surface and multiplying the quotient by 100 to produce a percentage. For the Great Bay transects, the land-based HOBO was located on the roof at Jackson Estuarine Laboratory. For the Fort Foster transects, the land-based HOBO was located on the premises of the UNH Coastal Marine Lab in New Castle, NH.
Complete SeagrassNet protocols for this project are found in the project QAPP (Matso and Short 2019).

Cross-transect Measurements

The SeagrassNet protocol suggests doing cross-transect measurements once each field season. This entails measuring out to the edge of the continuous eelgrass meadow and then to the last plant. In 2022, these measurements were completed on SCUBA on August 25 at Fort Foster (Table 2) and on August 29 at Great Bay (Table 3).

To clarify, “continuous” eelgrass means that the seagrass plants are less than 1 m apart. Eelgrass plants greater than a meter apart are considered outside the continuous seagrass bed, or in other words, sporadic or sparse (F. Short personal communication, Sept 2020). These distances are measured at Transect C (deepest site) and Transect A (shallowest site). A tape is run out perpendicularly from the 0, 25, and 50 meter points on each transect. For Transect C, the distance is measured out towards deeper water and for Transect A, towards the shoreline, typically shallower.

Results

Note that the primary focus of this report is on 2022 results. Inter-year comparisons and more detailed discussions will be featured in other publications, such as future State of Our Estuaries reports. In addition, please note that “Evidence of grazing” was not assessed in 2022, although it is part of the SeagrassNet protocol. Results are reported without determination of significant differences between sites or transects using parametric statistics.

Table 1: Mean values for SeagrassNet parameters; standard deviation in parentheses. The median is given for reproductive shoots because of the skewed distribution of values. Canopy heights for each quadrat are an average of 5 measured plants. These averages were used to calculate the mean values. Great Bay was sampled on July 14 and 15, 2022; Fort Foster was sampled on August 2, 3, and 9, 2022.

	Great Bay Site			Fort Foster Site		
	Transect A	Transect B	Transect C	Transect A	Transect B	Transect C
Biomass (g/m2)	4 (4)	15 (8)	110 (61)	608 (255)	500 (264)	172 (179)
Eelgrass % Cover	16 (19)	40 (16)	88 (13)	96 (7)	87 (18)	47 (40)
Density (shoots/m2)	44 (50)	115 (47)	237 (71)	388 (103)	268 (113)	121 (111)
Canopy Height (cm)	28 (6)	48 (7)	67 (11)	114 (18)	112 (17)	71 (39)
Repro Shoots (#/m2)	8 (11)	0 (2)	0 (11)	48 (26)	14 (17)	0 (5)
Seaweed % Cover	4 (4)	41 (19)	3 (4)	1 (3)	3 (7)	6 (8)

Eelgrass Biomass

Biomass refers to the weight of eelgrass plant tissue per square meter, e.g., grams/m^2. In this case, biomass includes a combined measure of both below-ground and above-ground plant tissue. Biomass is considered very dependent on light and is therefore an important metric (Krause-Jensen et al. 2004).

At the Great Bay site, Transect C had the highest biomass in July with 110 g/m^2. Transects A and B had substantially less biomass, with 4 g/m^2 and 15 g/m^2, respectively (Table 1; Figure 6). At the Fort Foster site, Transect A had the highest biomass in August with 608 g/m^2, followed by Transects B and C with 500 g/m^2 and 172 g/m^2, respectively (Table 1; Figure 7).

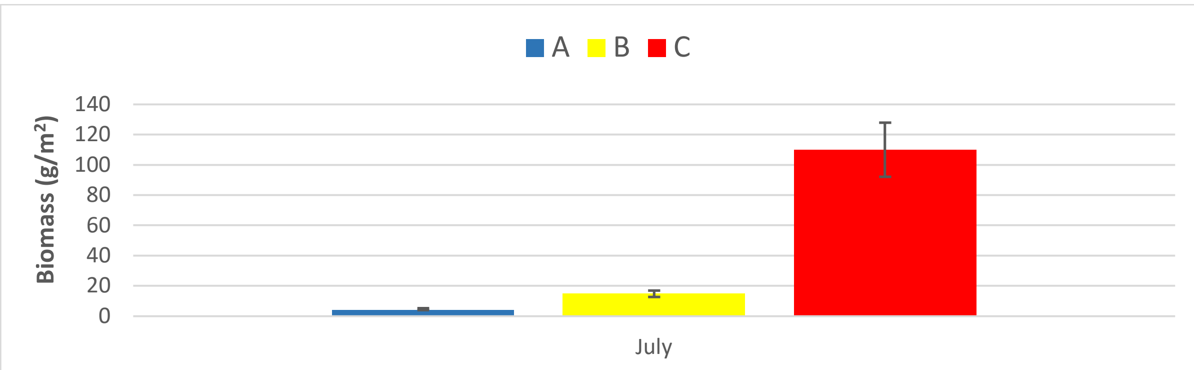


Figure 6. Eelgrass biomass at SeagrassNet site NH9.2 (Great Bay), Transects A, B, and C for 2022. Error bars indicate Standard Error.

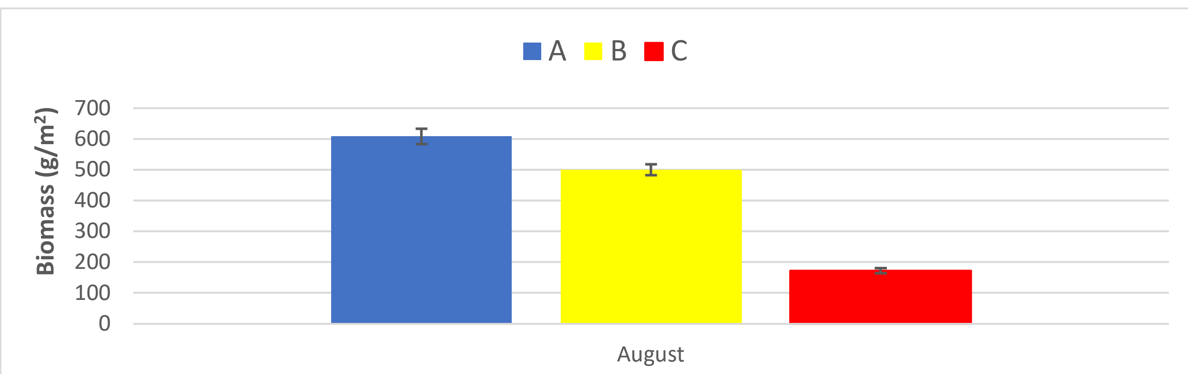


Figure 7. Eelgrass biomass at SeagrassNet site NH9.3 (Fort Foster), Transects A, B, and C for 2022. Error bars indicate Standard Error.

Eelgrass Percent Cover

Percent cover is a visual measure, looking straight down, of how much of the substrata within the quadrat is covered by seagrass on a scale of 0–100%. Each person on the team is trained using a percent cover guide, a standard scientific field technique for vegetation measurements.

At Great Bay, Transect C had the highest percent cover in July with 88%. Transects A and B had 16% and 40%, respectively (Table 1; Figure 8). At the Fort Foster site, Transect A had the highest percent cover in August with 97%, followed by Transects B and C with 87% and 47%, respectively (Table 1; Figure 9).

Eelgrass Shoot Density
Shoot density is the number of shoots in a given space, e.g., square meters. Density is considered more sensitive to changes in light than percent cover, which can also be impacted by leaf length (Krause-Jensen et al. 2004). When using density as an indicator of eelgrass health, it is important to also consider canopy height, since eelgrass can grow more densely but with much shorter shoots, depending on light. In that case, without considering other parameters, one could misinterpret a change in density for a change in overall biomass.

To determine shoot density, the total number of eelgrass shoots within each $0.25m^2$ quadrat was counted. If the eelgrass was very dense, a $0.0625m^2$ quadrat was placed inside the larger quadrat in a location representative of the overall shoot density and shoots within counted instead. To calculate density in square meters, the total number of shoots in each $0.25m^2$ or $0.0625m^2$ quadrat was multiplied by 4 or 16, respectively.

In Great Bay, Transect C had the highest shoot density in July, with a mean shoot density of 237 shoots/m^2. Transect B had a mean shoot density of 115 shoots/m^2, and Transect A had the lowest value, with a mean shoot density of 44 shoots/m^2 (Table 1; Figure 8). At Fort Foster, Transect A had the highest value in August with 388 shoots/m^2, followed by Transect B with 268 shoots/m^2. Transect C had the lowest value, with a mean shoot density of 121 shoots/m^2 (Table 1; Figure 9).

Eelgrass Canopy Height
Canopy height is a useful metric, especially when combined with other indicators (e.g., density and percent cover) to achieve a proxy for biomass. Biomass can be a very time-consuming metric to achieve. If a relationship can be established between biomass and a combination of percent cover, density, and canopy height, one can use a model approach to predicting biomass across the estuary (Neckles et al. 2012).

To determine canopy height, in each $0.25m^2$ quadrat, the heights of five representative plants were measured. Plants were randomly selected from different parts of the quadrat. The plants were held up straight and a folding ruler used to measure height to the nearest centimeter. The mean of these five heights equals canopy height.

In Great Bay, Transect C had the tallest plants in July, with a mean canopy height of 67 cm. For Transect B, mean canopy height was 48 cm, while Transect A had the shortest leaves, with a mean canopy height of 28 cm (Table 1; Figure 8). At Fort Foster, unlike in Great Bay, the shallower transects had longer leaves. In August, Transect A had the tallest plants, with a mean canopy height of 114 cm. Transects B had a similar mean canopy height of 112 cm. Transect C had the lowest value, with a mean canopy height of 71 cm (Table 1; Figure 9).

Eelgrass Flowering
Counting the number of flowering shoots per square meter helps to assess eelgrass sexual reproduction, which can play a critical role in eelgrass resilience, via the plant's response to stress (Jarvis et al. 2014). Below, the median number of reproductive shoots, rather than the mean, are given for each site due to the skewed distribution of the values.

In Great Bay, Transect A had the most reproductive shoots with a median of 8 shoots/m^2, while both Transect B and C had medians of 0 reproductive shoots/m^2 (Table 1; Figure 8). At Fort Foster, Transect A had the highest median reproductive shoots at 48 shoots/m^2. Transect B had a median of 14 reproductive shoots/m^2, and Transect C had the least reproductive shoots, with a median of 0 shoots/m^2 (Table 1; Figure 9).

