Investigating suitability for eelgrass at Pier 94 (San Francisco) with test plantings

Final Report to Golden Gate Audubon Society

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Margot Buchbinder, Melissa Patten and Katharyn Boyer
Estuary & Ocean Science Center, San Francisco State University

The aim of this project was to assess the suitability of the Pier 94 wetland restoration site as a candidate for eelgrass restoration. Eelgrass (*Zostera marina*) is a submersed flowering plant that occurs in temperate estuaries worldwide, performing many valued functions, including providing habitat to invertebrates, fish, and birds; stabilizing sediments; and contributing to carbon sequestration. In San Francisco Bay, it covers roughly 3000 acres, primarily in the central and San Pablo Bay regions (Merkel & Associates 2014). In the central bay it is found mostly on the east side, and considering that winds largely come from the west, rafting flowering shoots are unlikely to land on the western side and provide seed to establish eelgrass populations. Hence, there may be unoccupied suitable habitat along the western shoreline where active restoration could result in new eelgrass populations, including at Pier 94 in San Francisco.

Pier 94 is located along the southeastern waterfront of San Francisco (37.74586, -122.37532). This 5-acre parcel is owned by the Port of San Francisco, and the Golden Gate Audubon Society (GGAS) maintains and restores the wetland and adjacent upland habitat under a 10-year agreement with the Port (renewed for a second 10-year term in 2021). The site is bordered to the north by Islais Creek, to the west and south by industry including Martin Marietta (formerly Hanson Aggregates), Central Concrete Supply, CEMEX, Darling International and Recology.

Scientists (Dr. Katharyn Boyer, Margot Buchbinder, and Melissa Patten) from the Estuary & Ocean Science Center were engaged by GGAS to determine the suitability of Pier 94 for eelgrass restoration. Factors known to contribute to suitable habitat for eelgrass include adequate light, cool temperatures, and protection from high wave action, among others; however, the exact conditions are not well understood and are an ongoing subject of study and modeling (e.g., the Audubon California-led habitat suitability modeling effort currently underway with Merkel & Associates and the EOS Center). Restoration practitioners typically identify suitable depths (based on measurement of depths occupied in natural eelgrass beds) and then conduct test plantings. Survival and spread of transplanted eelgrass are then used to gauge suitable conditions at a particular site. Researchers also evaluate overall indications of eelgrass health, including presence of macroalgae that can block light or raft through and dislodge eelgrass plantings, as well as herbivory by birds or invertebrates that can damage eelgrass tissues and negatively influence establishment success.

The project consisted of two phases: an initial trial of test plot plantings in 2020 (Year 1), followed by a second round of test plots planted in 2021 (Year 2). Here, we summarize results from both years of plantings and assess the viability of Pier 94 as a future eelgrass restoration site candidate. Excerpts from detailed memos documenting activities at the site are included in Appendix A.

Year 1

In the first year, we completed the following field activities:

- June 8, 2020: Initial site assessment
- July 5, 2020: Drift algae and planting assessment
- July 21, 2020: Eelgrass collection and rigging
- July 22, 2020: Year 1 test plot plantings
- September 1, 2020: Summer test plot monitoring
- November 15, 2020: Fall test plot monitoring
- April 2, 2021: Spring test plot monitoring and assessment for year 2 planting

In June 2020, we visited Pier 94 and made an initial assessment to determine whether there may be suitable planting areas available at the site. We evaluated the full shoreline, and determined that the beach at the southern shore was the only area that had adequate space for test plots at the depths typically occupied by eelgrass in the bay (-1.5 to -2.0 ft MLLW) (Fig. 1). However, we noticed large amounts of drift algae (mainly *Gracilaria* spp.; Fig. 2) in the water column and on the beach that could smother or dislodge new plantings. Before beginning test plots, we returned to the site on July 5 to ascertain whether the algal deposits were still present; we determined that the remaining amount was not likely to be detrimental to eelgrass plantings, and decided to go forward with test plots.

