Tidal Marsh Experiments and Restoration at Steedman Woods Reserve in York, Maine

By
David Burdick
and
Devin Batchelder

Jackson Estuarine Laboratory
University of New Hampshire
85 Adams Point Road
Durham, NH 03824

Final report to:
Old York Historical Society
207 York Street,
York, Maine

August 31, 2017

ACKNOWLEDGEMENTS

The authors of this final report wish to thank all those individuals and organizations involved in funding this research and restoration. This project was launched and initially funded by Old York Historical Society, with the direct involvement of executive director Scott Stevens, succeeded by Joel Lefever; and with the encouragement and support of Old York's Steedman Woods Committee.

Donors to the project included: Steve and Georgia Bennett, David and Marge Carley, David and Barbara Chase, Jared and Ann Chase, Stu and Ellen Dawson, Robert and Patricia Dempsey, William and Deborah Ethridge, Patricia Fox, Kevin and Sandra Freeman, James and Melissa Gerrity, Nancy Gustad, Edward and Peggy Harding, Henry and Mary Harding, Connie Hanley, Robert and Paula Hoy, Cal and Cynthia Hosmer, Ann Ramsay-Jenkins, James and Bran Johnston, Edward and Suzanne Little, Brian and Bobbie McGann, Susan Meffert, Sarah Newick, Scott and Gretchen Ramsay, Jeff and Darcy Rice, Jim Smith, Sally Sulloway, Charles and Julie Steedman, Scott and Nancy Stevens & Gordon Wallace.

<u>2012 – 2013</u>

Following up on plans developed in 2011, the initial season of the Steedman Woods Reserve shoreline research project was supported by donations to Old York from individuals and families, as well as grants from the Davis Conservation Foundation and the Harbor Foundation, and a corporate donation provided by Exeter Subaru. Old York provided administrative and logistical support.

<u>2014 – 2015</u>

The Steedman Woods Reserve Shoreline research project was supported by donations to Old York from individuals and families, as well with support provided by the UNH College of Life Sciences and Agriculture, and by the Jackson Estuarine Laboratory.

<u>2016</u>

The Steedman Woods Reserve Shoreline research project received support from the Jackson Estuarine Laboratory, a program development award from New Hampshire Sea Grant, and a grant from the Marine Biology Graduate Program of the School of Marine Sciences and Ocean Engineering. In addition, local funding was provided directly to the project by Edward Little and David Chase.

<u>2017 Season</u>

Research results evaluation and preparation of this final report were supported by the Jackson Estuarine Laboratory.

Cite as: Burdick, D., and D. Batchelder. 2017. Tidal Marsh Experiments and Restoration at Steedman Woods Reserve in York, Maine. Final Report to the Old York Historical Society, York, Maine. 23 pp.

Tidal Marsh Experiments and Restoration at Steedman Woods Reserve in York, Maine

INTRODUCTION

Steedman Woods Reserve, a peninsula bounded by the York River and tidal Barrell Pond, is a property of the Old York Historical Society. In response to concerns raised in 2010 about shoreline erosion and loss of tidal marsh vegetation, the Historical Society contacted the University of New Hampshire Jackson Estuarine Laboratory, seeking an assessment of conditions and possible solutions. In 2011, Jackson Lab personnel examined the Steedman Woods shore, southwest and northwest of the Wiggley Bridge.

Several factors were identified that might cause the erosion and marsh loss problems, either directly, or interacting with other factors: unauthorized human use of the area as a beach; as a place to run dogs; strong currents associated with the sluiceway (under the bridge); wakes from boats traveling the York River; and shade from trees extending out over the shoreline. In addition, waves and currents had removed most of the fine-grained sediments from the sites (silts and sands), resulting in intertidal areas dominated by gravel to cobble and resulting in poor growing conditions for tidal marsh plants. In addition, the shorelines had eroded back to a steep scarp, providing an unprotected face where wave energy can focus and continue the cycle of erosion and plant loss. Finally, it was posited that two invasive species of European marine animals may be contributing to marsh grass loss: *Carcinus maenas* (the green crab) and *Littorina littorea* (the common snail or periwinkle).

Based on recommendations from the 2011 survey, a plan to restore the shorelines was developed (described in Burdick et al. 2013). Actions to prevent human use of the area were carried out: a visitor-friendly, well constructed fence was erected; riprap covered steps on both sides of the path; signs to warn off visitors from using the eroding areas and an informational sign about the project and need to protect the fragile area were developed and installed. Planting and erosion control were split into two phases, with the focus of restoration activities on the Barrell Pond shoreline in 2012 and restoration of the York River shoreline in 2013. Removal of some terrestrial vegetation (overhanging tree branches) was also suggested to reduce shade to the planted areas, but was not included in activities that were permitted by the Town of York.

The attempts at re-vegetating the shoreline with marsh plants in 2012 and 2013 to reduce erosion and restore the salt marsh were largely unsuccessful, in good measure because of the enormous population of common periwinkles living in Barrell Pond. Bare root culms of smooth cordgrass (*Spartina alterniflora*) were planted behind short stakes driven into the sediment at approximately one-foot centers with the rationale that the stakes would protect the plants from direct physical exposure of waves and currents. If the stakes could help stabilize the sediments, perhaps fine-grained sediments would be retained and the plants would also grow better. To reduce wave energy and catch fine-grained sediments, biodegradable baffles were constructed and staked onto the marsh surface and boulders were placed seaward of the York River shore in 2013.

The common periwinkle, introduced from Europe over 150 years ago (Blakeslee 2007), was found to climb and graze the plants. Dense aggregations of snails (over 800/m^2, or 70/$foot^2$) would traverse the shoreline from the mid to the high tide line in waves. The waves of snails would graze the sediments, destabilizing them and likely causing the loss of fine-grain sediments. The snails would also climb plants they encountered, grazing leaves or breaking their stems as the tide rose. Observations of leaf death and plant breakage from the snail grazing and climbing were documented following the restoration efforts (Burdick et al. 2013).

A small pilot experiment in summer 2013 excluded snails from planted plots and confirmed the importance of the common snail in preventing plant establishment and restoration of the salt marsh (Burdick et al. 2013). We learned that there were some unintended consequences of adding stakes, wave baffles and large boulders to the site. The snails, vulnerable to desiccation from heat and sunlight during low tide, would hide in the shade of all these features, thus allowing the snails even better access to the young marsh plants.