Figure 8. Eelgrass percent cover, shoot density, canopy height, and number of reproductive shoots at SeagrassNet site NH9.2, Transects A, B, and C in Great Bay for 2022. All values are averages except for number of reproductive shoots, which are medians. Error bars indicate Standard Error of the means.

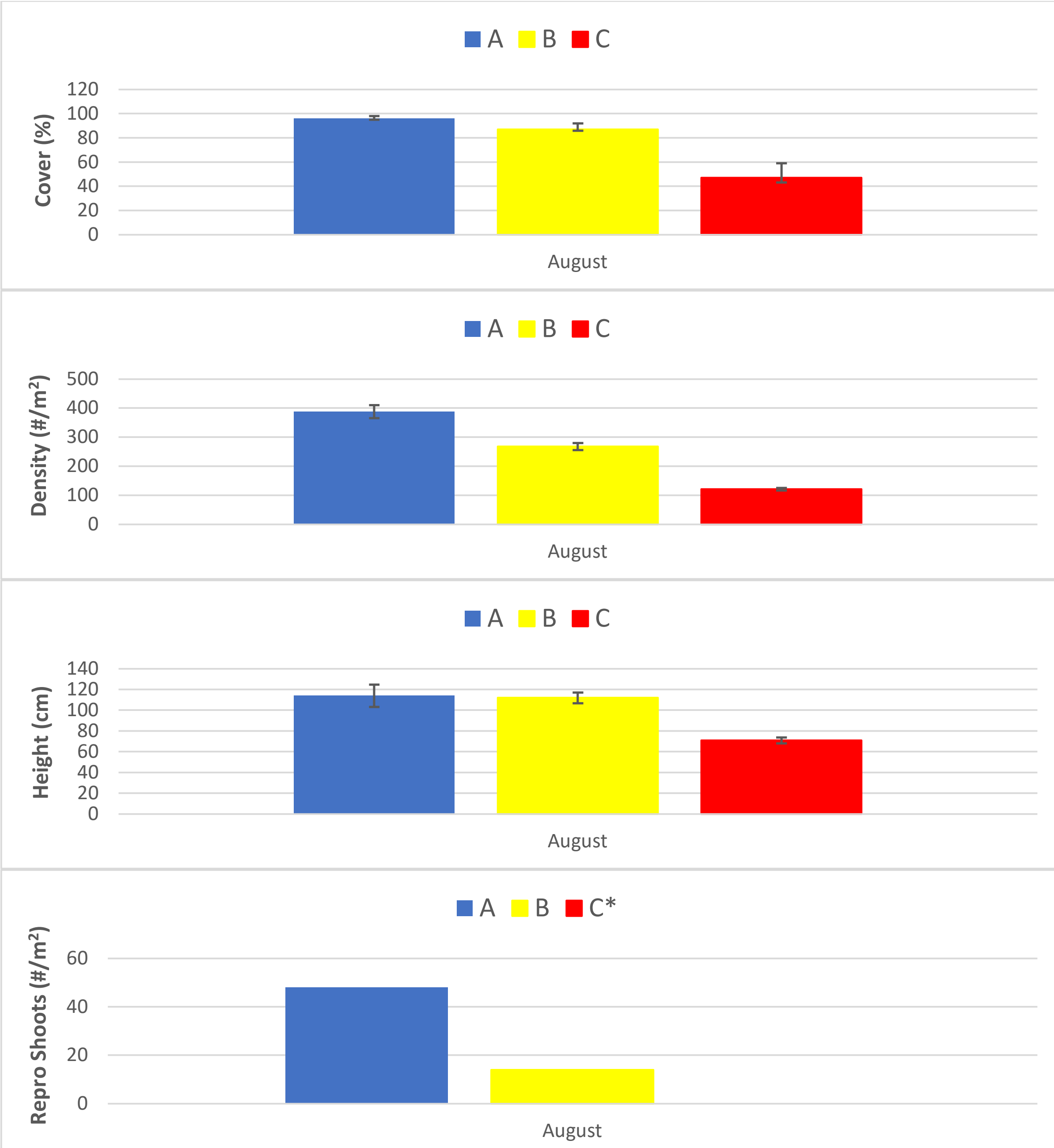


Figure 9. Eelgrass percent cover, shoot density, canopy height, and number of reproductive shoots at SeagrassNet site NH9.3, Transects A, B, and C at Fort Foster for 2022. All values are averages except for number of reproductive shoots, which are medians. Error bars indicate Standard Error of the means.

Percent Cover of Seaweeds

While many factors impact seaweed abundance, it is well established that changes in subtidal seaweed biomass and species composition can be a reflection of eutrophication status and, furthermore, that relatively well-flushed estuaries are more likely to see eelgrass degradation from seaweeds than from plankton (Valiela et al. 1997; van den Heuvel et al. 2019).

In Great Bay, seaweed percent cover was higher at Transect B than at Transects A and C in July 2022. Transect B quadrats had an average of 41% seaweed cover, whereas Transects A and C had 4% and 3% seaweed cover, respectively (Table 1; Figure 10).

At Fort Foster, seaweed percent cover was relatively low in early August 2021. Transect A had 1% mean seaweed cover, Transect B had 3%, and Transect C had 6% (Table 1; Figure 11).

At Fort Foster, the seaweed was predominantly confined to the area near the water-sediment interface and so did not seem to interfere with light for seagrass plants. In contrast, the seaweed in Great Bay was often found higher in the water column where it could potentially interfere with light.

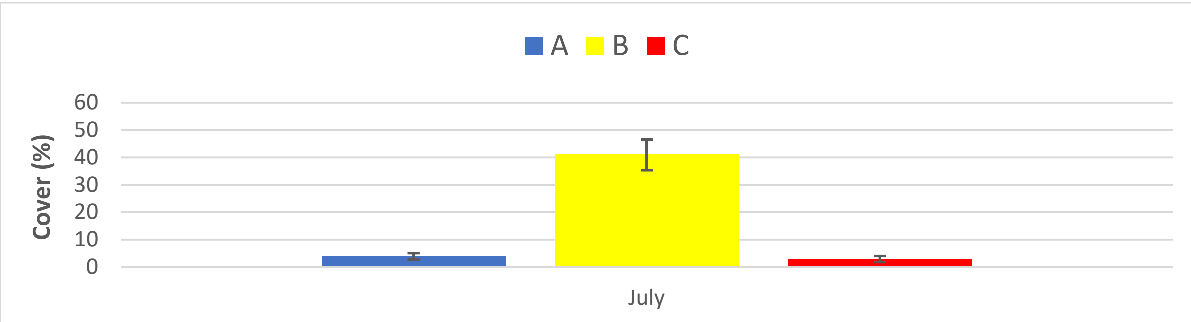


Figure 10. Seaweed percent cover at site NH9.2 (Great Bay), Transects A, B, and C for July 2022. Error bars indicate Standard Error of the means.

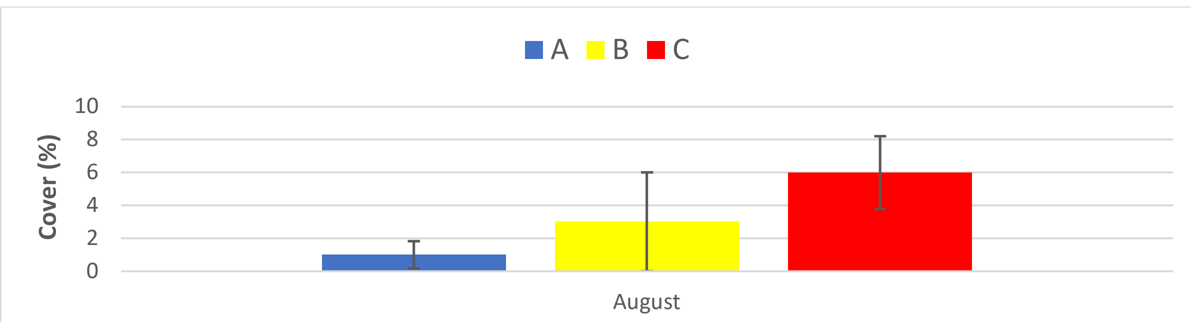


Figure 11. Seaweed percent cover at site NH9.3 (Fort Foster), Transects A, B, and C for August 2022. Error bars indicate Standard Error of the means.

Temperature

Eelgrass can tolerate wide ranges for both temperature and salinity, but studies indicate that optimal levels are narrower. Lee et al. (2007) report an optimal range of 13° to 24° C. Temperatures warmer than 24° C can be associated with factors that degrade eelgrass (Burdick et al. 1993; Kaldy 2014). In the Great Bay, especially at the shallowest transect (A), summer temperatures in excess of 30° C have been observed; temperatures this high can result in eelgrass mortality due to increased metabolic demands, which in turn requires higher water clarity to maintain carbon balance and growth.

In Great Bay, between 7/15/2022 and 8/25/2022, temperatures at Transects A and C ranged from 19° to 28° C (Figure 12). Temperature data were collected at Transect A for only a week. As this is the shallowest transect where plants are frequently exposed at low tide, it typically displays higher temperatures and greater extremes than Transect C. At Transect C, temperatures rose above 25° C on sixteen days in late July and early August, with a maximum temperature of 27° C.

At Fort Foster, between 7/1/2022 and 8/25/2022, temperatures at Transects A and C ranged from 10° C to just over 21° C (Figure 13). In general, the temperature difference between the transects, which are much closer together than the Great Bay transects, was usually less than 4º C. Transect C is 2-3 meters deeper than Transect A, and is located close to a high-current, deep water channel. Therefore, it can show greater temperature variability within tidal cycles and lower temperatures overall.