In late July 2020, we collected eelgrass shoots from a natural bed at Bay Farm Island (Fig. 1; 37.7304, -122.2631), the nearest, easily accessible large bed in this region of the bay. Our lab's standard practice is to spread out our collections across patches in an eelgrass bed to maximize the genetic diversity represented in the transplants. We also make sure to include rhizomes 5-10 cm in length to aid in anchoring and provide carbon stores for the plants to use in initial establishment. We returned the plants to the EOS Center and rigged them into transplanting units (Fig. 1). For these, eelgrass (2-3 shoots per unit) is attached with a paper twist tie toward the top of a bamboo stake (75-cm long) and then the majority of the stake's length is inserted into the sediment to hold the eelgrass in place until it can root (Boyer and Wyllie-Echeverria 2010). The units are biodegradable and are left at the site; the tops sticking out above the sediment surface by ~10 cm aid in finding the plants when monitoring later.

We planted 16 test plots on the southern shore of Pier 94. Ten plots were located at the deeper margin (-2 ft MLLW; 'deep' plots), while six were located closer to shore at -1.5 ft MLLW ('shallow' plots) (Fig. 1; Fig. 2). We determined the depth using predicted tides for the site at that time and measurements of water depth. Fewer plots at the shallower depth was due to the more limited space available at that depth along the curved shoreline. Each plot was 0.5 m by 0.5 m (0.25 m^2) and contained five planting units (described above), with one planting unit in each corner of the plot and one in the center (Fig. 2). As each planting unit contained 2-3 shoots, there were approximately 12 shoots per plot (~192 shoots total across all plots). It was difficult to plant at the site due to a lot of gravel and larger rock in the sediment, and we sometimes shifted a plot slightly to find more penetrable substrate; we noted that shorter stakes might be considered in future plantings (Appendix A). We marked the locations of the plots with a handheld Trimble GPS unit.

Figure 1. A) Map of Pier 94 (study site) and Bay Farm Island (eelgrass donor site) in San Francisco Bay; B) eelgrass transplanting unit; C) Satellite image showing locations of the shallow (-1.5 ft MLLW) and deep (-2 ft MLLW) plots at Pier 94.