OBJECTIVES AND RESEARCH QUESTIONS

In 2015 several experiments were set up at the site to quantify the impact of the snails on shoot proliferation and plant growth at several elevations and two levels of fertilizer. The overall objective of these experiments was to quantify the potential impact *Littorina littorea* was having on *Spartina alterniflora* biomass and marsh persistence in restoration areas, as well as existing marsh areas dominated by *S. alterniflora*. In 2016 another restoration effort was designed and implemented based on the results of the experiments. Here our objective was to develop and test a more effective restoration method that could be used to restore the York River shoreline and inform other coastal resources managers dealing with salt marshes dominated by *S. alterniflora* that are being negatively impacted by *L. littorea.*

The specific questions asked were:

Question 1. What are the densities of the snails present and how do they differ across variations in elevation and time?

Rationale: Although *L. littorea* has already been recorded in dense aggregations in the region (Tyrrell et al. 2008), the population density for any specific site has not been measured. This knowledge could identify a baseline for experimental work and help determine how vulnerable a site is to further salt marsh loss. Additionally, it would be valuable to understand what elevation and substratum is preferred by *L. littorea* to better understand their movements and feeding activities, as well as identifying areas of potential damage which could be helpful in controlling *L. littorea* populations at similar sites.

Question 2. If planted cordgrass is enclosed with the average density of snails found at the site, what impacts to plant growth can be expected? Do impacts vary across the range of marsh elevations? Are newly planted areas more susceptible to snail damage than existing marsh edges?

Rationale: Previous research suggests that *L. littorea* can have a large impact on *S. alterniflora* biomass at low elevations, thus reducing overall marsh integrity (Tyrrell et al., 2008). However, it remains unclear what the impacts are from snail activities in marshes being restored, and how that tolerance varies with elevation. Consequently, it is important to determine the impact of snails that can inhabit existing and planted stands of *S. alterniflora* during the growing season. This would allow for better understanding of potential impacts of *L. littorea* and which areas of existing and restored marshes are going to be most susceptible to loss due to snail activity.

Question 3. Could nitrogen enrichment stimulate the vegetation growth enough to overcome the snail driven biomass loss?

Rationale: In previous studies, nitrogen enrichment has been used successfully to stimulate *S. alterniflora* growth in low marsh environments (Silliman & Zieman 2001). Also denser, more robust stands of *S. alterniflora* are not as susceptible to damage as those that have been degraded (Bertness 1984). Can nitrogen stimulate growth and can it be enough to overcome the biomass loss caused by large *L. littorea* populations? Questions 2 and 3 will be examined by planting cordgrass within wire mesh cages to control snail densities.

Question 4. Can sediments and snails be manipulated to improve restoration outcomes?

Rationale: Previous restoration activities at this site explored several planting methods including sheltering the plugs using wooden stakes, attempting species combinations with alkali grass *(Puccinellia maritima)*, salt hay *(Spartina patens)* and smooth cordgrass *(Spartina alterniflora)*, as well as using biodegradable wave baffles to reduce physical exposure and encourage sediment buildup for a more hospitable environment. Sheltering using stakes failed; however, there was success in rebuilding sediment using the baffles. Using the baffles, fine sediments will be restored on the York River shoreline before establishing plantings since fine sediment will provide a better growing medium for the plugs (Morris et al. 2002). Cordgrass will be planted within plots formed by a grid of wire mesh fencing to control snail density and movement; half of the site will have snail removal and half will not. This experiment is designed to resemble efforts that could reasonably be made over a large area by a restoration practitioner.

METHODS

Site Description

South of the Wiggley Bridge (York River side) is a small tidally influenced area of shoreline, mostly devoid of marsh peat and containing no living vascular plants (Figure 1). Erosion from the York River is clearly evident, likely from daily boat traffic and storms. What little peat is found here is the remnant of marsh that has been eroded away. The sediments consist mainly of inorganic, sandy to gravely areas that are wetter at lower elevations and steadily dry out up gradient. The salinity of the floodwaters is near seawater concentration, around 30 ppt.

North of the Bridge (Barrell Pond side), the area is comprised mostly of barren inorganic sediments with small islands of marsh and unvegetated pools (Figure 1). The sediments of the barren areas vary from silt to cobble. The sediment surface is also littered with common periwinkle shells. Very little organic matter is found here except in the marsh areas and at the higher elevations where terrestrial soil has been eroded down slope. Islands of existing marsh growing on thin peat deposits are mostly populated by stunted smooth cordgrass (*Spartina alterniflora*), with macroalgae mixed in. Although no motorboat traffic occurs on the pond side, a strong current flowing under the bridge appears to contribute to erosion. Similar to the York River side, the salinity of the floodwaters is also around 30 ppt.

Figure 1. Restoration sites at Steedman Woods along Barrell Pond and York River shorelines. Restoration efforts in 2012, 2013 and 2016 are color coded by area. Cage experiments to examine snail impacts to plants were conducted in 2013 and 2015 along the Barrell Pond shoreline and a fencing experiment was performed at York River shoreline in 2015.

Snail Densities (Question 1)

Counts of snails within 0.25 m^2 quadrats were conducted on Barrell Pond shoreline on May 2, July 7 and August 30, 2015. Eleven transects running perpendicular to the shore were established from mid tide to high tide (12 to 38 meters in length) and samples were collected every two meters along each transect. Elevation was collected at each sample point and corrected to '0' at the lowest elevation of healthy *Spartina alterniflora*. A similar survey was conducted along the York River shoreline on May 2, 2015. Simple averages were calculated for each date, elevation and site and were used to establish snail density in subsequent experiments.

Barrell Pond Experiments (Questions 2 & 3)

Galvanized wire mesh (a.k.a. hardware cloth), will deter snails from traveling across the marsh (Bertness 1984) and can be used to prevent grazing on plants. On the Barrell Pond shoreline, small enclosures, 50 cm on a side, were installed along edges of existing marshes that overlapped the existing vegetation by about a quarter of the cage length. A series of flags inside the cage were used to denote where the existing vegetation initially ended. Plant expansion beyond the existing edge (flags) is based on biomass measurements, calculated using plant height and number of plants.