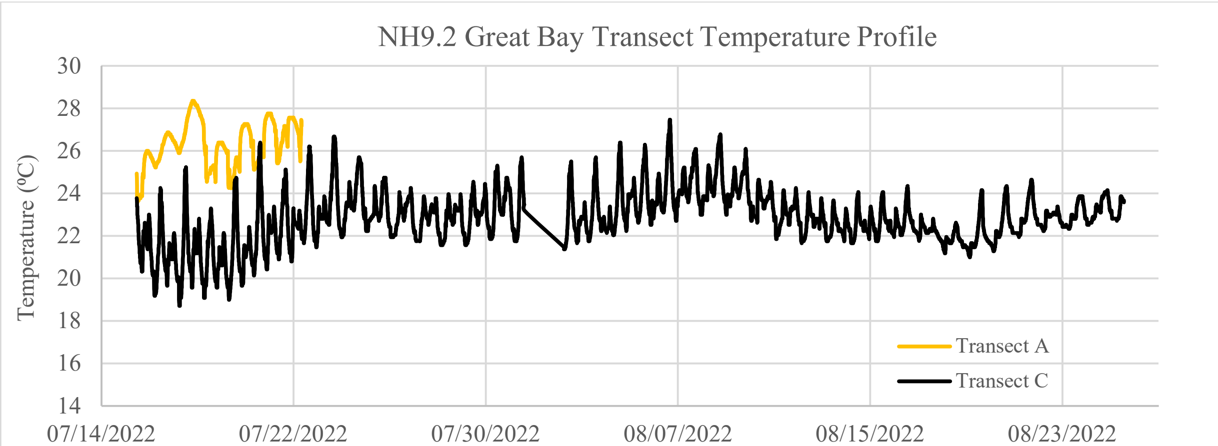


Figure 12. Temperature data collected by HOBO sensors (every 10 minutes) at Transects A and C at site NH9.2 (Great Bay): Transect A 7/15 – 7/22/2022, Transect C 7/15 – 8/25/2022. Note the vertical axis starts at 14° C.

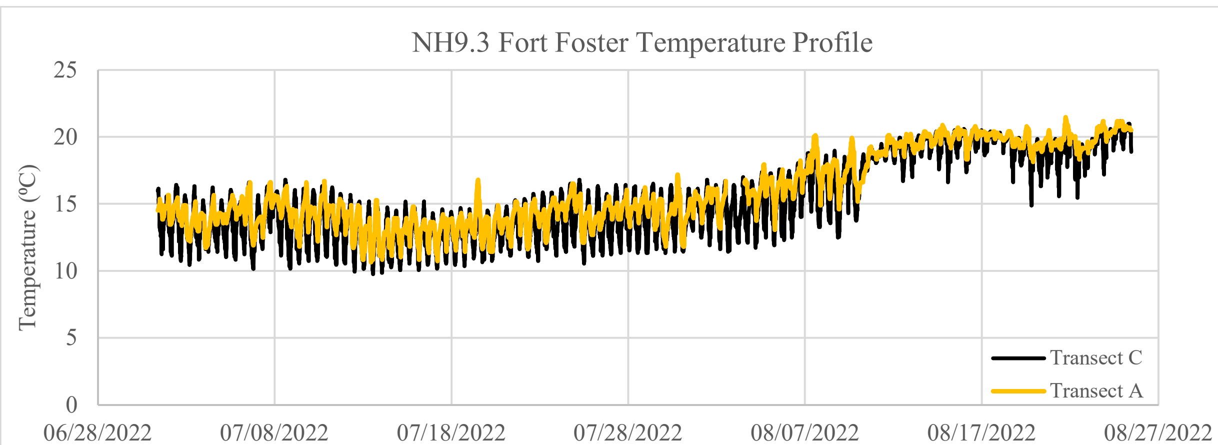


Figure 13. Temperature data collected by HOBO sensors (every 10 minutes) at Transects A and C at site NH9.3 (Fort Foster), 7/1/2022 – 8/25/2022.

Salinity

Eelgrass can tolerate virtually all salinities from 0 to 35 ppt for limited times. In general, however, higher salinity is beneficial to eelgrass, with salinities below 15 ppt negatively affecting eelgrass health indicators (Nejrup and Pederson 2008). However, if eelgrass is experiencing a wasting disease epidemic, salinity excursions below 12 ppt can halt the progression of the disease (Burdick et al. 1993).

In Great Bay, salinity can be highly variable. It is impacted by water depth and proximity to the mouths of the three rivers that feed the Bay, as well as the main channel (Figures 1 and 2). Salinity data were collected at Great Bay Transect C. Data were collected from the beginning of July to early October (Figure 14). The data show that salinity began the period around 29 ppt, and then slowly increased throughout August, maxing out at 31.4 ppt. In early September, there was a dip, and the period ended with salinity averaging around 29 ppt.

At Fort Foster, salinity is higher with less variation relative to Great Bay since this site is adjacent to the Atlantic Ocean (Figures 3 and 4). The salinity at Fort Foster is also much less susceptible to declines caused by precipitation and watershed inputs from freshwater tributaries. Salinity data were collected at Fort Foster Transect C from the beginning of July to the beginning of October (Figure 15). The data show salinity averaging 31-32 ppt July through September. The salinity range begins to increase in late-September, showing more variability during tidal cycles.

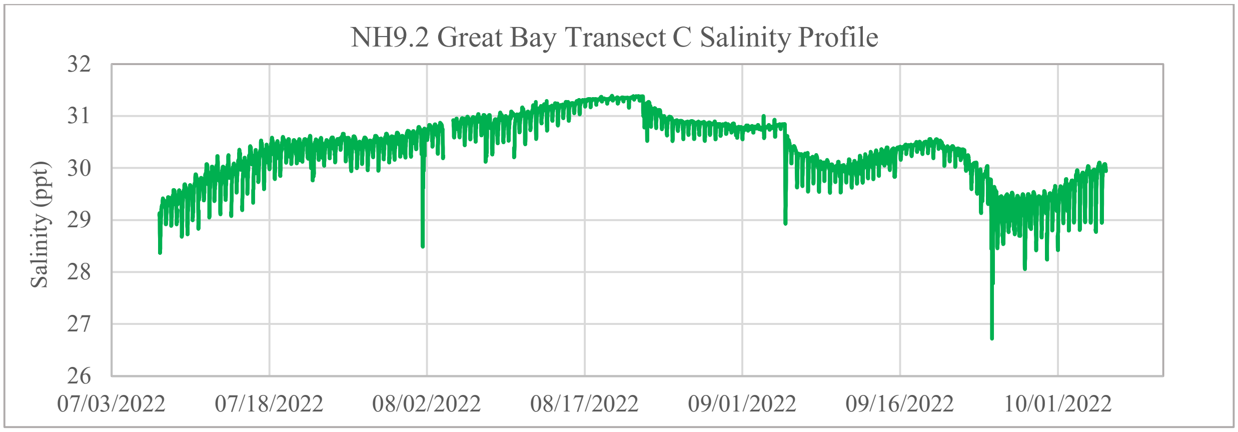


Figure 14. Salinity data collected every 15 minutes by a YSI EXO2 datalogger at Transect C, site NH9.2 (Great Bay), 7/7/2022 – 10/4/2022. Note the vertical axis starts at 26 ppt.

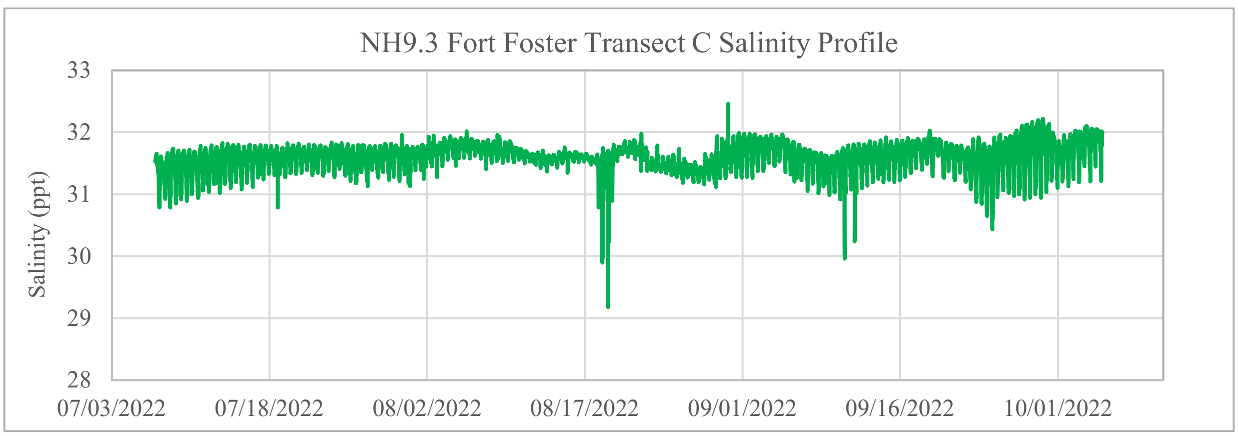


Figure 15. Salinity data collected every 15 minutes by a YSI EXO2 datalogger at Transect C, site NH9.3 (Fort Foster), 7/7/2022 – 10/4/2022. Note the vertical axis starts at 28 ppt.

Light

Seagrasses require more light than other marine primary producers because of their need to support growth and respiration of below-ground structures (roots and rhizomes), which exist in an environment of low (if any) oxygen levels (Lefcheck et al. 2017). Therefore, light availability is often but not always the most important factor governing eelgrass growth rates (Ochieng et al. 2010). Previously, 11% in situ Surface Irradiation (SI) — the amount of light reaching the plants compared to the amount of light at the surface — was noted as the minimum threshold for eelgrass survival; however, subsequent research (e.g., Short et al. 1995; Ocheing et al. 2010) indicate that long-term eelgrass health can be negatively impacted when SI levels are consistently below 34%. Kenworthy et al. (2014) note that light requirements at Massachusetts study areas varied from 9.5% to 29.7%, with the central tendency between 15% and 22%. Moreover, the Massachusetts study agreed with previous research indicating that light requirements tend to increase in areas with poorer water clarity and higher levels of organic matter.

Here, we focus on light results for the July/August timeframe. For Great Bay, we assess only Transect C, because Transects A and B are frequently in very little water, which can skew the light data collected by the HOBO loggers. In Great Bay, Transect C, the highest mean percent light values were generally between 25% and 30% (Figure 16). As expected, higher light values occurred on those days when the tide heights were lowest; lower tides result in less difference between the surface versus underwater light levels at a fixed height above the sediment surface because there is less water to absorb the sunlight.

At Fort Foster, percent light levels were lower overall than in Great Bay, most likely due to the plants growing in much deeper water (See Discussion below). The highest mean level at Transect A was 10% (Figure 17), whereas at Transect C, the highest mean level was 5% (Figure 18). Transect A had the highest percent light values at Fort Foster, which is expected since it is in shallower water. Note that the differences in percent light values between A and C most likely reflect differences in water depth (Figures 17 and 18).