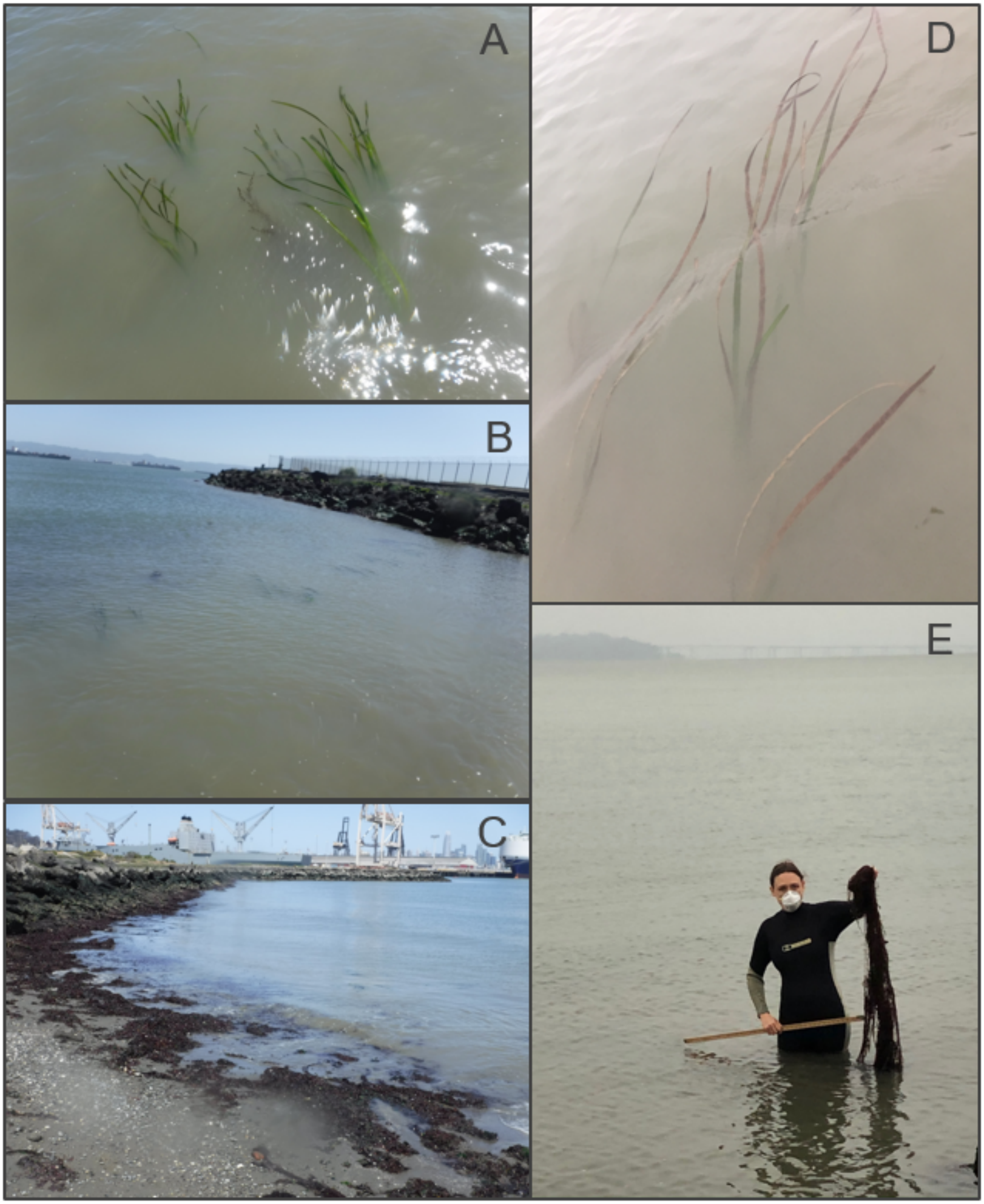

Figure 2. A) Planted plot containing 5 planting units with 2-3 shoots each; B) plots visible from the surface; C) algal wrack on the Pier 94 shoreline; D) plants in September 2020; E) M. Patten with *Gracilaria* algae removed from a plot in September 2020.

In September and November 2020, we monitored the plots for survivorship and possible expansion, finding them again using the GPS unit and by feeling for bamboo stakes. In September, we found shoots in seven of the 10 deep plots, and four of the six shallow plots, with greater survivorship at the southern end of the bands of plots at each depth, which we observed to be somewhat less rocky (see Appendix A). All plots with plants remaining showed significant losses, with a maximum of five shoots remaining of the approximately 12 planted shoots in each plot. The plants that remained looked generally healthy (Fig. 2) with a typical coverage of algal epiphytes on older blades and no signs of amphipod herbivory (which can damage leaves; Lewis and Boyer 2014). They were similar in height to plants we monitor in other beds (e.g., Carr et al. 2011), but were sometimes broken at the tips, which can be a sign of bird herbivory or of physical wear. This level of survivorship from initial plantings made us cautiously optimistic that we would observe spread at the site over time. However, when we returned in November 2020, we found no remaining plants in the shallow plots, and we only found plants in four of the 10 deep plots, for a total of ten shoots remaining at the site. While we searched for plants we found large pieces of thick plastic sheeting (that perhaps once wrapped wharf pilings) over the plots; this sheeting or other debris may have contributed to the loss of plants in the area. When we returned for the final monitoring in April 2021, we found no remaining plants in any of the test plots (Fig. 3).