The experiment was designed as a factorial treatment arrangement using two factors: snail manipulation (no snails and average density of snails) and fertilizer (nitrogen addition and no addition) applied evenly over 20 plots (five exclosures/enclosures for each treatment combination) 0.25 m^2 in size. Half the plots had snails removed and the other half had numbers maintained weekly at 48 per cage. Half the plots were supplemented with urea fertilizer (placed within perforated 15 ml centrifuge tubes) at levels used in published fertilizer studies of salt marsh plants (Silliman and Zieman 2001). The centrifuge tubes were inserted in a grid with twelve tubes per cage. The cages were spaced at least half a meter apart to ensure the nitrogen did not reach any of the non-enriched cages.

A larger experiment examined the effects of snails and fertilizer on planted cordgrass. Sixty cages, 0.25 m^2 is area, were established at three general tidal elevations (low, medium and high) and planted five groups of cordgrass culms. The *S. alterniflora* plugs were taken from a healthy marsh in Durham NH. Each plug had 4-6 healthy plants and there were five plugs planted in each cage. Half the cages had snails removed while the other half had snails maintained weekly at 48/enclosure. In addition half had nutrients added at levels described above, while the others did not. The four treatment combinations included no snails and no nitrogen, no snails plus nitrogen, average snail density and no nitrogen, and snails plus nitrogen enrichment. Five replicates of each treatment combination were randomly placed within each elevation range. Both experiments were run for 12 weeks and biomass was calculated from leaf number and height of individual stems to determine effects of elevation, snails and nitrogen addition on plant expansion of existing plants and plant development within planted plots. At the start and end of the experiment, biomass was calculated for each shoot based on a regression developed earlier from a set of 200 shoots, which explained 82% of the variability in biomass:

$$\text{Biomass} = -0.0264*(\text{plant height cm}) + 0.000668*(\text{plant height}^2) + 0.0894*(\text{\# leaves})$$

York River Experiment (2015) and Planting (2016)

In 2015, two bands of hardware cloth were installed roughly parallel with the shoreline on the York River. Six fence lines were installed perpendicular to the shoreline and this produced 18 plots surrounded by fencing, with six plots at each elevation (Low, Mid and High). Each of the plots were planted with cordgrass obtained from a local marsh in Durham (NH) or purchased from Pinelands Nursery (NJ). The six plots at each of three elevations were planted in a plot of 40 plants, 10 inches apart, then randomly assigned to one of two treatments: snail removal or no snail removal. Plant survival and biomass, based on plant stem number and height, were used to determine the effect of the snail exclusion fences in 2015.

In 2016 an effort was made to restore the shoreline using techniques that were based on information developed from the previous year’s experiments. The planed restoration area encompassed the upper two-thirds of the shoreline. Jute baffles were constructed and installed for erosion control, wire mesh fencing was erected for snail control and smooth cordgrass was planted on one-foot centers throughout the site. In fall 2016 the area was visually assessed and on August 25, 2017 samples were collected by placing a 0.25m^2 frame haphazardly six times within each of the three elevation zones (18 samples total). Planted plugs that contributed to plant cover within the frame were counted, even if their centers were outside the frame (some plants expanded from 5 cm (2 inches) to over 20 cm diameter (8 inches). Missing plants were noted to obtain a survival rate for each sample frame. The number of cordgrass shoots greater than 5 cm were counted and the percentage cover for each vascular plant species as well as an algae, marsh felt (*Vaucheria* spp.) were estimated within each frame to assess marsh development.

RESULTS

Snail Density

Large numbers of snails were found along intertidal shorelines of the York River and Barrell Pond in May (Table 1). General observations coupled with the quantitative data collected in May suggest more snails are using the pond shoreline, but snails were prevalent enough to severely damage plantings, as shown by the results from past and current restoration attempts (Burdick et al. 2013).

The number of snails found along the intertidal shoreline of Barrel Pond varied by cover type and collection date (Table 1 and Figure 2). Snails were more likely to be found within existing vegetation or using the little rivulet draining the landward pool (Figure 1) than on bare sediment. Snails within each cover type (bare sediment, stream, marsh vegetation) were most dense in late August and least dense in mid summer (Figure 2). Results suggest snails prefer vegetation over bare sediment and they were always numerous enough to damage unprotected plants. Snails ranged over the entire elevation zone of the shoreline, from below the lowest marsh grass to the high tide line, about two meters (6.5 feet), but numbers fell to low levels after the first meter above the lowest marsh grass. Statistically, each of the three variables of cover type, elevation and collection date were highly significant and combined they explained 42% of the variability in snail number.

Table 1. Snail density means sampled over a grid on each shoreline in 2015. York river sampled on one date only.

		Averge Density (#/m²)		
Cover Type	n	May	July	August
Barrell Pond				
Bare Sediment	96	71	27	74
Marsh Vegetation	36	199	106	236
Stream	3	134	113	150
York River				
Bare Sediment	15	47	NA	NA