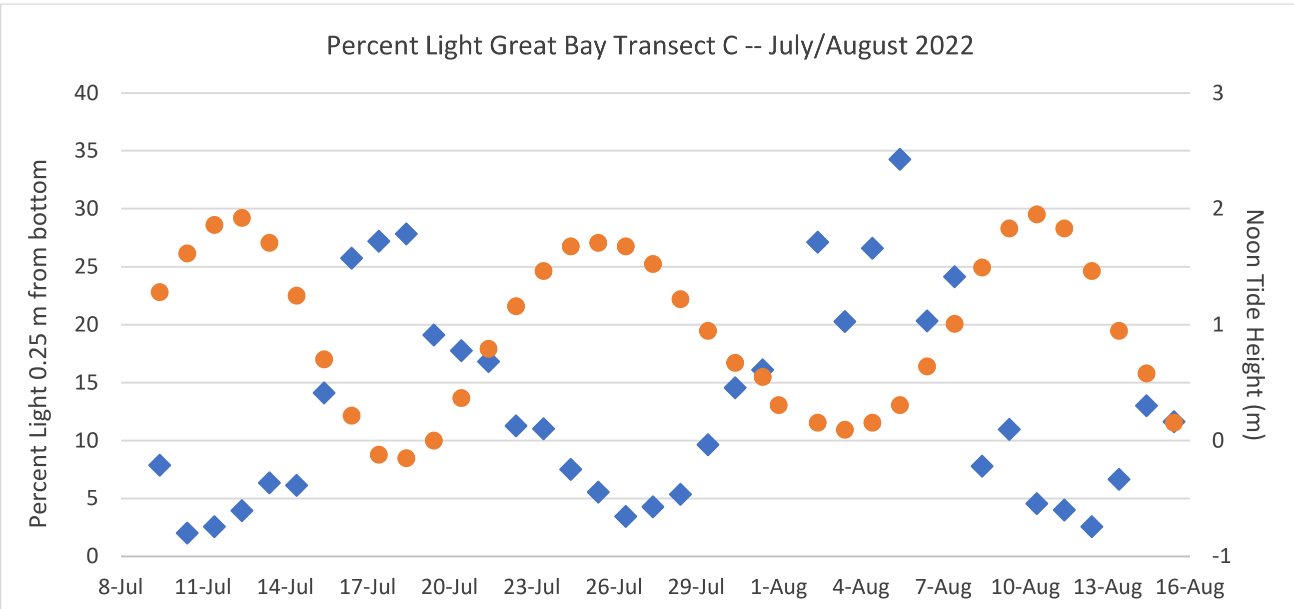


Figure 16. Mean values (blue diamonds) of percent light at 0.25 m from the bottom at Transect C, site NH9.2 (Great Bay), 7/09/2022 – 8/15/2022. Percent light data not recorded on 8/01/22. Values represent means from data collected by HOBO sensors every 10 minutes, between 10 a.m. and 2 p.m. Tide height at noon in meters (orange circles) is plotted on the secondary axis.

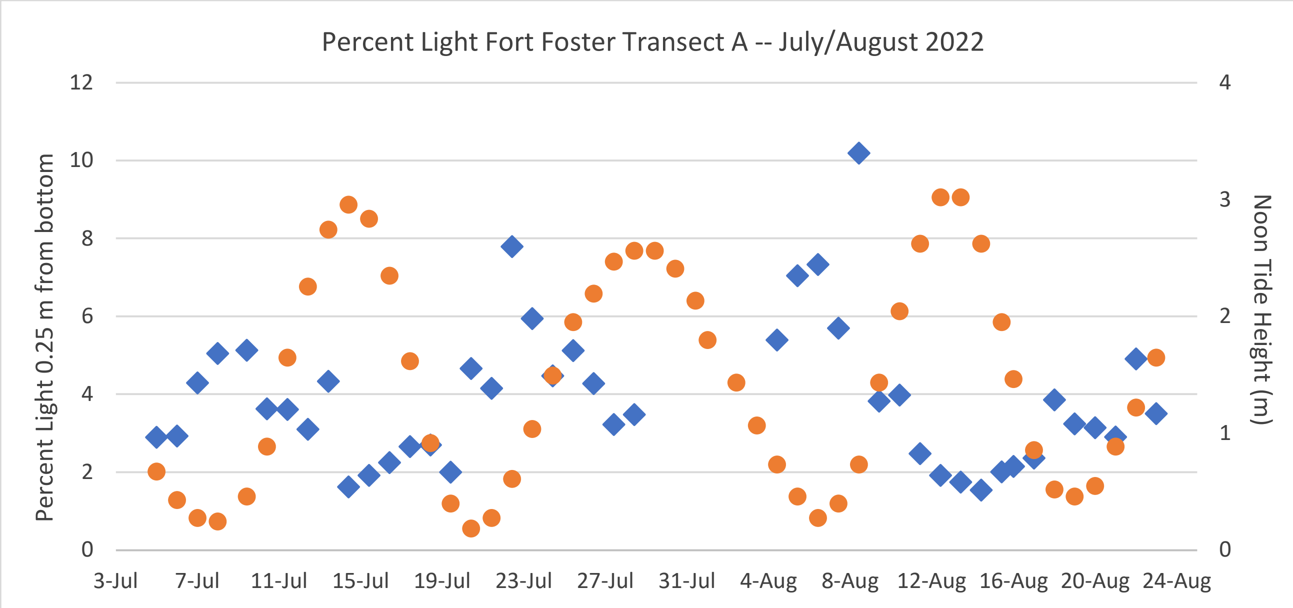


Figure 17. Mean values (blue diamonds) of percent light at 0.25 m from the bottom at Transect A, site NH9.3 (Fort Foster), 7/5/2022 – 8/23/2022. Percent light data not recorded 7/29/22 – 8/03/22. Values represent means from data collected by HOBO sensors every 10 minutes, between 10 a.m. and 2 p.m. Tide height at noon in meters (orange circles) is plotted on the secondary axis.

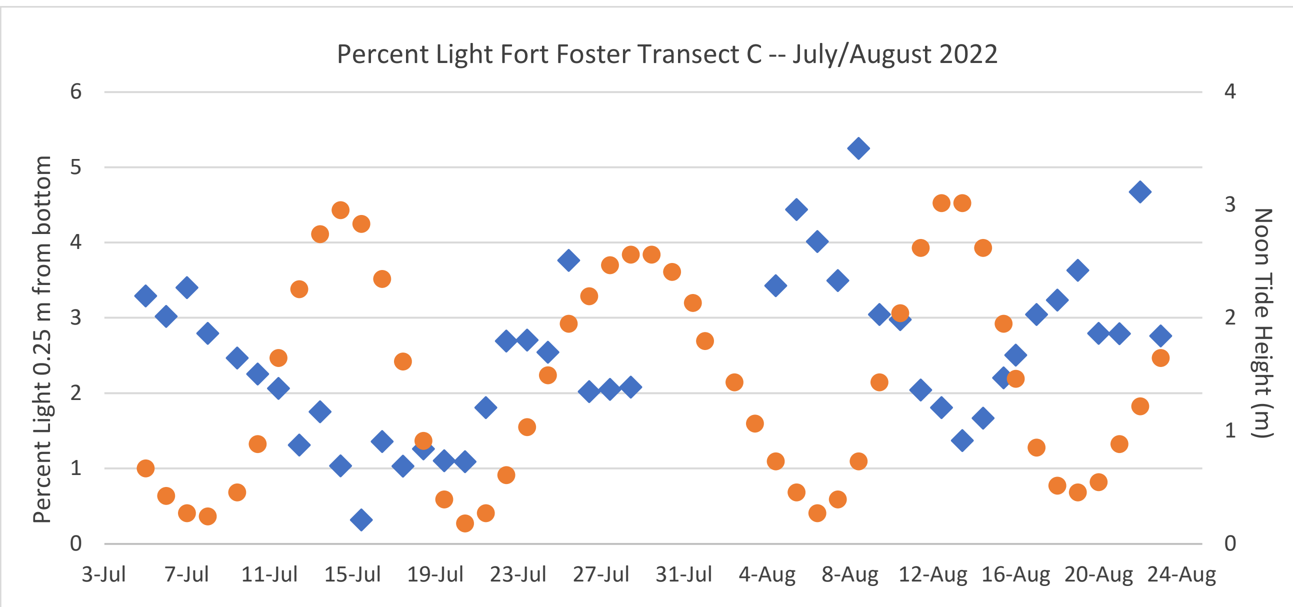


Figure 18. Mean values (blue diamonds) of percent light at 0.25 m from the bottom at Transect C, site NH9.3 (Fort Foster), 7/5/2022 – 8/23/2022. Percent light data not recorded 7/29/22 – 8/03/22. Values represent means from data collected by HOBO sensors every 10 minutes, between 10 a.m. and 2 p.m. Tide height at noon in meters (orange circles) is plotted on the secondary axis.

Cross-transect Measurements

Cross-transect measurements as described in the SeagrassNet protocol are difficult to establish in Great Bay due to the nature of the eelgrass beds where the transects are located. At Transect A, the eelgrass can be very sporadic when it is present and does not provide a consistent, continuous bed from which to make these measurements. Therefore, measurements from this transect were not completed. At Transect C, the transect line lies too far from the deep edge of the bed to make an accurate measurement. As a result, on September 15, 2021, an alternative 50 m transect with new benchmarks was established outside of the

Transect C eelgrass bed, running approximately parallel to the deep edge to allow for accurate measurements of deep edge movement (Table 2). Measurements are now made from the 0, 25, and 50 m points on the new transect towards, rather than away from, the existing bed. Therefore, if eelgrass is found growing on the other side of the transect, the deeper side, it is noted as a negative number. Similarly, decreasing "edge of continuous bed" values indicate bed expansion. At Fort Foster, increasing "edge of continuous bed" values indicate bed expansion. Note that unlike Fort Foster, the edge of the continuous bed at Great Bay Transect C can be quite abrupt, and therefore, can be equal to the measurement to the last shoot.

Table 2: Distances measured from each transect point to the edge of the continuous bed and then to the last eelgrass shoot at NH9.3 Fort Foster.

Transect Point	2020		2021		2022	
	Edge of Continuous Bed (m)	Last Shoot (m)	Edge of Continuous Bed (m)	Last Shoot (m)	Edge of Continuous Bed (m)	Last Shoot (m)
A00	29.1	35.3	36.5	50	19.0	51.0
A25	28.3	30.5	30.5	48	20.7	44.4
A50	21.8	32.6	25.5	50	7.5	45.4
C00	21.1	26.1	21.4	29.9	19.5	45.0
C25	10.1	18.1	10.8	17.5	9.6	14.0
C50	0.7	42.3	9	14.5	0.0	17.1

Table 3: Distances measured from newly established alternate transect points to the edge of the continuous bed and then to the last eelgrass shoot at NH9.2 Great Bay.

