# FACTORS FOR LOSS AND RESTORATION OF *VALLISNERIA AMERICANA* IN THE HUDSON RIVER - HERBIVORY AND DEPTH IN SEDIMENT

A Final Report of the Tibor T. Polgar Fellowship Program

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**ABSTRACT**

Two storm events, Hurricane Irene and Tropical Storm Lee, struck the Hudson River watershed at the end of the 2011 growing season. In 2012, distribution of the most common species of submerged aquatic vegetation (SAV), *Vallisneria americana* (wild celery), in the Hudson River estuary had declined by more than 90 per cent, with no appreciable recovery in 2013 and 2014. Because of SAV's important role in providing habitat for aquatic life and increasing dissolved oxygen, managers and scientists have begun discussing the reasons for the loss, as well as how to assist its recovery through restoration efforts in the estuary.

Two factors, potentially important for the loss, recovery and restoration of *V. americana* in the Hudson River were investigated: sprouting success at varying depths in sediment, and herbivory pressure. Sediment washed into the river by the storm events may have added considerably to the depth at which the overwintering buds of *V. americana* are buried, impeding their ability to sprout. This hypothesis was tested in a greenhouse as well as in the river itself. Sprouting success was found to decrease drastically with depth in the river. This supports the hypothesis that sediment burial was a factor in the 2011-2012 loss of the plant in the river.

Herbivory was hypothesized to be a factor impeding recovery in the river and a potential reason for lack of recovery. Herbivory pressure was tested in the Hudson River using an exclusion cage experiment with controls. No significant difference in growth was found between treatments. There was no evidence to support the idea that herbivory pressure is a significant factor impeding growth of *V. americana* in the river.

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# INTRODUCTION

Aquatic life in the Hudson River, like that of many shallow rivers and estuaries, benefits greatly from submerged aquatic vegetation (SAV). The hidden nature and less than spectacular appearance of SAV often makes it underappreciated by the public, but it is in many ways the basis for a productive ecosystem in the river. SAV provides important ecological services to rivers and estuaries (Miller 2013) as well as other aquatic systems, for example, by increasing dissolved oxygen levels in the river, benefiting aquatic life in otherwise low-oxygen areas (Caraco et al. 2006; Findlay et al. 2006). SAV beds also provide habitat (Rozas and Odum 1988) and food (Schmidt and Kiviat 1988; Heck and Thoman 1984) for fish and other aquatic life, with densities of benthic invertebrates in the sediment under SAV beds 3X higher than unvegetated areas in the Hudson River (Strayer and Smith 2001).

This importance to the ecosystem makes the last century's large-scale loss, and sometimes even complete disappearance, of SAV from many aquatic ecosystems (e.g. Orth and Moore 1983) even more disconcerting. This loss is often attributed to agricultural and urban runoff increasing nutrient loading, leading to worsened light conditions, but in other cases attributed to weather events such as hurricanes (e.g. Rybicki et al. 2001; Stankelis et al. 2003) or drought (Harwell and Havens 2003), disease, destruction of habitat, competition with invasive species (Lotze et al. 2006) or by destruction and potential herbivory by aquatic wildlife (Crivelli 1983; Rodríguez et al. 2005). Even when the direct loss of SAV has been attributed to a single disturbance event, the lack of regrowth may still be due to more enduring changes in the ecosystem (Rybicki et al. 2001). The loss of SAV translates into loss of fish and other aquatic life and a declining health of the system, in turn leading to economic loss for fisheries and tourism (Kahn and Kemp 1985).

*Vallisneria americana*, an endemic, submerged aquatic species, historically represented the large majority of the submerged aquatic vegetation (SAV) in the lower Hudson River (Findlay et al. 2006), with SAV covering 6% of the total area of the Hudson River below the Troy dam and 18% of shallows (<3 m) in the mid 1990's (Nieder et al. 2004). *V. americana* generally grows in dense beds in the river. It has tape-like leaves that are submerged and rooted but can float on the surface. *V. americana* reproduces sexually as well as asexually, through stolons growing off the main plant and creating new rosettes that later detach, and by producing tubers from which new plants sprout in the next season (Korschgen and Green 1989). The spread and growth of *V. americana* is influenced by light conditions, composition of sediment, flow, competition, climate, salinity, herbivory, human disturbance and storm events (Caraco and Cole 2002; Korschgen and Green 1989; Nieder et al. 2004; Jarvis and Moore 2008; French and Moore 2003; Moore et al. 2010; Rybicki et al. 2001). *V. americana* has been in modest decline from the late 1990s and early 2000s in the Hudson River, losing about a third of its coverage in the river, from approximately 18 $km^2$ to 12 $km^2$ (Findlay et al. 2014; Nieder et al. 2004; Strayer et al. 2014).