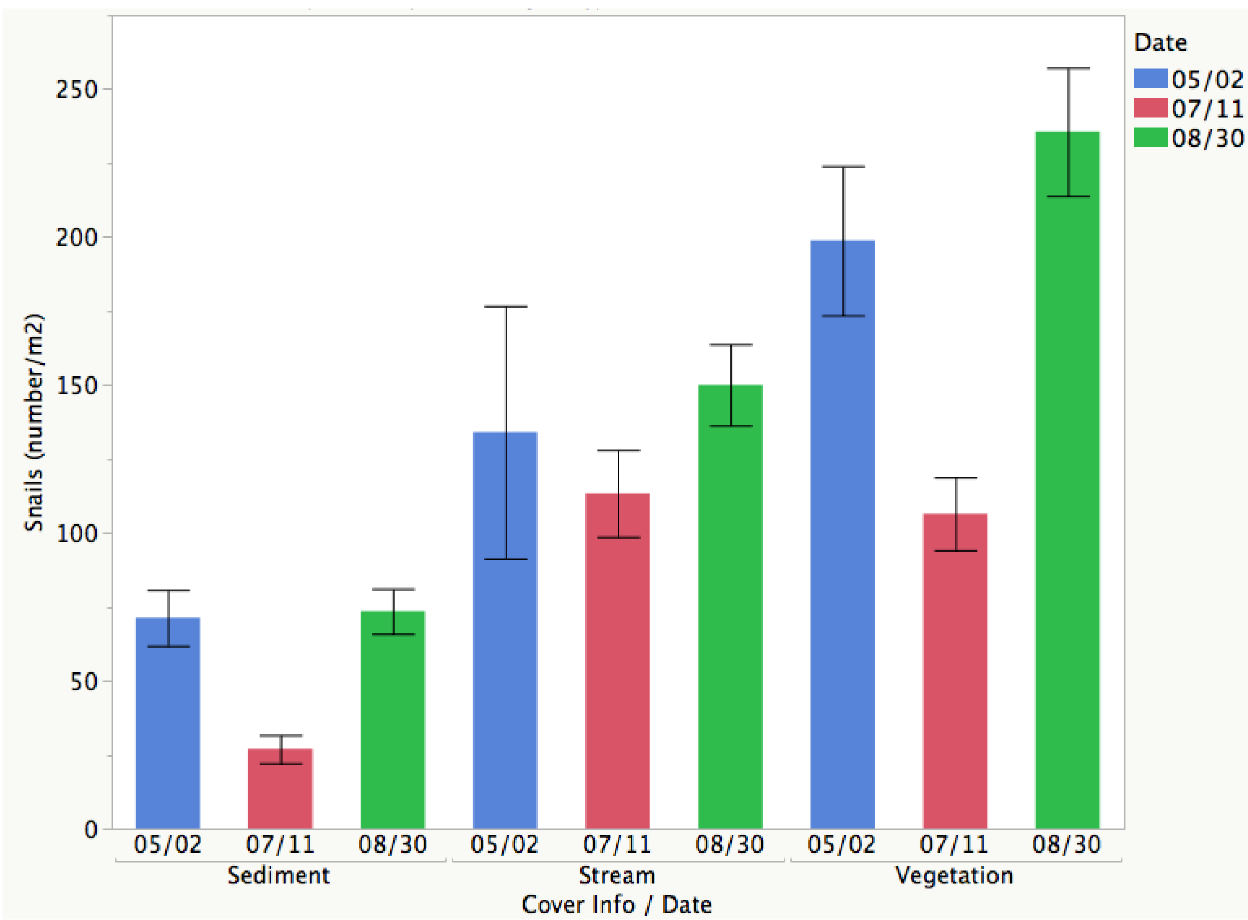


Figure 2. Means and standard errors of snail densities found along the shoreline of Barrell Pond on three collection dates in 2015.

Barrell Pond Experiments

Twenty cages were placed along existing marsh edges and the number of shoots were counted before and after application of snail and nitrogen treatments. After 12 weeks, the number of shoots expanded in cages without snails (both with and without added nitrogen), but on average retreated in the cages with snails and without nitrogen fertilization (Figure 3). Surprisingly, when snail numbers were maintained in the cages and the plants fertilized, the number of new shoots was no different than without snails. The effects of: 1) snail exclusion; or 2) fertilization with snails allowed, both led to significantly greater numbers of shoots, important for habitat restoration efforts. In addition, the application of nitrogen fertilizer may have a beneficial effect on new shoot number, but the increase was not statistically significant in this experiment.

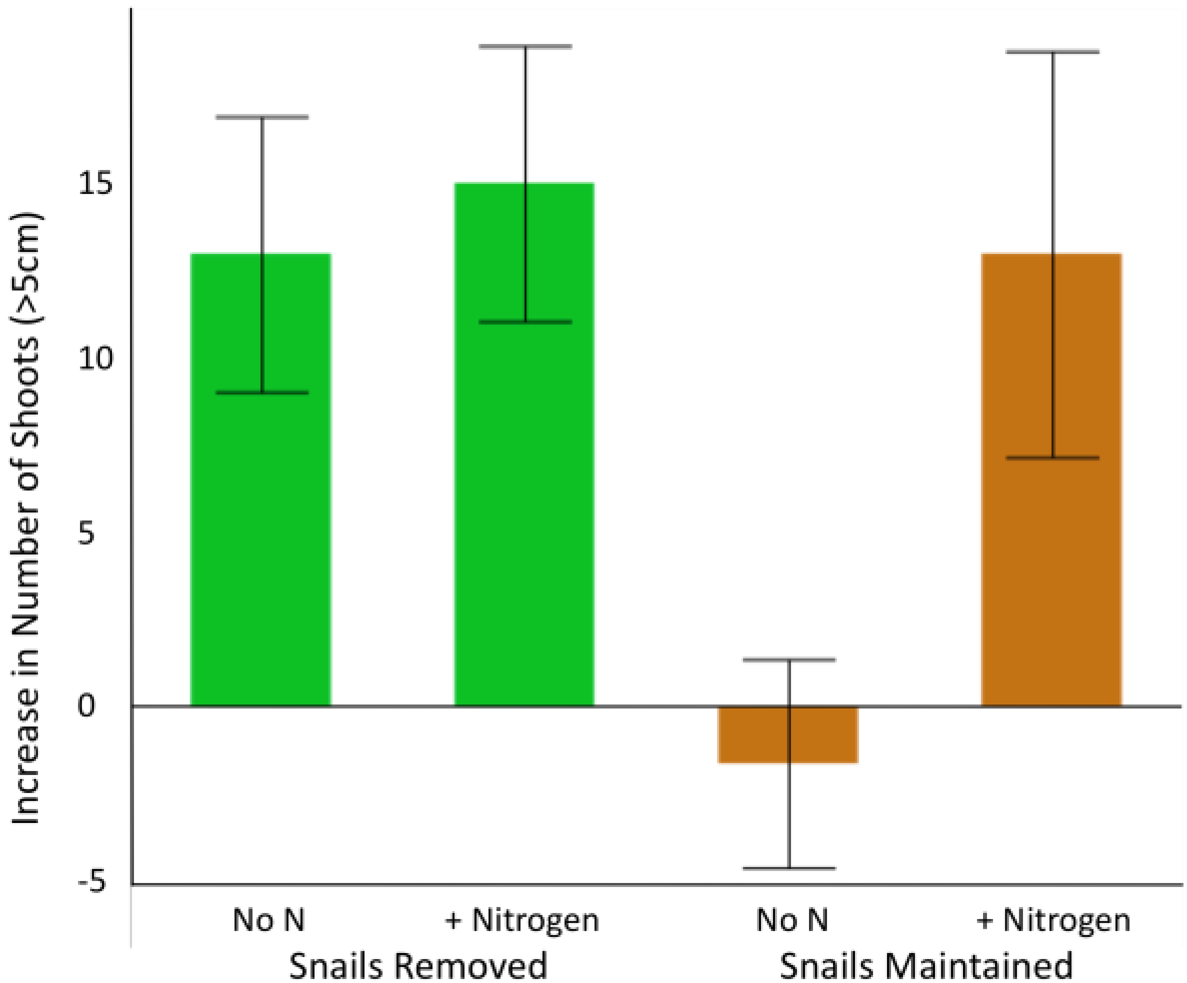


Figure 3. Expansion of existing salt marsh plants from existing salt marsh in cages with and without snails and with and without nitrogen fertilizer (n=5).