Transect Point	2021		2022	
	Edge of Continuous Bed (m)	Last Shoot (m)	Edge of Continuous Bed (m)	Last Shoot (m)
C00	0.7	0.7	0.5	-3.0
C25	17.2	17.2	19.6	19.6
C50	23.3	23.3	20.4	20.4

Discussion

In 2022, for the areas where the SeagrassNet sites are located (west portion of Great Bay and the Maine side of Portsmouth Harbor), eelgrass abundance remains lower than levels from the 1980s for Great Bay but higher for Portsmouth Harbor. Short et al. (1993) report 1987-88 biomass levels in Great Bay (near Transect C) of 263 g/m^2. In 2022, in contrast, peak biomass levels in Great Bay were 110 g/m^2. Similarly, in 1988, eelgrass density in Great Bay near Transect C was 427 shoots/m^2 (Short et al. 1993) compared with approximately 237 shoots/m^2 in 2022. The same 1993 report notes biomass levels at Fishing Island in Portsmouth Harbor (near the Fort Foster SeagrassNet site) of 506 g/m^2 supported by a shoot density averaging over 800 shoots/m^2. In 2022, peak biomass levels at Fort Foster surpassed those levels; Transect A had the highest biomass (608 g/m^2) with a density of 388 shoots/m^2. Whereas the temporal comparisons for the sites in Great Bay are justified by the consistency of the meadows there, the Fishing Island site was largely intertidal, with minimal self-shading to allow for very high biomass and shoot density compared to the subtidal meadow at Fort Foster, so these two sites cannot be compared.

Results from SeagrassNet in 2022 show contrasting conditions, both between the two sites (Great Bay and Fort Foster) overall, as well as between the Great Bay transects. The difference in conditions at the three Great Bay transects are much greater than at the Fort Foster transects, which are much closer together and are more similar in terms of depth profile. It is important to note that Great Bay's Transect A is completely exposed at low tide, making the eelgrass there very susceptible to wind and wave effects as well as impacts from ice, warm water, and desiccation, both in the summer and winter. Overall, these results emphasize the more stressful conditions affecting the Great Bay eelgrass, which experiences greater fluctuations in light, temperature, and salinity than the eelgrass at Fort Foster. Also, results show that summer water temperatures in Great Bay are frequently above 25°C, even at the deepest transect. In contrast, conditions at Fort Foster during the sampling period remained well below 25°.

In looking at light data, consider that studies indicate a threshold at between 15 and 22% light, below which the plant becomes less healthy (e.g., Kenworthy et al. 2014). According to data for Transect C at Great Bay over the sampled 38-day period, eelgrass plants experienced conditions below the 15-22% range at any time the tide was higher than mid-tide levels. This indicates that eelgrass in the Great Bay may be experiencing low-light levels whenever the tide is high enough to prevent the eelgrass blades from lying on the surface of the water.

In the deeper waters at Fort Foster, where the influence of the tides is less dramatic, eelgrass experienced no light levels of over 12% at Transect A and none over 6% at Transect C. This may seem surprising given the clearer water in Portsmouth Harbor. Several points are important in interpreting these data. First, the metric being discussed is percent light, not light attenuation (K_d). Light attenuation tends to increase as one moves upriver, so Great Bay would have more light attenuation than Portsmouth Harbor. Percent light, on the other hand, represents the proportion of light that makes it to the eelgrass beds relative to a surface light meter. Therefore, the depth of the eelgrass may have a significant impact, and the Fort Foster eelgrass beds are in much deeper water than the Great Bay eelgrass meadows. For example, at low tide at Transect C in Great Bay, the water depth can be as low as 1.5 ft. At Fort Foster's Transect C, the shallowest water depth is close to 12 ft. Despite lower levels of light reaching eelgrass at Fort Foster, the beds have comparable or greater biomass than the meadows in Great Bay, where the percent light reaching plants is much greater. These results are in agreement with previous work showing that high temperatures can impact carbon balance and biomass (as observed in Great Bay) as well as the conclusions from Kenworthy et al. (2014) that eelgrass growing in coarser sediment with less organic content (as observed at Fort Foster eelgrass beds) will have lower light requirements.

References

Burdick, D.M., Short, F.T., and Wolf J. 1993. An index to assess and monitor the progression of wasting disease in eelgrass Zostera marina. *Marine Ecology Progress Series*, Vol. 94, No. 1 (March 31 1993), pp. 83-90.

Jarvis, J.A., Brush, M.J., and Moore, K.A. 2014. Modeling loss and recovery of Zostera marina beds in the Chesapeake Bay: The role of seedlings and seed-bank viability. Aquatic Botany. 113: 32-45.

Kaldy, J. 2014. Effect of temperature and nutrient manipulations on eelgrass Zostera marina L. from the Pacific Northwest, USA. *Journal of Experimental Marine Biology and Ecology*. Volume 453, April 2014, Pages 108-115.

Kenworthy, W.J., Gallegos, C.L., Costello, C., Field, D., and Di Carlo, G. 2014. Dependence of eelgrass (*Zostera marina*) light requirements on sediment organic matter in Massachusetts coastal bays: Implications for remediation and restoration. *Mar. Pollution Bulletin* 459:126-136.

Krause-Jensen D., Queresma, A.L., Cunha A.H., and Greve, T.M. 2004. How are seagrass distribution and abundance monitored? In, “European seagrasses: an introduction to monitoring and management,” eds. Borum, Duarte, Krause-Jensen, and Greve. A publication by the EU project Monitoring and Managing of European Seagrasses (M&MS) EVK3-CT-2000-00044.

Lee, K.S., Park, S.R., Kim, Y.K. 2007. Effects of irradiance, temperature, and nutrients on growth dynamics of seagrasses: a review. *Journal of Experimental Marine Biology and Ecology*, 350(1-2): 144-175.

Lefcheck, J.S., Wilcox, D.J., Murphy, R.R., Marion, S.R., and Orth, R.J. 2017. Multiple stressors threaten the imperiled coastal foundation species eelgrass (Zostera marina) in Chesapeake Bay, USA. *Glob Change Biol*, 23: 3474–3483. doi:10.1111/gcb.13623.

Matso, K.M. and Short, F.T. 2019. SeagrassNet Monitoring Program 2019 - 2023: Quality Assurance Project Plan" (2019). *PREP Reports & Publications*. 420. https://scholars.unh.edu/prep/420

Neckles, H.A., Kopp, B.S., Peterson, B.J., and Pooler, P.S. 2012. Integrating scales of seagrass monitoring to meet conservation needs. *Estuaries and Coasts*. Vol. 35, No. 1, pp. 23-46

Nejrup, L.B. and Pedersen M.F. 2008. Effects of salinity and water temperature on the ecological performance of Zostera marina. *Aquatic Botany*. 88 239-246.

Ochieng, C.A., Short, F.T., and Walker, D.I. 2010. Photosynthetic and morphological responses of eelgrass (*Zostera marina* L.) to a gradient of light conditions. Journal of Experimental Marine Biology and Ecology 382: 117–124.

Rivers, D.O. and Short, F.T. 2007. Impact of grazing by Canada geese (*Branta canadensis*) on an eelgrass (*Zostera marina* L.) meadow, New Hampshire, USA. *Marine Ecology Progress Series* 333:271–279.

Short, F.T., Burdick, D.M., Wolf, J.S., and Jones, G.E. 1993. Eelgrass in Estuarine Research Reserves Along the East Coast, USA. *PREP Reports & Publications*. 393. http://scholars.unh.edu/prep/393

Short, F.T, Burdick, D.M., and Kaldy, J.E. 1995. Mesocosm experiments quantify the effects of eutrophication on eelgrass, Zostera marina. *Limnology and Oceanography.* 40(4), 740 – 749.

Short, F.T., Koch, E., Creed, J.C., Magalhaes, K.M., Fernandez, E., and Gaeckle, J.L. 2006. SeagrassNet monitoring across the Americas: case studies of seagrass decline. *Marine Ecology* 27:277-289.

Short, F.T., Moore, G.E., and Mills, K. 2009. Biological Monitoring of Seagrass in Great Bay Estuary, New Hampshire, USA. Report to Great Bay National Estuarine Research Reserve, Durham, NH.

Short, F., Coles, R., Fortes, M., Victor, S., Salik, M., Isnain, I., Andrew, J., and Seno A. 2014. Monitoring in the Western Pacific Region shows evidence of seagrass decline in line with global trends. *Marine Pollution Bulletin* 83: 408–416.

Short, F.T., Coles, R.G., Short, C.A. 2015. SeagrassNet Manual for Scientific Monitoring of Seagrass Habitat, Worldwide edition. University of New Hampshire Publication. 73 pp. https://scholars.unh.edu/prep/445/

Short, F.T. 2017. SeagrassNet Monitoring in Great Bay, New Hampshire, 2015. *PREP Reports & Publications*. 365. https://scholars.unh.edu/prep/365

Valiela I., McClelland J., Hauxwell J., Behr P.J., Hersh D., and Foreman K. 1997. Macroalgal Blooms in Shallow Estuaries: Controls and Ecophysiological and Ecosystem Consequences. *Limnology and Oceanography*, Vol. 42, No. 5, Part 2: The Ecology and Oceanography of Harmful Algal Blooms (Jul., 1997), pp. 1105-1118.

Van den Heuvel, M.R., Hitchcock, J.K., Coffin, M.R.S., Pater, C.C., Courtenay, S.C. 2019. Inorganic nitrogen has a dominant impact on estuarine eelgrass distribution in the Southern Gulf of St. Lawrence, Canada. *Limnology and Oceanography*. doi: 10.1002/lno.11185.

Appendix 1

Eelgrass data for biomass, percent cover, shoot density, canopy height, and reproductive shoots and percent cover seaweed at SeagrassNet site NH9.2 (Great Bay), Transects A, B, and C in July 2022.