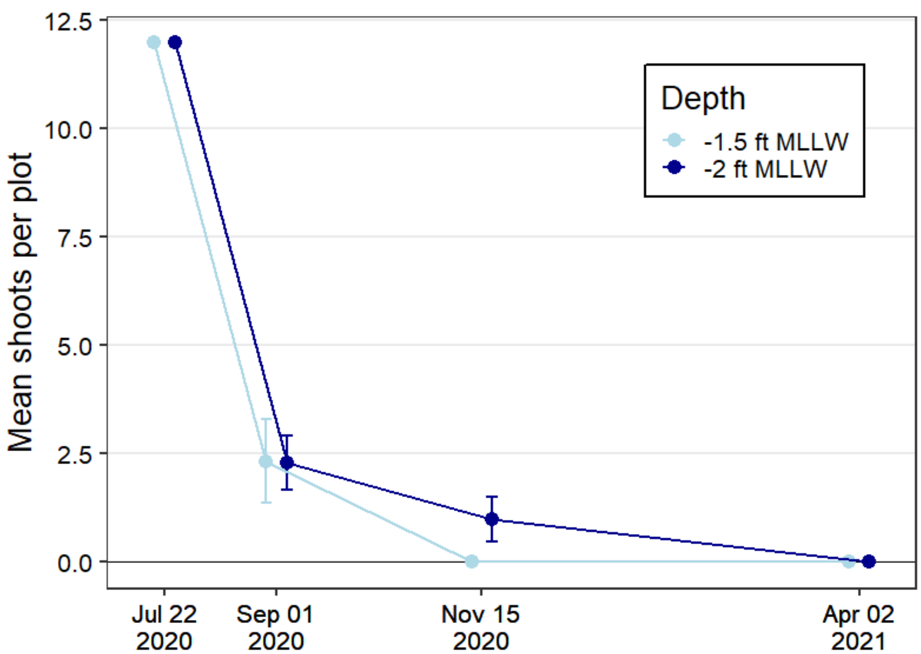

Figure 3. Mean shoot counts for the shallow (-1.5 ft MLLW) and deep (-2 ft MLLW) plots at Pier 94 in Year 1. Error bars indicate ±1 standard error.

Although there was no eelgrass remaining in April 2021, we assessed that it could be beneficial to repeat the test plots at Pier 94 in order to see if there was improved success at the site after the removal of large debris that may have smothered some of the plots in 2020 and contributed to the loss of plants in all the test plots. We therefore went ahead with the test plots in year 2.

Year 2

In the second year, we completed the following field activities:

- April 29, 2021: Drift algae assessment
- May 1, 2021: Eelgrass collection and rigging
- May 2, 2021: Year 2 eelgrass plantings
- August 9, 2021: Summer test plot monitoring
- November 5, 2021: Fall test plot monitoring

In late April 2021, we visited Pier 94 to re-assess whether eelgrass could be transplanted into the site during that tide series. Minimal drift algae was present at the site, so we made the decision to proceed with plantings. On May 2, 2021 we planted 17 test plots at two depths along the southwest shoreline, in approximately the same locations as the 2020 test plots (Fig. 1). Eleven plots were located along the 'deep' transect at approximately -2 ft MLLW, and six plots were located closer to shore at approximately -1.5 ft MLLW. The test plots were planted in the same configuration as in 2020, with five bundles of 2-3 shoots planted within a 0.25 m^2 quadrat, for a total of approximately 12 shoots per plot. One difference from the previous year is that we cut the bamboo stakes to ~35 cm length to facilitate insertion into the gravel layer just below a more sandy layer at the surface of the sediment. There were more patches of drift algae present than expected based on our assessment just three days earlier, but these were not as thick or the patches as abundant as observed in spring of 2020.

The plots were monitored in August and November of 2021. In August 2021, we found plants in only five of the 11 deep plots, and in two of the six shallow plots. The shoots appeared generally healthy, but some of the shoots seemed delicate and broke apart easily in our hands, suggesting some loss of structural integrity. We did not observe debris on the scale that had been seen in 2020, but we observed high wave action at the site and it is possible that debris that had since washed away could have impacted the plants; we noticed some signs of abrasive mechanical damage to the shoots at the time. We also observed some exposed rhizomes, which could be a sign of erosion on the beach that could have caused plants to wash away. When we completed our final monitoring in November 2021, no plants remained in any of the plots (Fig. 4).