Twenty cages were placed at each of three elevations (high, middle and low) and one of four treatments manipulating nitrogen (N) and snails was assigned randomly to each cage: 1) No snails without N; 2) No snails with N; 3) Snails without N; and 4) Snails with N). Five groups of shoots were planted in each cage and snails and fertilized were removed or added according to treatments specified in the Methods. After 12 weeks, the length and number of leaves of each shoot were counted. Applying a regression equation for each shoot, final biomass was predicted and the initial biomass of each cage was subtracted from the final to show biomass increase (growth). Statistical analysis using ANOVA showed significant effects from snails, fertilizer and elevation (Figure 4).

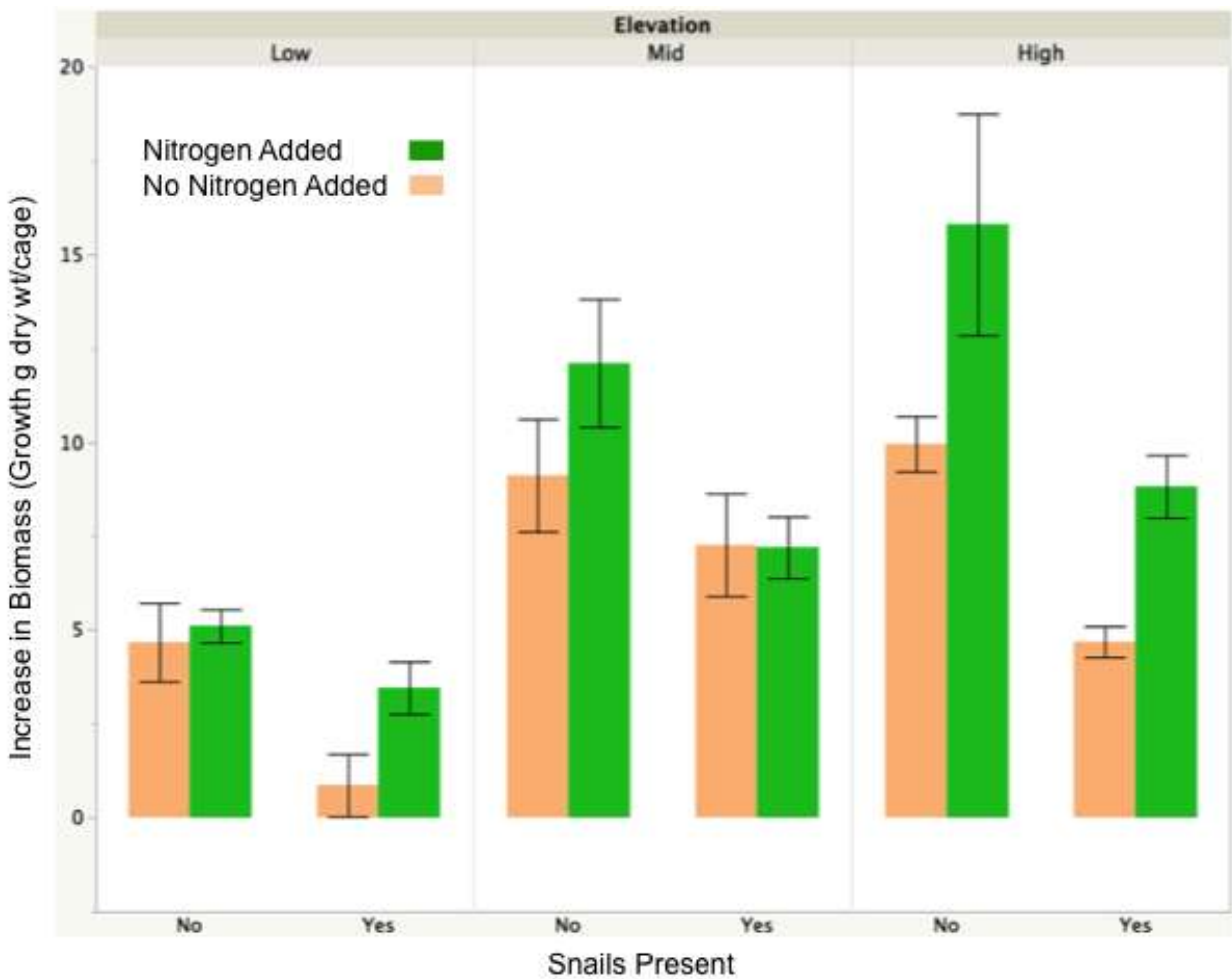


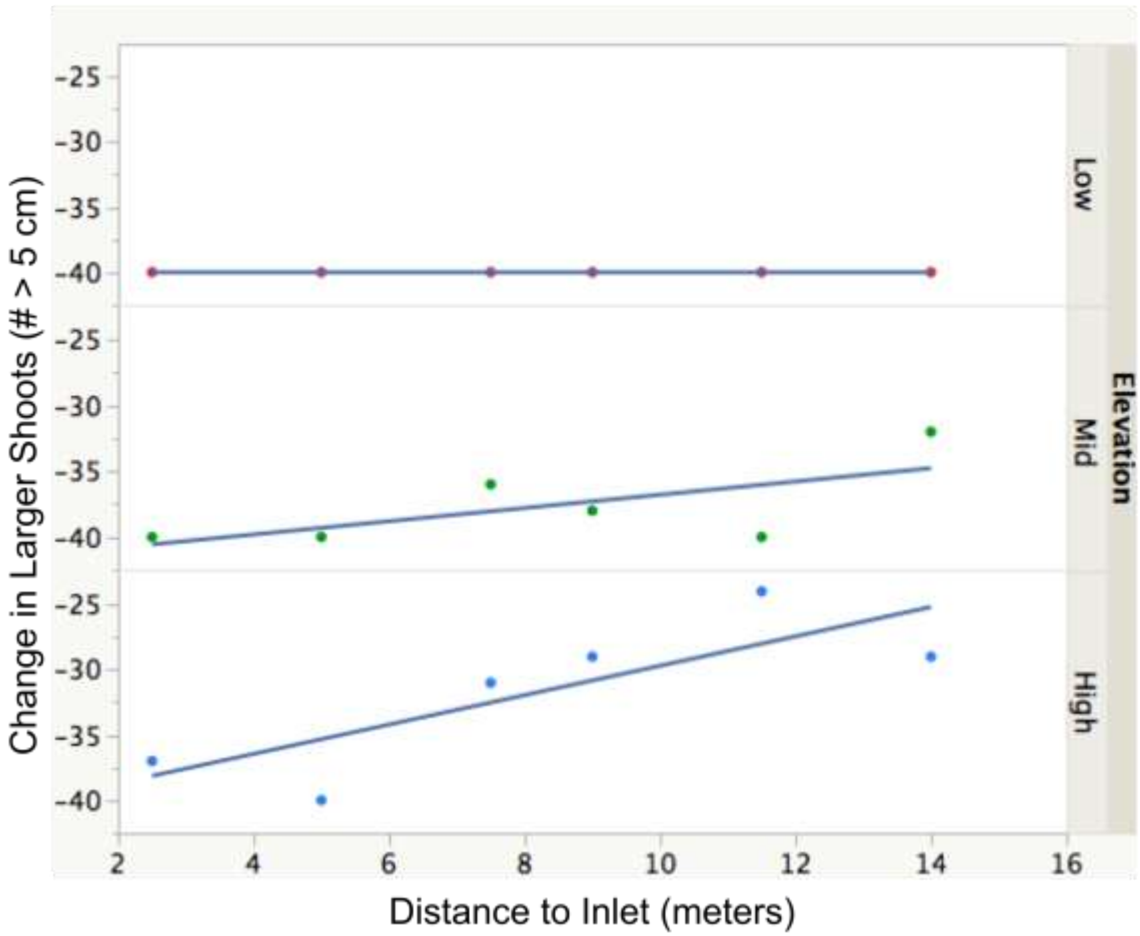
Figure 4. Change in biomass of *Spartina alterniflora* grown in cages with and without snails and with (green bars) and without (tan bars) added nitrogen at low, medium and high elevations. Means of 5 replicate cages (grams dry weight) are shown with standard error bars.

Snails added to cages resulted in 43% lower biomass growth in the plants; nitrogen addition led to 43% greater biomass increase; and lower elevation cages had 38% less growth than mid and high elevation cages. The interaction between Nitrogen addition and Snail presence was not significant (i.e., the effect of snails on growth was the same with or without nitrogen addition), nor were interactions between elevation and the two treatments. The mean biomass increases for each set of five replicate cages are graphed in Figure 4 to show both main effects (statistically significant) and interactive effects (not significant) found for this experiment.