Location	Transect	Quad #	Date	Biomass (g/m^2)	Eelgrass % Cover	Algae % Cover	Shoot Density ($\#/m^2$)	Canopy Height (cm)	Repro Shoot ($\#/m^2$)
NH9.2 Great Bay	A	1	7/15/2022	0	0	0	0	NA	0
NH9.2 Great Bay	A	2	7/15/2022	7	20	1	60	35	24
NH9.2 Great Bay	A	3	7/15/2022	0	0	1	4	40	0
NH9.2 Great Bay	A	4	7/15/2022	4	20	5	72	27	12
NH9.2 Great Bay	A	5	7/15/2022	5	20	5	52	24	20
NH9.2 Great Bay	A	6	7/15/2022	2	10	1	24	25	4
NH9.2 Great Bay	A	7	7/15/2022	0	0	0	0	NA	0
NH9.2 Great Bay	A	8	7/15/2022	13	70	15	176	28	32
NH9.2 Great Bay	A	9	7/15/2022	8	25	3	76	19	20
NH9.2 Great Bay	A	10	7/15/2022	0	0	3	0	NA	0
NH9.2 Great Bay	A	11	7/15/2022	2	15	5	28	27	8
NH9.2 Great Bay	A	12	7/15/2022	8	10	5	32	24	8
NH9.2 Great Bay	B	1	7/14/2021	3	25	25	28	50	0
NH9.2 Great Bay	B	2	7/14/2021	11	30	60	96	42	0
NH9.2 Great Bay	B	3	7/14/2021	16	40	60	128	51	4
NH9.2 Great Bay	B	4	7/14/2021	11	40	20	68	41	0
NH9.2 Great Bay	B	5	7/14/2021	19	70	30	128	58	4
NH9.2 Great Bay	B	6	7/14/2021	27	40	60	176	49	0
NH9.2 Great Bay	B	7	7/14/2021	7	25	10	56	40	0
NH9.2 Great Bay	B	8	7/14/2021	20	50	50	176	48	0
NH9.2 Great Bay	B	9	7/14/2021	27	70	30	144	56	0
NH9.2 Great Bay	B	10	7/14/2021	8	30	30	96	53	0
NH9.2 Great Bay	B	11	7/14/2021	12	40	50	128	54	4
NH9.2 Great Bay	B	12	7/14/2021	13	20	70	160	37	4
NH9.2 Great Bay	C	1	7/15/2022	119	75	3	320	72	0
NH9.2 Great Bay	C	2	7/15/2022	192	90	0	208	69	0
NH9.2 Great Bay	C	3	7/15/2022	127	90	3	192	67	4
NH9.2 Great Bay	C	4	7/15/2022	0	90	10	272	77	0
NH9.2 Great Bay	C	5	7/15/2022	98	95	5	208	64	0
NH9.2 Great Bay	C	6	7/15/2022	50	80	5	160	66	16
NH9.2 Great Bay	C	7	7/15/2022	117	100	0	272	40	16
NH9.2 Great Bay	C	8	7/15/2022	16	70	10	96	62	0
NH9.2 Great Bay	C	9	7/15/2022	164	65	0	208	79	0
NH9.2 Great Bay	C	10	7/15/2022	131	100	0	272	77	0
NH9.2 Great Bay	C	11	7/15/2022	190	100	0	320	55	32
NH9.2 Great Bay	C	12	7/15/2022	115	100	0	320	130	16

Eelgrass data for biomass, percent cover, shoot density, canopy height, and reproductive shoots and percent cover seaweed at SeagrassNet site NH9.3 (Fort Foster), Transects A, B, and C in August 2022.

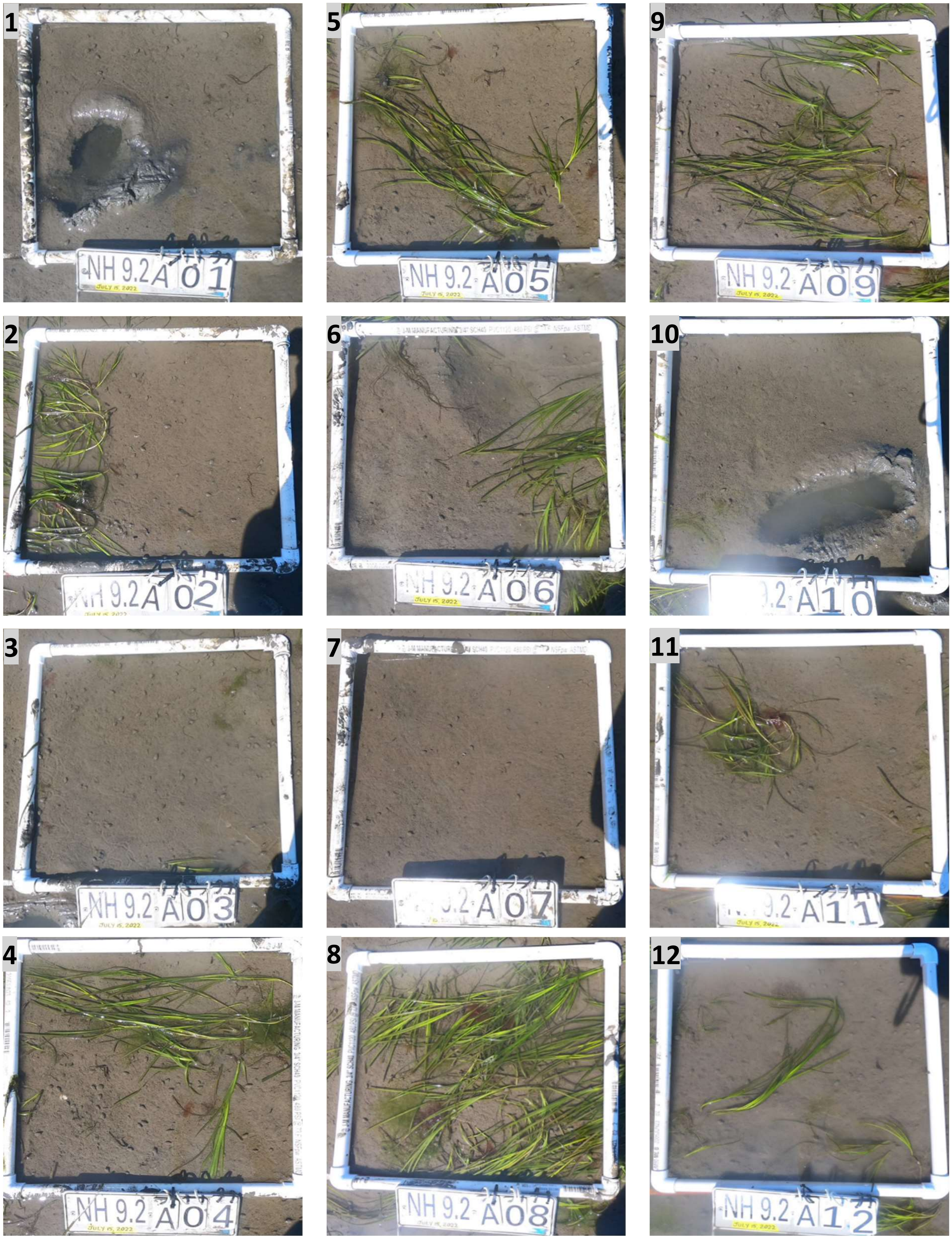
Location	Transect	Quad #	Date	Biomass (g/m^2)	Eelgrass % Cover	Algae % Cover	Shoot Density ($\#/m^2$)	Canopy Height (cm)	Repro Shoot ($\#/m^2$)
NH9.3 Fort Foster	A	1	8/9/2022	728	80	0	368	92	32
NH9.3 Fort Foster	A	2	8/9/2022	565	100	0	272	136	64
NH9.3 Fort Foster	A	3	8/9/2022	525	100	0	400	141	48
NH9.3 Fort Foster	A	4	8/9/2022	474	100	0	384	111	96
NH9.3 Fort Foster	A	5	8/9/2022	987	85	0	400	77	16
NH9.3 Fort Foster	A	6	8/9/2022	672	100	0	320	115	48
NH9.3 Fort Foster	A	7	8/9/2022	200	100	0	256	124	32
NH9.3 Fort Foster	A	8	8/9/2022	823	100	0	336	122	64
NH9.3 Fort Foster	A	9	8/9/2022	307	100	0	560	122	80
NH9.3 Fort Foster	A	10	8/9/2022	565	95	0	368	111	64
NH9.3 Fort Foster	A	11	8/9/2022	1040	100	0	608	106	16
NH9.3 Fort Foster	A	12	8/9/2022	418	90	10	384	115	16
NH9.3 Fort Foster	B	1	8/3/2022	686	85	0	304	135	8
NH9.3 Fort Foster	B	2	8/3/2022	773	100	0	336	126	0
NH9.3 Fort Foster	B	3	8/3/2022	319	85	5	336	89	0
NH9.3 Fort Foster	B	4	8/3/2022	176	40	0	84	100	12
NH9.3 Fort Foster	B	5	8/3/2022	340	65	25	176	105	48
NH9.3 Fort Foster	B	6	8/3/2022	281	100	0	288	96	16
NH9.3 Fort Foster	B	7	8/3/2022	758	95	0	432	93	48
NH9.3 Fort Foster	B	8	8/3/2022	659	95	0	336	103	16
NH9.3 Fort Foster	B	9	8/3/2022	851	100	0	288	119	16
NH9.3 Fort Foster	B	10	8/3/2022	745	100	0	384	142	0
NH9.3 Fort Foster	B	11	8/3/2022	173	80	0	96	109	4
NH9.3 Fort Foster	B	12	8/3/2022	244	100	0	160	121	16
NH9.3 Fort Foster	C	1	8/2/2022	297	70	10	128	98	16
NH9.3 Fort Foster	C	2	8/2/2022	116	50	10	96	111	8
NH9.3 Fort Foster	C	3	8/2/2022	541	75	5	192	115	0
NH9.3 Fort Foster	C	4	8/2/2022	400	90	0	208	93	0
NH9.3 Fort Foster	C	5	8/2/2022	164	90	0	224	93	4
NH9.3 Fort Foster	C	6	8/2/2022	256	70	0	208	84	0
NH9.3 Fort Foster	C	7	8/2/2022	252	100	0	336	92	0
NH9.3 Fort Foster	C	8	8/2/2022	4	5	10	12	14	0
NH9.3 Fort Foster	C	9	8/2/2022	31	5	25	28	44	0
NH9.3 Fort Foster	C	10	8/2/2022	6	5	10	20	29	0
NH9.3 Fort Foster	C	11	8/2/2022	2	3	0	4	75	0
NH9.3 Fort Foster	C	12	8/2/2022	0	0	0	0	0	0

Appendix 2

Photomosaic of quadrat photos from the 3 SeagrassNet transects (A, B, and C) taken during the July 2022 surveys in Great Bay, New Hampshire and the August 2022 surveys at Fort Foster, Portsmouth Harbor. Each photomosaic represents a single transect (A, B, or C) and photos are organized into 3 columns showing Quadrats 1-4, Quadrats 5-8, and Quadrats 9-12. Some photos from Transect A and C in Great Bay are difficult to interpret due to enhanced turbidity. No pictures were taken of Great Bay Transect B.

