Possible causes of eelgrass (*Zostera marina* L.) loss in Frenchman Bay, Maine

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Eelgrass beds in upper Frenchman Bay failed to produce shoots during the 2013 growing season. We investigated three possible causes for the die-off: a nutrient deficiency or toxicity of sediments, decline in water quality over years and destruction by invasive green crabs. After pursuing these three lines of investigation, we conclude that change in sediment was probably not the cause of eelgrass decline. However, a precipitous drop in silica in the bay over the last several years combined with impacts of green crabs may explain eelgrass loss in Frenchman Bay.

We have been restoring eelgrass (*Zostera marina* L.) in Frenchman Bay since 2007 and have developed successful methods for eelgrass restoration in Maine[5]. Despite progress in a 5.6-hectare restoration site at Hadley Point and spread of restored eelgrass to surrounding areas between 2007 and 2012, eelgrass continued to decline elsewhere in the bay, and in late summer 2012, eelgrass was lost entirely from the restoration site and surrounding areas. In Frenchman Bay 88% of 456 ha of eelgrass mapped in 2008 by the Maine Department of Marine Resources had disappeared by 2013, with the remaining eelgrass concentrated in outer Frenchman Bay (see companion paper on eelgrass loss). Eelgrass is widely recognized for provision of valuable ecosystem services, including essential fish habitat, nutrient uptake, sediment and shoreline stabilization, and carbon sequestration. Consequently the immediate impacts of eelgrass loss are expected to extend to reduced landings of commercial and recreational fisheries, increased shoreline erosion, and reduced water quality, while long-term impacts include loss of ability to mitigate impacts of climate change.

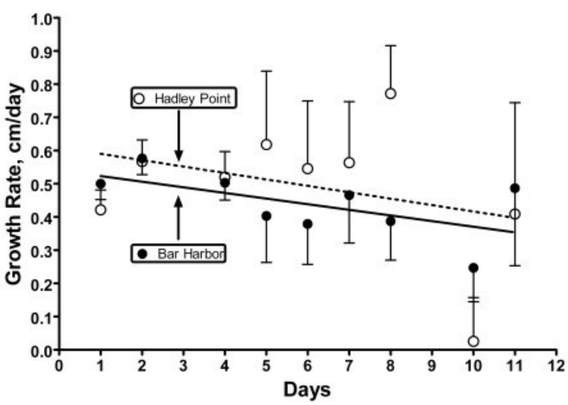

Figure 1. Comparison of the growth rate of eelgrass plants in sediment from Hadley Point, where eelgrass was lost, and sediment from near Bar Island; where eelgrass remains intact revealed no significant difference (t-test, P = 0.32).

Possible explanations for recent losses include sediment toxicity and/or nutrient deficiencies, declines in water quality, and destruction of shoots by the European green crab (*Carcinus maenas*). We explored each possibility through a variety of assessments, including, plant growth studies in tanks with sediments from areas of eelgrass loss and areas without eelgrass loss, comparison of water quality data from years pre- and post eelgrass loss, and by doing crab exclusion studies in the field.

We investigated the growth of plants in sediments from Hadley Point and near Bar Island. To investigate whether the sediment in the upper bay was nutrient deficient or toxic, we compared the growth rate of eelgrass in sediment from the upper bay and in sediment from the outer bay. Twelve 5-gallon tanks were set up on a seawater flow table. Six of the tanks contained 3 cm of sediment from near Bar Island, a site in the outer bay where eelgrass was not lost. The other six tanks contained the same depth of sediment from Hadley Point, a site in the upper bay where eelgrass died off. All tanks were then filled with seawater. Vegetative (non-flowering) eelgrass plants were harvested from near Bar Island; six were planted in each of the 12 tanks. Growth was measured over a period of 11 days as described by Colletti et al[1]. The average growth rate for plants in each tank is shown in Figure 1. There was no statistical difference in rate of growth of eelgrass in the two types of sediment (two-tailed two-sample t-test, P = 0.32). Differing sediment quality does not seem to be a factor in eelgrass die-off.

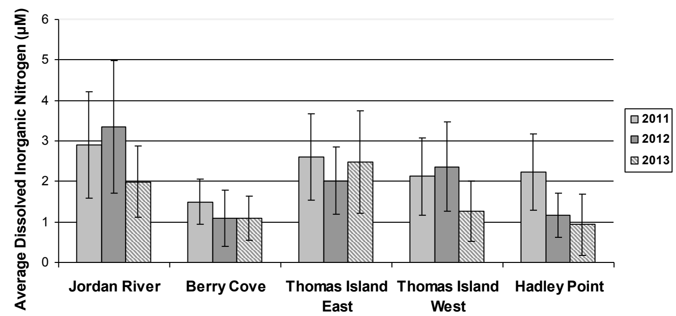

Figure 2. Dissolved inorganic nitrogen (NO_3+NO_2+NH_4) in Frenchman Bay 2011-2013. Sites showed no significant change over the three years (n = 4 at each site in each year).