Even though the effects of the snails on shoot number and growth were clear for these two experiments, the wholesale destruction of all the plantings as seen following the 2012 and 2013 restoration attempts was not observed. Similar to the results observed by Bertness along a fringing marsh with coarse sediments in Rhode Island and later by Tyrell et al. (2008) in a low marsh in Wells Maine, snails were found to have significant but not devastating impacts to the cordgrass planted for these experiments. The difference in effects between 2012-2013 and 2015 may be due to using cages in 2015, which prevent the snails from moving and grazing in waves across the shoreline.

York River Shoreline Experiment

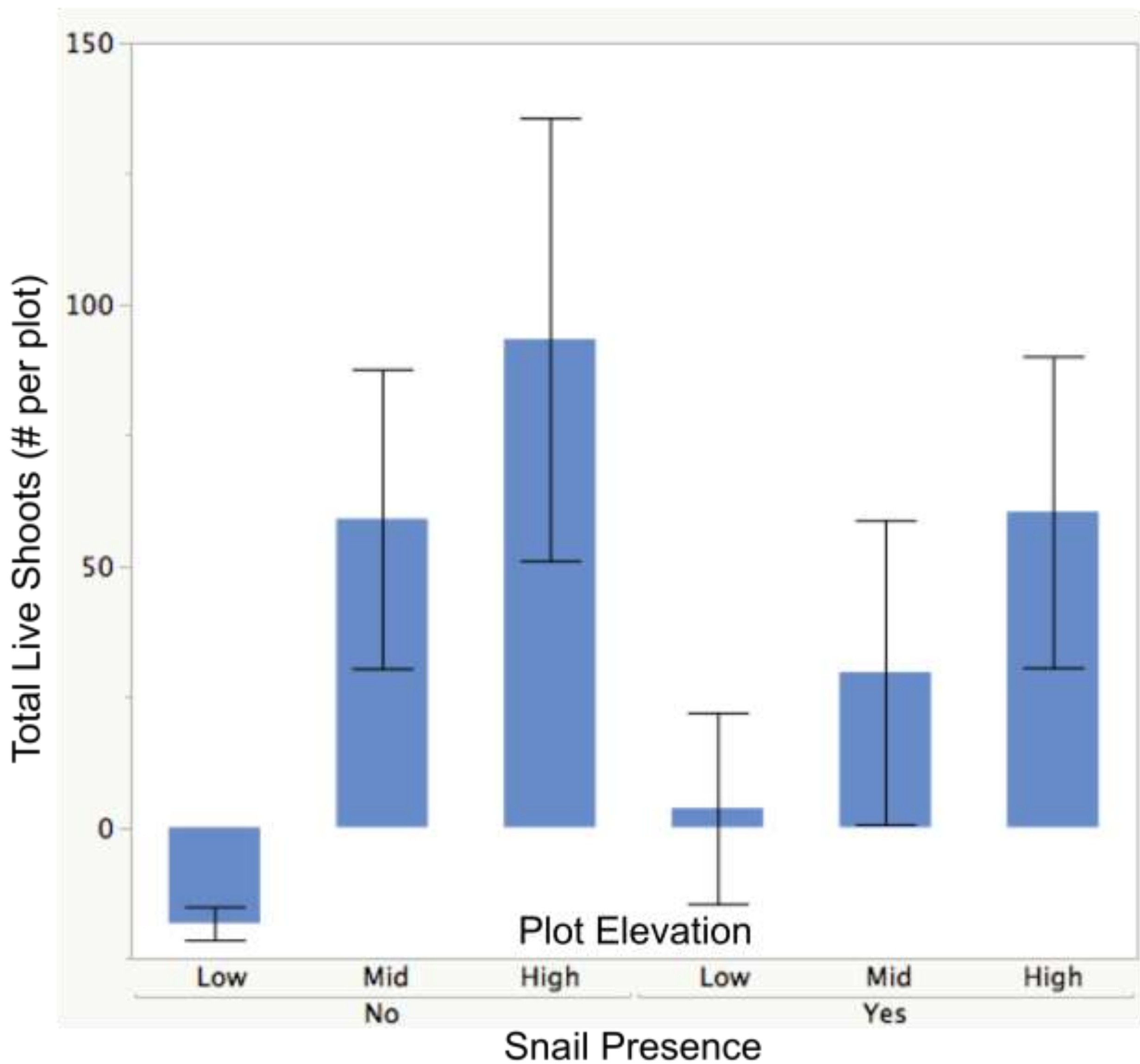
The shoreline was stabilized using baffles constructed from jute and wrack and then divided into 18 plots, with six plots at each of three elevations (high, mid and low). Smooth cordgrass was planted across the entire site and snails were removed weekly from half the plots and unmanipulated in the other half. By the end of the experiment, most of the taller shoots (greater than 5 cm) had been lost to snail grazing or physical breakage from currents or wave action, but most of the plantings put up many new young shoots. Figure 5 shows no survival of large shoots at the lowest elevation, but also very poor survival near the inlet. There was no effect of snails on these taller shoots, suggesting currents and waves contributed to their loss.