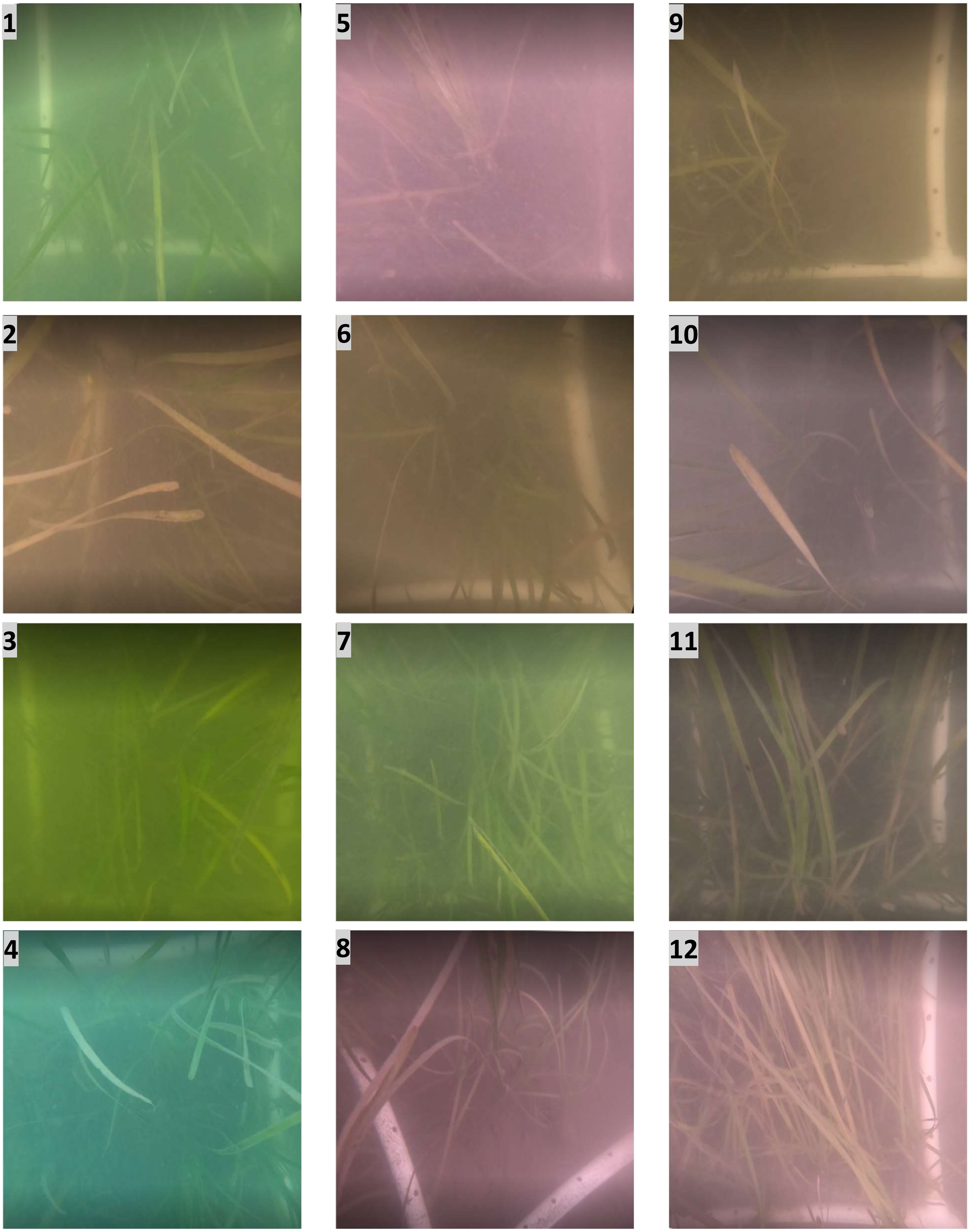
Appendix 2, Site NH9.2 – Great Bay, Transect A, July 2022

<u>Quadrats 1-4</u> <u>Quadrats 5-8</u> <u>Quadrats 9-12</u>



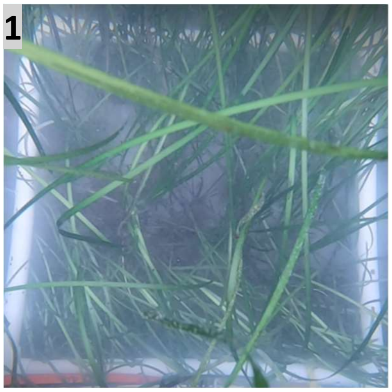
Appendix 2, Site NH9.2 – Great Bay, Transect C, July 2022

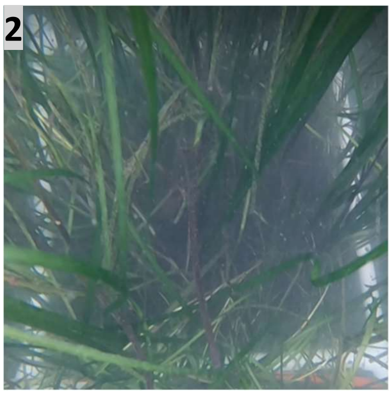
Quadrats 1-4 | Quadrats 5-8 | Quadrats 9-11

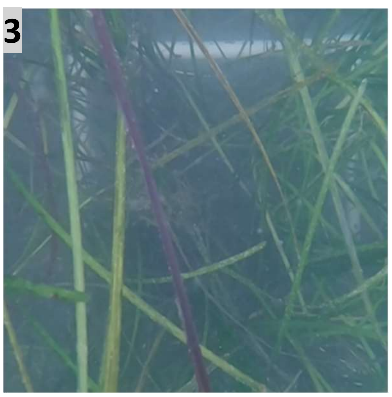


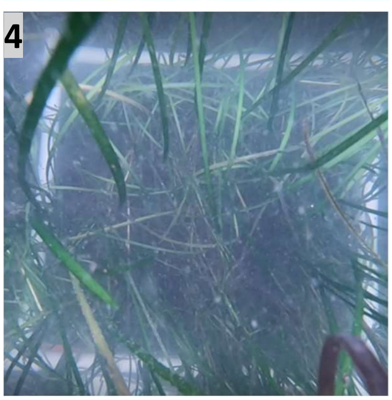
Appendix 2, Site NH9.3 – Fort Foster, Transect A, August 2022