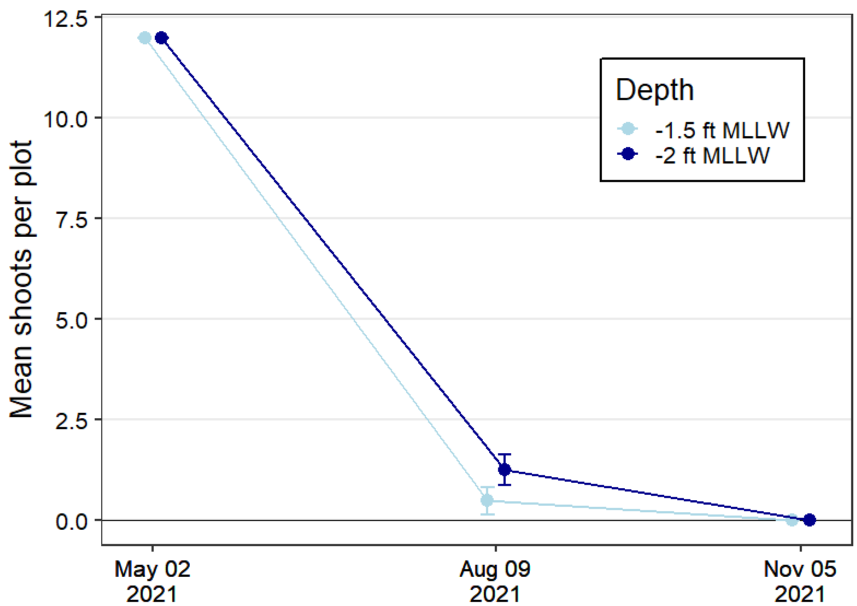

Figure 4. Mean shoot counts for the shallow (-1.5 ft MLLW) and deep (-2 ft MLLW) plots at Pier 94 in Year 2. Error bars indicate ±1 standard error.

Conclusions

Test plot plantings at Pier 94 in 2020 and 2021 were initially successful but did not persist in either year; in year 1 all plants were gone within nine months of planting, and in year 2 no plants survived after six months. The site is very dynamic, and appears to experience a great deal of disturbance. Drift macroalgal (mostly *Gracilaria* spp.) was frequently observed and large debris (large plastic sheeting) was found over the plants in fall of 2020. Large logs (likely from pier pilings), parts of docks, and other debris are also commonly observed higher in elevation, on the marsh plain; therefore, it is possible that even when large debris is not present in the plots, it may have contributed to the decline of plantings. Additionally, high wave action likely played a role in erosion observed on the beach; when eelgrass at other restoration sites die back, we can often find the attached bamboo stakes for years after the restoration. However, in August 2021 many of the bamboo stakes were missing from the plots, indicating that they might have been dislodged and washed away. Plants that were still attached to stakes often had rhizomes exposed, indicating erosion around the plants. The substrate was much coarser than what we typically plant into (sand layer over gravel, interspersed with larger rock), which may have contributed to substrate movement and difficulties in plant establishment.

We believe the dynamic nature of the site makes it unsuitable for larger-scale eelgrass plantings at this time. If additional wave barriers such as living shorelines elements are constructed at the site (e.g., oyster recruitment structures that also provide shoreline protection), it is possible that the south beach area of Pier 94 could become more appropriate for eelgrass shoreward of the protective structures. In this case, we would recommend additional test plantings be conducted to determine if there is increased suitability of site conditions. In the meantime, it would be helpful for GGAS staff and volunteers to track (via photograph with date and time) large marine debris and timing of algal blooms at the site. Further, we recommend that GGAS staff keep current on SF Bay eelgrass restoration efforts by participating in upcoming workshops that explore eelgrass habitat suitability modeling (Audubon California collaborative efforts mentioned above), living shorelines, and other pertinent topics, and attend the State of the San Francisco Estuary and other conferences and workshops that summarize conservation and restoration efforts for eelgrass.