-25
-30
-35
-40
Change in Larger Shoots (# > 5 cm)
Low
Mid
High
Elevation
2
4
6
8
10
12
14
16
Distance to Inlet (meters)

Figure 5. Pattern of loss of larger cordgrass shoots on the York River shoreline plantings relative to elevation and distance to the inlet under the Wiggley Bridge. Data are raw numbers for large shoots planted in each plot of 40 plants.

Despite the loss of many of the larger shoots, most of the plants survived and produced new shoots that were still small by the close of the experiment. When tall and new short shoots are combined, there was a clear effect of elevation on their number, with mid and high elevation plots averaging many more shoots (Figure 6). Although the effect of snails was not statistically



significant at this site due to high variability (as indicated by large error bars), we found 60 to 90 shoots per plot if snails were removed but only 30 to 60 shoots in the presence of snails.

Figure 6. Total shoot number of cordgrass plantings averaged (with standard error bars) across three replicate plots of 40 planting units for each elevation and snail treatment on the York River shoreline.

York River Shoreline Marsh Restoration 2016

In spring 2016, a smaller portion of the marsh shoreline was replanted with *Spartina alterniflora* (cordgrass) on 25 cm (10 inch) centers. Plants were only installed along the upper two elevations relative to the previous year, since low elevation plants did not survive the 2015 growing season. Plants were protected by a wire mesh fence to prevent snails from migrating landward from the River into the planted area. Plants that had survived the winter from the previous year's experiment were not removed, but planted around. Snails were removed from the site periodically though the growing season. Observation of the marsh in fall 2016 suggested the plantings were surviving and growing well.

In Summer 2017 the plants were found to be growing well (Figure 7) and the site was cleaned of materials such as extra stakes and broken wire mesh. The wire mesh excluding snails was repaired and snails within the planted area were removed (580 on two occasions in July, 28 on one occasion in August). In August, the restoration site was evaluated for plant survival and proliferation of new shoots as well as 'volunteer' plants that seeded themselves. Survival of the planted cordgrass was estimated to be 92% at the close of the second growing season. The density of living plant plugs was about $28/m^2$. Thus plant density was almost twice as great as expected due to the expansion of plants. (We would expect to find $16/m^2$ if all the plants survived but did not expand.) In addition, the number of shoots greater than 5 cm in height averaged 114 $/m^2$. These results all indicate the restoration actions performed in 2016 (collection of fine sediments using jute baffles, fencing to exclude snails) are setting the conditions needed for marsh recovery at this site.

Vascular plant cover averaged just over 20% and the algae *Vaucherria* was estimated at 16% cover (Table 2). This is both important and a good sign that the marsh sediments are stabilized, at least in the lower portion of the planted marsh, because this algae forms a thin erosion-resistant mat. The planted cordgrass was the most abundant vascular plant species (about 11% cover), but common glasswort, sea-blite and sea lavender all contributed to the plant cover of the marsh, which averaged 20% (Table 2, Appendix 1). Plant cover varied by elevation, with cordgrass and the protective algal mat increasing, but high marsh plants decreasing from high to low elevations (Table 2).

Figure 7. Restoration along the York River shoreline in July, 2017.

Table 2. Percentage cover by species and relative elevation of York River shoreline in 2017. Cover values are means of six replicate samples, each $0.5m^2$ in area.

Relative Elevation	Cordgrass	Sea Lavender	Glasswort	Sea Blite	Marsh Felt (algae)	Bare
High	7.5	0.2	10.5	6.8	0.0	75.0
Mid	12.0	0.0	9.7	0.3	16.7	61.3
Low	13.3	0.0	0.5	0.0	31.7	54.5
Overall Average	10.9	0.1	6.9	2.4	16.1	63.6

The high marsh species were not associated with the cordgrass plugs, so they must have sprouted from local seeds that were able to germinate and produce plants. Sea blite and sea lavender were limited to the high elevation, but glasswort was prevalent at high and mid elevations. Visual observation of the upper edge of cordgrass showed smaller plants with significantly less shoots (>5 cm) than the low elevation plots (19 versus 38 shoots per plot, Appendix 1).

When the survey was performed, only 28 common periwinkles were removed from within the restoration fencing. However most of the plants showed signs of snail damage such as broken shoots, broken leaves, torn leaves and grazed leaves (Figure 8). Snail damage was assessed carefully in only one of the plots. The fifth sample at the mid elevation had 27 live shoots within the frame, but 22 of those shoots had at least one leaf that appeared to be damaged by grazing.