Quadrats 1-4

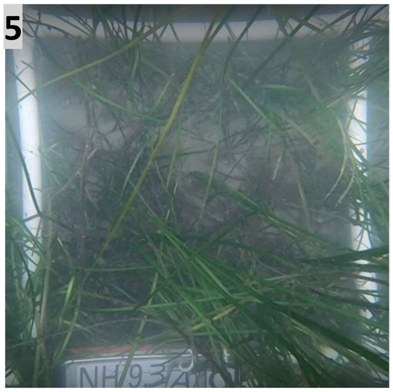


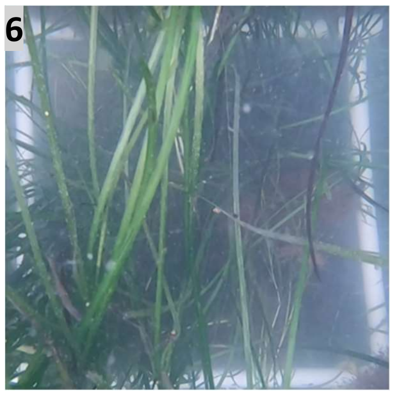




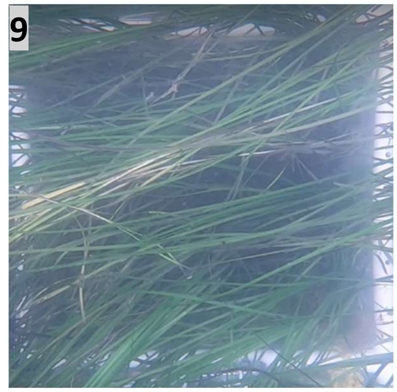


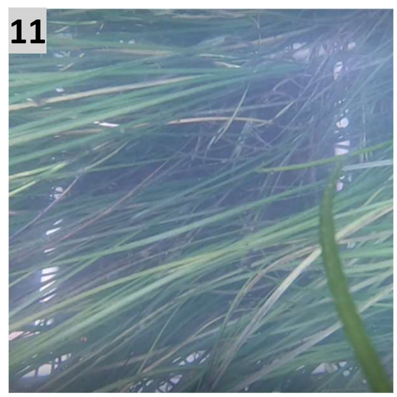
Quadrats 5-8





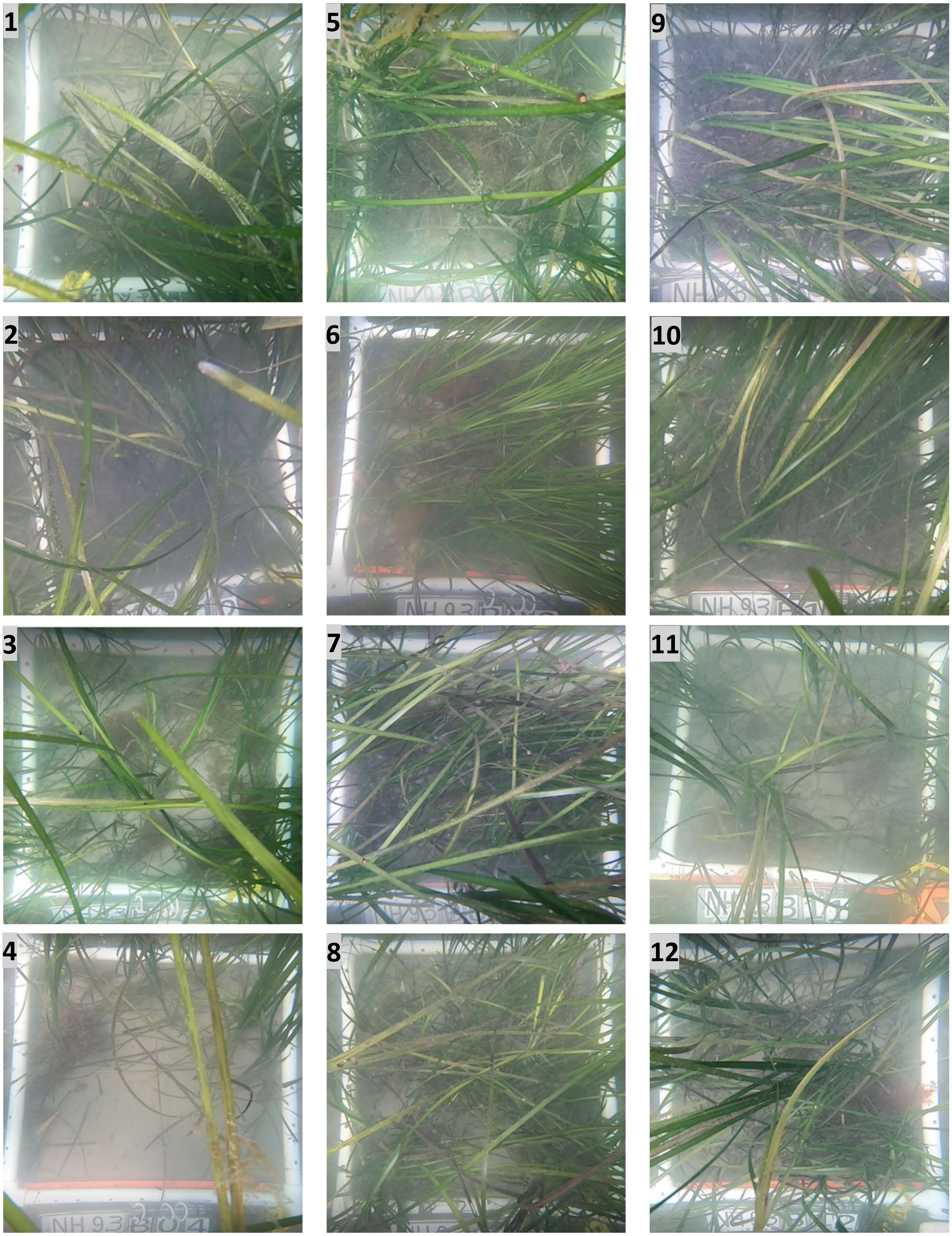
Quadrats 9-12





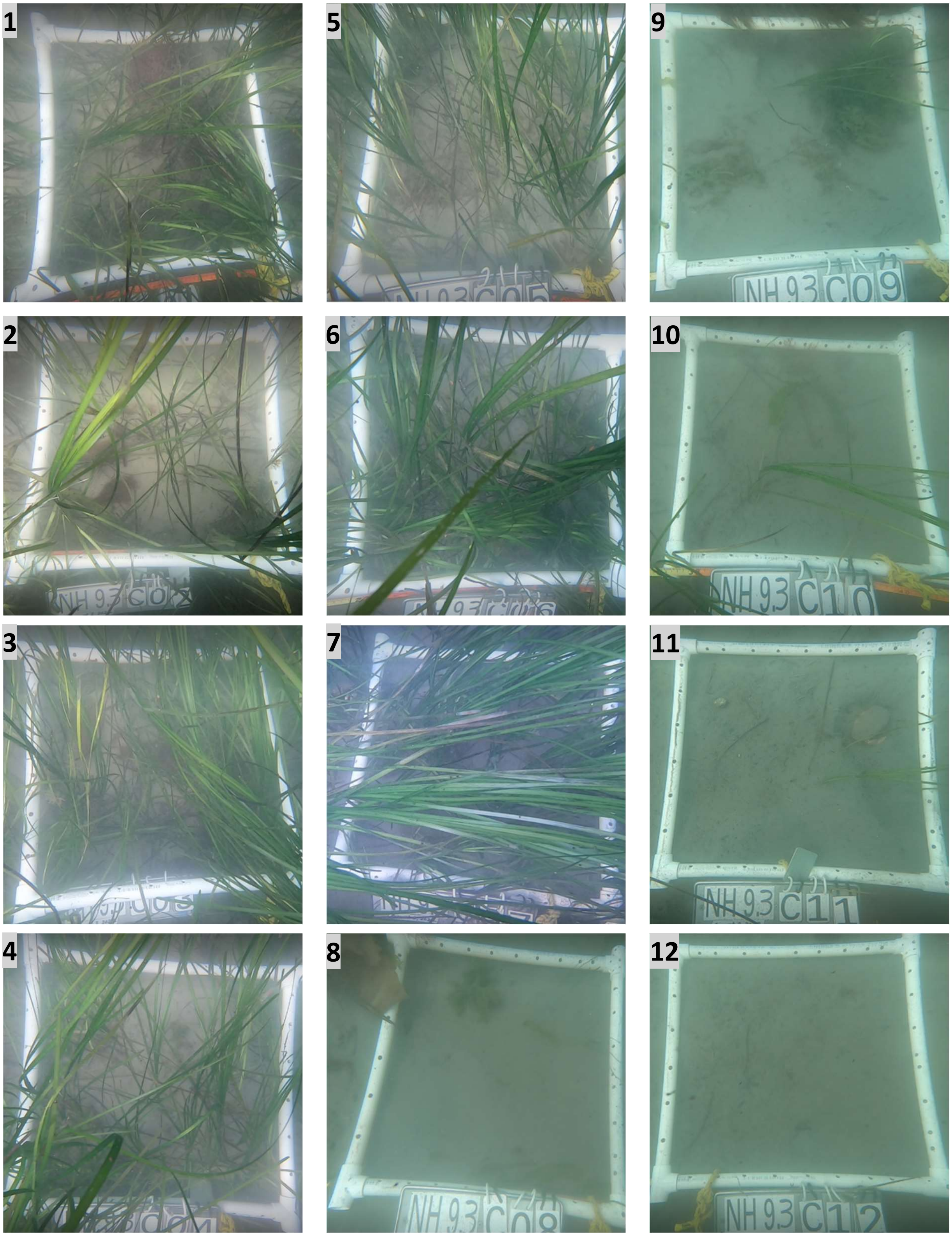
Appendix 2, Site NH9.3 – Fort Foster, Transect B, August 2022

Quadrats 1-4 | Quadrats 5-8 | Quadrats 9-12



Appendix 2, Site NH9.3 – Fort Foster, Transect C, August 2022

Quadrats 1-4 | Quadrats 5-8 | Quadrats 9-12



Appendix 3

QA/QC MEMORANDUM

To: Erik Beck, USEPA

From: Kalle Matso, PREP (Project QA Officer for SeagrassNet Monitoring)

Date: August 16, 2023

Re: Quality Assurance of 2022 SeagrassNet Monitoring Program

PURPOSE

The purpose of this memorandum is to document the results of quality assurance checks on the 2022 SeagrassNet monitoring program conducted by staff from UNH Jackson Estuarine Laboratory and PREP.

The project consisted of the continued monitoring and sampling of two established SeagrassNet sites: one located in Great Bay, NH, and one located in Portsmouth Harbor at the site designated as "Fort Foster."

PREP reviewed these data with reference to the data quality objectives for the approved Quality Assurance Project Plan, available online: https://scholars.unh.edu/prep/420/

The following table contains assessments of the data quality objectives of the project. Supporting tables and figures are also provided below.

DATA QUALITY OBJECTIVE ASSESSMENTS

Data Quality Objective	Criteria	Protocol	Assessment of Criteria	Data Quality Objective Status
Precision	Biomass measurements should be maintained to 1/100 of a gram.	Laboratory analysis will measure biomass with a Sartorius Balance (Type = E2000D).	All of the biomass measurements were maintained to 1/100 of a gram and were measured using a Sartorius Balance (Type = E2000D).	**Achieved**
Bias	Percent cover, shoot density, canopy height, and grazing estimates should be comparable across members of the field assessment team within ±10%.	Field assessment team members will "calibrate" their assessments of percent cover, shoot density, canopy height, and grazing estimates prior to field work by reviewing published examples of visual representations of different percent covers (Short 2017). Field estimates will then be made by consensus of the field team. The field assessment team will also review photographs and associated percent cover estimates from previous years before the field season begins.	Field staff training included a "calibration" using published examples of visual representations of different percent covers prior to data collection, as well as a review of estimates to confirm a comparability across field staff members within ±10%. Field estimates were made by consensus of the field team. However, photographs and associated percent cover estimates from previous years were not reviewed prior to the field season.	**Achieved**
Spatial Accuracy	GPS units should have a reported accuracy less than or equal to 2 meters.	New transects will be established using a highly accurate, real-time kinematic (RTK) GPS. Transect locations will then be staked in the field using screw anchors. The minimum accuracy tolerance of the unit will be set to reject saving of waypoints with spatial accuracy less than 0.03m, thereby assuring spatial accuracy requirements are met or exceeded.	Field staff used GPS units that have a reported spatial accuracy of 3-5 meters under normal conditions. The Satellite Information screen was not used during field work, so the current spatial accuracy of the GPS units was not observed. Neither the Great Bay site nor the Portsmouth Harbor site were established using an RTK GPS. **This criterion and the method for georeferencing need to be reevaluated by PREP for future monitoring.**	**Partially Achieved**
Comparability	Field and laboratory data should be collected using standardized methods.	Check that protocols from the QAPP were used for field observations. The QA Manager should use filtering functions to check the field assessment team's spreadsheets for data entry errors. All percent cover values should fall into one of the categories specified in the sampling methods. All biomass values should be between 0 and 500 grams. A minimum of 10% of field observations should be checked against electronic spreadsheets.	Field staff collected data using a standardized field data sheet. The protocols in the QAPP were used for all field observations made (see Completeness below) except for Shoot Density. In some cases, it was not clear which of the two size quadrats was used for density counts. In those cases, counts were reassessed and verified using photographs. Data entry errors were assessed and any anomalies were explainable when the field personnel were asked about the issue at hand.	**Achieved**

Data Quality Objective	Criteria	Protocol	Assessment of Criteria	Data Quality Objective Status
Completeness	Field observations should be made for percent cover, shoot density, canopy height, grazing, and wasting disease estimates. In addition, environmental data collection should include light levels, temperature, and salinity.	Check field observations for completeness. Document reasons for any deviations from sampling protocol.	Field observations were made during sampling events for percent cover, shoot density, and canopy height. Per environmental data criteria, light levels, temperature, and salinity data were collected via HOBO data loggers.	Achieved

Table 1: Field observations and environmental data collection performed.

Parameter Observed:	Completed	Pass or Fail
Percent Cover	Yes	Pass
Shoot Density	Yes	Pass
Canopy Height	Yes	Pass
Grazing	Yes	Pass
Wasting Disease	Yes	Pass
Light Levels	Yes	Pass
Temperature	Yes	Pass
Salinity	Yes	Pass