Acknowledgements

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Appendix A: Interim Field Reports (excerpts from emailed memos documenting activities)

YEAR 1

June 8, 2020 memo on opportunities/constraints for eelgrass at Pier 94 from K. Boyer to N. Weeden following initial field visit

South end by the small beach: There is enough area available at appropriate depths for test plots. We typically look for depths of about -1.5’ to -2’ MLLW when we are scouting for appropriate eelgrass restoration sites. Today’s low tide gave us a good look at this southern area, which has adequate space (~30 m parallel to shore in an arc following the shoreline) available to do two rows of test plots testing two depths (-1.5 and -2’). The sediment is firm and sandy and should be suitable. However, we are concerned about the large amount of drift and attached algae in this area, which was composed primarily of *Gracilaria*, *Mastocarpus*, and *Ulva*. These algae filled the water column thickly and some large *Gracilaria* clumps were attached into the sediment (probably to shell or small rocks).

Middle region, along the main axis of the Pier 94 wetlands: This area is too deep and likely too exposed for eelgrass to succeed. The lower portion of the riprap is right at about -1.5 to 2’ MLLW, thus there is little to no soft sediment to plant into at appropriate depths and there is a long fetch causing wind waves even with the relatively calm conditions of this morning.

North end, where there is an eastward bend of the land/riprap: This area is pretty deep but has some appropriate depths at about -2’ MLLW. However, the sediment here contains a lot of small (2-5”) rocks and shell (largely native oyster shell!). We believe this is only marginally suitable habitat. It would be quite difficult to plant here and the plants would likely abrade on the rocks.

Our conclusions: We don’t see the north or middle regions as suitable for eelgrass restoration, matching our expectations prior to our visit today. We would be interested in testing the south area for eelgrass suitability using test plantings as we have discussed. However, we think the plants would not receive enough light to establish and grow with so much algae in the water column currently and the shifting rafts of algae would very likely rip the plants from their anchors. We suggest returning in about a month to see if the algae has persisted. If it is only present seasonally and has dissipated at that point, we would go ahead and do the test plantings. But if the algae has persisted we believe we should not plant this year, but rather should check again next spring to see if it is present. If such large accumulations of algae are an annual spring-early summer phenomenon, then we would reconsider this test planting effort.

July 9, 2020 memo from K. Boyer to N. Weeden, following visit to assess drift algae and whether to proceed with planting

There is still attached *Gracilaria* but much less drift algae, so I think we will go ahead with the test plots the week of July 20.

July 23, 2020 memo from K. Boyer to N. Weeden, following eelgrass collection/rigging and planting days

We got the eelgrass test planting done at Pier 94 south beach yesterday: 10 plots of 5 planting units each at about -2’ MLLW (in a 30 m long arc following the shape of the shoreline) and 6 plots of the same at -1.5’ MLLW (about 2 meter shoreward of the deeper plots and at the center of the deeper 30m arc). So, in all there are a total of 16 test plots, total of 80 planting units, and 2-3 shoots per unit.

It was very difficult to plant there using our bamboo stake anchoring technique because of a lot of gravel and larger rock in the substratum. If the plants are successful and further planting is warranted we would suggest other methods with an anchor that does not have to go in as deep. This could be either shorter bamboo stakes, perhaps 30-40 cm instead of the 75 cm lengths we typically use, or there are several other anchoring possibilities that we could consider.

There was still quite a bit of *Graciliaria* attached to the sediment in large mats, so that is somewhat of a concern for smothering the transplants, but the massive amounts of drift algae continue to be absent.

September 3, 2020 memo from M. Patten to N. Weeden following 1st monitoring of test plots

We monitored the eelgrass test plots at Pier 94 on Tuesday, and I'm happy to report there were plants present! We were there at about a 0 ft tide, and the plant leaves were visible floating on the water surface, so they were easy to find.

As a reminder, we planted 10 plots in the deeper line, and 6 plots in the shallow line, each plot with 5 planting units of 2-3 shoots each.