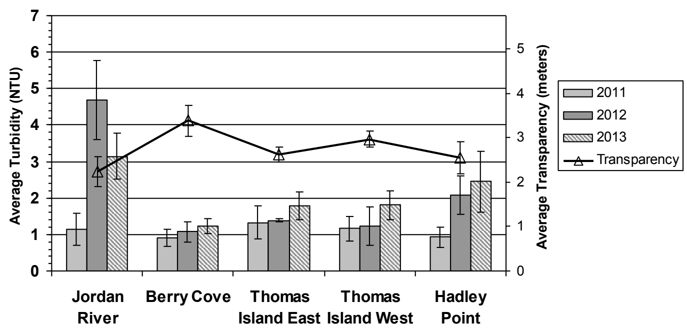

Figure 3. Turbidity and transparency in Frenchman Bay 2011-2013. Most sites showed no significant change over the three years. Jordan River displayed the most variability in turbidity and lowest average transparency.

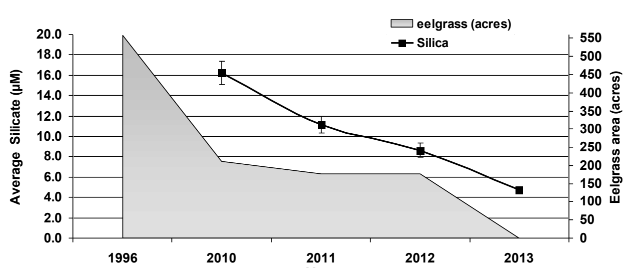

Figure 4. Silicate levels in the water column in upper Frenchman Bay 2010-2013 and eelgrass decline in the same area since 1996. Silicate levels were determined in water samples collected in each of 4 months at 4 sites in 2010 (n = 16) and 5 sites from 2011-2013 (n = 19 in 2011; n = 20 in 2012 and 2013) and declined significantly over four years (1-way ANOVA, F = 30.26, P = 1.03×10^{-12}).

We also assessed water quality. We have been monitoring water quality at multiple sites in upper Frenchman Bay since 2007 with complete datasets from 5 sites in the upper bay in 2011-2013. Samples were collected from June-September and tested for dissolved oxygen (Winkler titration), temperature (Taylor digital thermometer), salinity (hand-held refractometer), and nutrients (NO_3+NO_2, NH_4, $Si(OH)_4$ and PO_4), which were all measured with a Bran Luebbe autoanalyzer III by Maura Thomas at University of Maine. We also tested for transparency (Secchi disk) and turbidity (LaMotte 2020*e* turbidity meter). Between 2010 and 2013 bay-wide averages for dissolved oxygen were greater then 7.0 ppm. The average water temperature increased in upper Frenchman Bay in summer 2012 as it did throughout the Gulf of Maine. The average water temperatures in upper Frenchman Bay in 2010 was 15.7 ± 0.4˚C in 2010, 15.3 ± 0.2˚C in 2011, and 18.1 ± 0.6˚C in 2012 and 15.5 ± 0.4˚C in 2013 (n = 16-20). Salinity remained relatively constant during this same time period with summer averages for the upper bay ranging from 32-34 ppt. Dissolved inorganic nitrogen also remained unchanged between 2011 and 2013 (Figure 2). The same was true for phosphorous with averages ranging between 0.43 and 0.67 mg/L across all sites and years. An increase in turbidity could block light availability to eelgrass; however in the years preceding eelgrass loss, turbidity was low at all test sites and transparency remained stable (Figure 3). Hadley Point, where restored eelgrass was thriving until 2013, had no significant change in turbidity over the last three years (1 way ANOVA, F = 2.38, P = 0.148). In Jordan River, where eelgrass was lost in 2010, turbidity increased significantly between 2011 and 2013 (1-way ANOVA, F = 7.14, P = 0.014), possibly due to loss of the sediment stabilizing eelgrass.

The most striking observation in our analysis of water quality data was the decline in silicate (Si) in Frenchman Bay over the past four years (Figure 4). The relationship between eelgrass and Si was documented for a bay in the Netherlands. Percent cover of eelgrass was tightly correlated with dissolved Si levels over 20 years, and levels of Si in eelgrass plants also correlated with the amount of dissolved Si in the water column[4].