Since most of these damaged shoots have only 2-4 leaves, our observations suggest snail damage has significant impacts that weaken plants through the growing season.

Figure 8. Snail damage to live portions of four shoots of one planting unit (not counting four dead leaves where source of loss is unknown). Damage is highlighted by five orange ovals.

CONCLUSIONS AND RECOMMENDATIONS

A variety of human actions and environmental conditions have resulted in significant salt marsh loss along the shoreline of Steedman Woods Reserve, a property of the Old York Historical Society, especially in areas immediately east and west of the Wiggley Bridge. The Friends of Steedman Woods, working under the auspices of the Historical Society, have accomplished much to help the marsh recover. Rope barriers, covering over access routes, adding warning signs and creating a large educational sign all have contributed to reduced damage associated with public use of this fragile site. However, stress from grazing of plants by common periwinkles led to large-scale restoration failures in 2012, 2013 (Burdick et al. 2013) and 2015 (reported here).

Experiments conducted in 2013 and 2015 identified and quantified the impacts from caged snails on the plantings. We found that snails caused significant reductions in new shoot numbers and biomass produced by the planted cordgrass, preventing the plants from proliferating and weakening them. Our observations of caged and uncaged areas suggests the most dramatic snail damage is from the waves of snails that move landward as the tides rise (Figure 9). Although our experiments to document snail damage were successful, the cages prevented the snails from traveling in waves over the intertidal zone. We believe such waves had led to complete loss of our earlier restoration efforts.

Figure 9. Large dense (left) and small diffuse (right) waves of common periwinkles on the Barrell Pond shoreline.

In 2016 another restoration effort was conducted along the York River shoreline but the cordgrass was now protected from snail damage by wire mesh fencing. Erosion from currents and boat wakes along the York River shoreline was reduced by the jute wave baffles, boulders and galvanized mesh fencing. The jute baffles also helped stabilize the sediment and may have supported development of the algal mat that covers much of the planted area. The threat from snails is much lower on this side of the point, but it is still significant: 500 snails were removed from the planted area on one date in July 2017. Our limited observations in 2017 showed that most shoots had had been negatively impacted by the snails. We found wire mesh to be an effective barrier to snail movement and plant grazing. Once the fence was repaired, only 80 and 28 snails were found on two subsequent trips to the site. Plant survival and expansion through production of new shoots were both excellent by the middle of the second growing season.

Efforts to encourage the recovery of the York River marsh will need to include snail removal for several years. We recommend that a replacement snail exclusion fence be installed by mid-May 2018 and the site cleared of snails once a month throughout the summer. Revegetation of the upper edge of the recovering marsh may require some tree trimming of overhanging branches. We remain cautiously optimistic for the future development of the marsh along the York River shoreline. A similar approach may allow marsh restoration on the Barrell Pond shoreline: fencing to disrupt waves of snails, periodic snail removal, and catching fine sediments with jute baffles. Caged plants remain from the 2015 experiments (Figure 10) and could form the beginning of a successful restoration effort along this shoreline.


Figure 10. Cordgrass plants in 2017 from the plants caged in 2015 in the Barrell Pond.

References

Bertness, M. 1983. Habitat and Community Modification by An Introduced Herbivorous Snail. *Ecological Society of America*. *65*:370–381.

Blakeslee, A. 2007. Resolving the 150 year debate over the ecological history of the common periwinkle snail, Littorina littorea, in northeast North America. Doctoral Dissertation. University of New Hampshire, Durham.

Burdick, D. M., Peter, C. R. & Moore, G.E. 2013. Phase II of Tidal Marsh Restoration at Steedman Woods Reserve at York, Maine. Final report to Old York Historical Society, York, ME.

Morris, J. T., Sundareshwar, P. V, Nietch, C. T., Kjerve, B., & Cahoon, D. R. 2002. Responses of Coastal Wetlands to Rising Sea Level. *Ecology*, *83*:2869–2877.

Silliman, B. R., & Zieman, J. C. 2001. Top-Down Control of *Spartina alterniflora* Production by Periwinkle Grazing in a Virginia Salt Marsh. *Ecology*, *82*:2830–2845.

Tyrrell, M., Dionne, M., & Edgerly, J. 2008. Physical Factors Mediate Effects of Grazing by a Non-indigenous Snail Species on Saltmarsh Cordgrass (*Spartina alterniflora*) in New England Marshes. *ICES Journal of Marine Science*, 65:746–752.

Appendix 1. Plant data collected August 25, 2017 from York River shoreline restoration

Elevation	Distance from inlet	Live plants	Expected plugs	SpAl Survival (%)	SpAl Shoots >5cm	Cover Vascular Plants	Cover Vaucherria (algae)	Spartina alterniflora (%)	Limonium nashii (%)	Salicornia depressa (%)	Sueda lineraris (%)
High	A	5	6	83	30	36	0	20	0	6	10
High	B	7	7	100	24	19	0	7	1	7	4
High	C	6	8	75	17	27	0	5	0	7	15
High	D	8	10	80	14	17	0	4	0	8	5
High	E	6	7	86	9	24	0	3	0	15	6
High	F	9	9	100	21	27	0	6	0	20	1
Mid	A	8	9	89	39	24	20	12	0	12	0
Mid	B	8	8	100	44	39	5	14	0	25	0
Mid	C	5	5	100	44	17	20	12	0	5	0
Mid	D	5	6	83	24	8	20	8	0	0	0
Mid	E	8	9	89	27	12	30	6	0	6	0
Mid	F	7	8	88	51	32	5	20	0	10	2
Low	A	6	7	86	17	10	25	7	0	3	0
Low	B	7	7	100	38	20	30	20	0	0	0
Low	C	6	6	100	27	10	15	10	0	0	0
Low	D	6	6	100	25	8	30	8	0	0	0
Low	E	9	9	100	26	15	50	15	0	0	0
Low	F	8	8	100	36	20	40	20	0	0	0
Average		6.9	7.5	92.1	28.5	20.3	16.1	10.9	0.1	6.9	2.4
YORK RIVER SITE		PLOT SIZE = 0.25M2									
SNAILS REMOVED FROM SITE: 28											
MID-F PLOT DAMAGE FROM SNAILS ASSESSED: 22 OF 27 SHOOTS											