On September 1st, the deep line had plants in 7 of the 10 plots; the shoot count from the south was 2, 4, 5, 2, 5, 3, 0, 0, 2, 0. The shallow line had plants in 4 of the 6 plots; shoot count from the south was 1, 5, 3, 5, 0, 0. This means the plants haven't expanded yet but are hanging on, although there was less survivorship in the north end where the sediment was rockier and much harder to plant into. We also measured shoot lengths, which were between 100 and 150, a normal range for vegetative shoots. There were no flowering shoots.

The plants looked healthy. They were lightly epiphytized with a normal amount of what we call diatom scum, which is the brown-grey layer on the blades that you can see in the photos. There was none of the larger epiphytic macroalgae that we see sometimes on the blades (which can become a problem if it weighs down or tangles the plants). There were no signs of the invasive amphipod *Ampithoe valida* which sometimes consumes the plants. Some plants were broken at the tips, which can be because of bird herbivory, but can also just be from normal wear and tear. There were large clumps of *Gracilaria* still at the site, but less than when we installed the plants.

December 7, 2020 memo from M. Buchbinder to N. Weeden following November 2020 monitoring

We monitored the test plots at Pier 94 on Sunday November 15 on an outgoing tide, at or below 0 ft. We did not observe large amounts of algae as we had seen early in the summer, but there were clumps of brown algae present rooted to hard substrates, including on the bamboo poles that we used for the plantings. However, there was a lot of debris present in the area, including two very large sheets of heavy plastic that we removed from the water. The sheets were found on top of where some of our plots should have been but we were unable to find the plots themselves; we believe that they were crushed or scoured out by the sheeting or other debris. Usually if plants are gone we can still feel the bamboo they were staked to, but in this case we sometimes were not able to find any sign of the plots.

Unfortunately we did not find plants in the shallow plots (there had been plants in four of the six plots in September), and only found plants in four of the deep plots (there had been plants in seven of the ten plots previously). The plots that contained plants had 5, 2, 1, and 2 shoots each. Although there were some intact plants present, many of the remaining shoots were clipped very short, about 15-20 cm in length. This could possibly be due to herbivory by birds, but with the presence of the sheeting it's also possible that the plants were physically damaged by debris. The clipped plants could only be monitored by feel, but the intact plants looked healthy. Aside from a couple plants it was too deep to see the eelgrass, so we did not take pictures of the plots this time.

The site generally seemed very dynamic – in addition to the plastic sheeting, we also found other debris including broken tiles and a PVC stand and data logger that belonged to the SERC team. The water was very turbid so we were primarily searching by feel, so our observations were also limited. This is a little worrisome regarding the potential of the site to support eelgrass, since otherwise successful plantings can be quickly damaged.

YEAR 2

April 9, 2021 memo from K. Boyer to N. Weeden following April 2 site visit

We did not find eelgrass in any of the plots during our April 2 monitoring. As you know, when we monitored last November, there were no plants found in the shallow plots and only a few plants in four of the ten deeper plots. We indicated at that time that there was a lot of debris present, including the large plastic sheeting that likely damaged the plantings; further, the plants had been trimmed to about 15-20 cm in length, perhaps by bird herbivory. Although these plants seemed healthy, we were not optimistic about what we would find following winter storms. Consequently, we were not surprised by our findings last week.

We will proceed with our plan to replant the test plots this spring. On April 2, there was some algae (primarily the red alga *Gracilaria*), but it was not excessive like last spring. Our plan is to check again (I think this will be April 29) to see that the low algal coverage remains the case, and replant shortly after that.

July 3, 2021 memo from K. Boyer to N. Weeden following field visit in late April and early May re-plant

We assessed the south beach area of the Pier 94 wetlands site on April 29, 2021 to aid in our decision about whether we could conduct a new set of eelgrass transplants during that same low tide period. We generally elect to transplant during the spring months due to cooler weather and a longer period for plants to establish during the growing season. However, in 2020, large deposits of drift algae along the shore and in the shallow water in spring led us to delay our transplanting until summer, due to concerns that the algae would block light or intertwine and damage the eelgrass. The low tide on April 29 was sufficient to walk through the planting area and see (and feel) that there was minimal algae present, thus we proceeded with our plan to transplant eelgrass over the next few days.