It has been shown that green crabs have greatly impacted eelgrass beds in Nova Scotia[2]. Therefore, we set up an exclosure study that involved transplanting eelgrass outside of and inside of two 8 ft. x 8 ft. fenced exclosures made of ¾-inch mesh deer fencing. Eight biodegradable grids containing 20 plants each were placed inside each exclosure; two were placed outside. Crabs were trapped from inside exclosure 2 and from outside the exclosures in order to document crab density (Figure 5). There was no significant difference in the average number of crabs trapped from inside exclosure 2 and from outside the exclosures. This may be related to the capacity of the traps, rather than a true reflection of the density of crabs inside and outside of the exclosure. However, there was a significant difference in the survival of eelgrass transplants on grids inside and outside of exclosures (Figure 6). Nearly all the eelgrass on grids outside of the exclosures had disappeared after 47 days. Most of the eelgrass transplants on three grids removed from inside each of the two exclosures survived, and few of these were damaged. Those that were damaged showed the characteristic “chewing” attributed to green crabs.

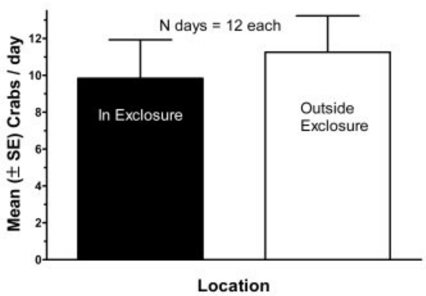

Figure 5. Average number of green crabs found and removed from inside exclosure 2 and outside the exclosures.

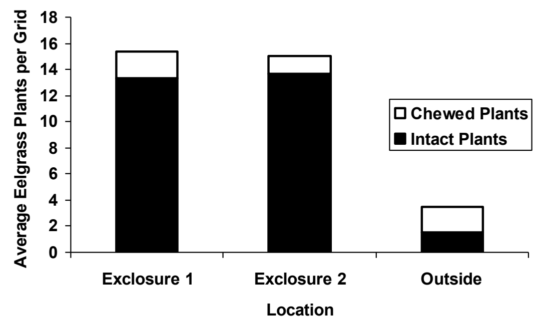

Figure 6. Plant survival and damage inside exclosures 1 and 2 and outside of exclosures.

Sediments quickly changed in areas where eelgrass was lost. With the loss of sediment binding by roots and rhizomes, sediment instability and re-suspension into the water column may result in water quality and bottom habitat conditions that are incompatible with eelgrass growth. In order to remediate the loss of eelgrass, the relationship between changing water quality, the explosion of green crab populations and widespread eelgrass disappearance must be understood. This understanding is also critical for future restoration site selection and marine spatial planning efforts. Silicon may play a role in eelgrass health as it does in land plants, increasing cell wall strength, which confers wear tolerance, disease resistance, and rigidity[2]. If that is so, then eelgrass may be more susceptible to damage by green crabs in years with low Si concentration in the water. Causes of low Si may be due to low rainfall, reducing rates of geological weathering, utilization by phytoplankton, shifts in tidal/wind driven mixing of deeper nutrient-rich waters into the surface layers, or a combination of these factors. Further study of silicate distribution in the water column and in eelgrass plants, and studies of green crab impact on eelgrass in high and low silicate conditions may help to elucidate the cause of eelgrass loss in Frenchman Bay and elsewhere in Maine.

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1. **Colletti S, Disney JE, Kidder GW.** The growth rate of eelgrass (*Zostera marina*) in Frenchman Bay. *Bull. Mt Desert Isl. Biol. Lab.* 48:120, 2010.
2. **Epstein E.** Silicon. *Annual Review of Plant Physiology and Plant Molecular Biology* 50: 641-664, 1999. (DOI: 10.1146/annurev.arplant.50.1.6412)
3. **Garbary DJ, Miller AG, Williams J, Seymour NR.** Drastic decline of an extensive eelgrass bed in Nova Scotia due to the activity of the invasive green crab (*Carcinus maenas*) *Mar Biol* DOI 10.1007/s00227-013-2323-4, 2013.
4. **Herman PMJ, Hemminga MA, Nienhuis PH, Verschuure JM, Wessel EGJ.** Wax and wane of eelgrass *Zostera marina* and water column silicon levels. *Mar Ecol Prog Ser*. 144: 303-307, 1996.
5. **Kidder GW, White S, Miller MF, Norden WS, Taylor T, Disney JE.** . Biodegradable Grids: A Preferred Method for Community-Based *Zostera marina* (Eelgrass) Restoration in Maine. *J. Coastal Research*. 2013 http://www.jcronline.org/doi/abs/10.2112/JCOASTRES-D-13-00062.1