On May 1, we traveled to the Bay Farm Island eelgrass bed (the nearest, easily accessible large bed in this region of the bay) and collected eelgrass shoots bare-root for transplanting. Our standard practice is to spread out our collections across patches in an eelgrass bed to maximize the genetic diversity represented in the transplants and to be sure to include rhizomes 5-10 cm in length to aid in anchoring and provide carbon stores for the plants to use in initial establishment. These shoots were returned to the EOS Center and attached to bamboo stakes to create transplant units. For these transplant units, eelgrass (2-3 shoots per unit) is attached with a paper twist tie toward the top of the stake and then the majority of the stake's length is inserted into the sediment to hold the eelgrass in place until it can root. The units are biodegradable and are left at the site; the tops sticking out above the sediment surface by ~10cm aid in finding the plants for monitoring later. Due to our experience planting at Pier 94 in 2020, we cut the stakes to 35 cm, to facilitate inserting them into the gravel layer beneath the sandy layer at the site. This bamboo stake length should still be suitable for sufficient anchoring.

On May 2, we traveled to Pier 94 to lay out the specific plot locations, using a handheld GPS to identify the previous locations where we had planted in 2020. We removed the previous year's bamboo stakes as encountered, which had all become devoid of eelgrass (see previous reporting). We planted the transplant units into 17 plots, with 11 at approximately -2' MLLW and 6 at -1.5' MLLW. These were laid out as in the previous year, with five transplant units arranged like the five on dice, for a total of 85 transplant units. Notably, there were patches of drift macroalgae, which was surprising considering these were not encountered on our visit just three days before. Anecdotally, these were not as thick or the patches as abundant as what we encountered the previous spring, but we still feel some concern that they will damage the eelgrass plantings, and more broadly that this could be a recurring problem at this site.

August 11, 2021 memo from M. Buchbinder to N. Weeden following August 9 monitoring

We monitored the eelgrass plots at Pier 94 on August 9. In May, we had planted six shallow plots at approximately -1.5 ft, and 11 deeper plots at approximately -2 ft. Each plot had contained five 'planting units' rigged on bamboo with 2-3 shoots each, resulting in approximately 12 shoots per plot. This week, we found plants in only two of the six shallow plots (the first plot containing one shoot and the other containing two). Five of the 11 deep plots still had plants; shoot counts ranged from 1-4 shoots, with a mean of 2.2 shoots per vegetated plot. Although the shoots that persisted seemed generally healthy, were lightly epiphytized by algae, and did not have bite marks indicating herbivory by amphipods or other animals, some of the shoots were delicate and broke very easily. The plants that we found had persisted but did not show any signs of expansion as we would expect at this point.

Generally speaking, we continued to see a good amount of wave action at the site, and it's possible that this was related to the generally low numbers of plants that remained. One of the shoots showed signs of abrasive mechanical damage, which might have been caused by debris scraping against the plant. We rarely found bamboo stakes that did not have attached plants; in most of our restoration sites, we are able to find bamboo stakes with or without plants for years after the planting is completed. Since we have lost most of the bamboo here, it is likely that most of the loss of planting units was due to mechanical removal of entire planting units, rather than plants dying after being transplanted. One of the remaining planting units was present but the portion of the unit containing the rhizome bundle was exposed, so the unit had either been pulled up or the beach had eroded several inches. It's unclear whether the bamboo staking method itself was related to the losses, or whether the bamboo is merely an indicator of the mechanical removal of planting units. As before, the substrate was composed of sand mixed with large gravel, which is much coarser than what we usually plant into.

November 13, 2021 memo from K. Boyer to N. Weeden following November monitoring

I'm sorry to say that we found no eelgrass in the test plots. We will work on writing up our final report for you soon.