In 2011, the Hudson River experienced two large storm-events: Hurricane Irene (August 21-28), and Tropical Storm Lee (September 1-5). Hurricane Irene produced 30 to 45 cm of rain in some parts of the Hudson River watershed, followed by an additional 8-23 cm of rainfall during Tropical Storm Lee over a 48 hour period (Villani et al. 2012), a massive increase compared to an average monthly precipitation of 10 cm for the months of August and September (NOAA/NWS 2014). Estimates place the flooding from these events in the 100-500 year recurrence interval (Smith 2012). The precipitation from these events caused a historically high summertime discharge of 8680 $m^3/s$ at the mouth of the river (Horowitz et al. 2014). The year after the storm, in 2012, *V. americana* beds had an observed loss of >90% (Strayer et al. 2014). Due to its importance to the Hudson River estuary, the potential assisted restoration of *V. americana* has been discussed by managers and researchers in the years after the loss (Miller 2013; HRNERR 2014).

This study addressed two factors related to the loss and potential restoration of *V. americana* in the Hudson River after storm events in August and September 2011. The first hypothesis tested is that the recovery of this species in the growing seasons after the storm has been hampered by new sediment settling out after the storm and burying the overwintering buds from the earlier season which do not have enough energy stored to reach the surface. The second hypothesis is that regrowth has been hampered by herbivory pressure and destruction by animals on the few remaining *V. americana* beds in the river.

Other potential factors of loss could be light extinction, scouring or a simultaneous event unrelated to the storm such as disease or pollution. Light extinction was considered improbable as the storm event occurred close to the end of the growing season. Scouring would have caused uneven loss depending on flow but the loss in 2012 was consistent through the whole system. No other unrelated disturbance event has been observed or reported.

**Lack of Recovery due to Burial by Sediment**

The hypothesis of the burial of SAV in the Hudson River is based on the large amount of sediment that was washed into the river during the storm events in 2011. A total of 2.7 million metric tons (MMT) of sediment was washed in from tributaries, especially in the Mohawk Valley, and only 1 MMT were observed passing the monitoring station in Poughkeepsie in the next month (Ralston et al. 2013). The remaining 1.7 MMT would be enough, if spread evenly, to cover the river-bed from the dam at Troy to Poughkeepsie in 3 cm depth of new sediment. The actual amount deposited in SAV beds in 2011 may have been higher as SAV is known to trap sediment as well (Findlay et al. 2006)

For *V. americana*, the most common mode of reproduction is asexual (McFarland and Shafer 2008). When doing so, it relies on energy stored in reproductive structures (tubers) in the sediment to achieve enough stem and leaf growth in early summer in order to reach the portion of the water column with enough light for photosynthesis to take place. If plant structures (tubers or seeds) are buried too deeply, they may lack sufficient energy stores to send up shoots through the sediment. With *V. americana's* already modest decline in the last decade in the Hudson River, burial by sediment from the double impact of Hurricane Irene and Tropical Storm Lee may have been enough to cover the remaining beds of *V. americana*. Sediment burial as a potential factor of loss has been explored earlier in the Potomac River. There, laboratory experimental results showed a steep drop-off of visible plant growth with tubers of *V. americana* buried beyond 10 cm depth in sandy as well as silty-clay sediment (Rybicki and Carter 1986).

**Lack of Recovery due to Herbivory**

SAV restoration, including for *V. americana*, has been conducted in multiple rivers in the United States with multi-year projects ongoing by the Virginia Institute of Marine Science (VIMS) in Chesapeake Bay (Kenneth Moore, personal communication, 2014). This work has developed successful methods of transplanting and seeding of plants and puts emphasis on certain factors of success (Moore and Jarvis 2007). One major factor of success has been herbivory protection, with experiments showing no regrowth of new seed beds unless netting is set up to protect the young plants (Moore et al. 2010).

The rate of herbivory on aquatic macrophytes by fish and other aquatic life has been contentious (Lodge 1991) but considering the dramatic difference between exclusion and non-exclusion plots in the Chesapeake Bay (Moore et al. 2010), and the geographic and ecological (including species composition) similarities between the Chesapeake Bay and the Hudson River, herbivory is a valid candidate as a reason for continued lack of recovery in the Hudson River. Blue crab (*Callinectes sapidus*) has been indicated as the possible reason for destruction as the crab clips the plants (Kenneth Moore, personal communication, 2014). Other potential candidates are waterfowl that eat plants or tubers (Sponberg and Lodge 2005; Stafford et al. 2012) and common carp (*Cyprinus carpio*), a well-established non-native species in the Hudson River that has been shown to destroy submerged vegetation in other systems (Crivelli 1983).

## METHODS

### Study Site

Field experiments on herbivory and depth in sediment were conducted during the growing season of 2014. These experiments were located in the main stem of the Hudson River outside of Tivoli Bays (river mile 98, coordinates 42°2'27"N 73°54'38"W) near the eastern shore in between Magdalen Island and train tracks, in an area with earlier documented SAV beds according to GIS data based on aerial surveys in 1997, 2002 and 2007 (Cornell IRIS 2011).

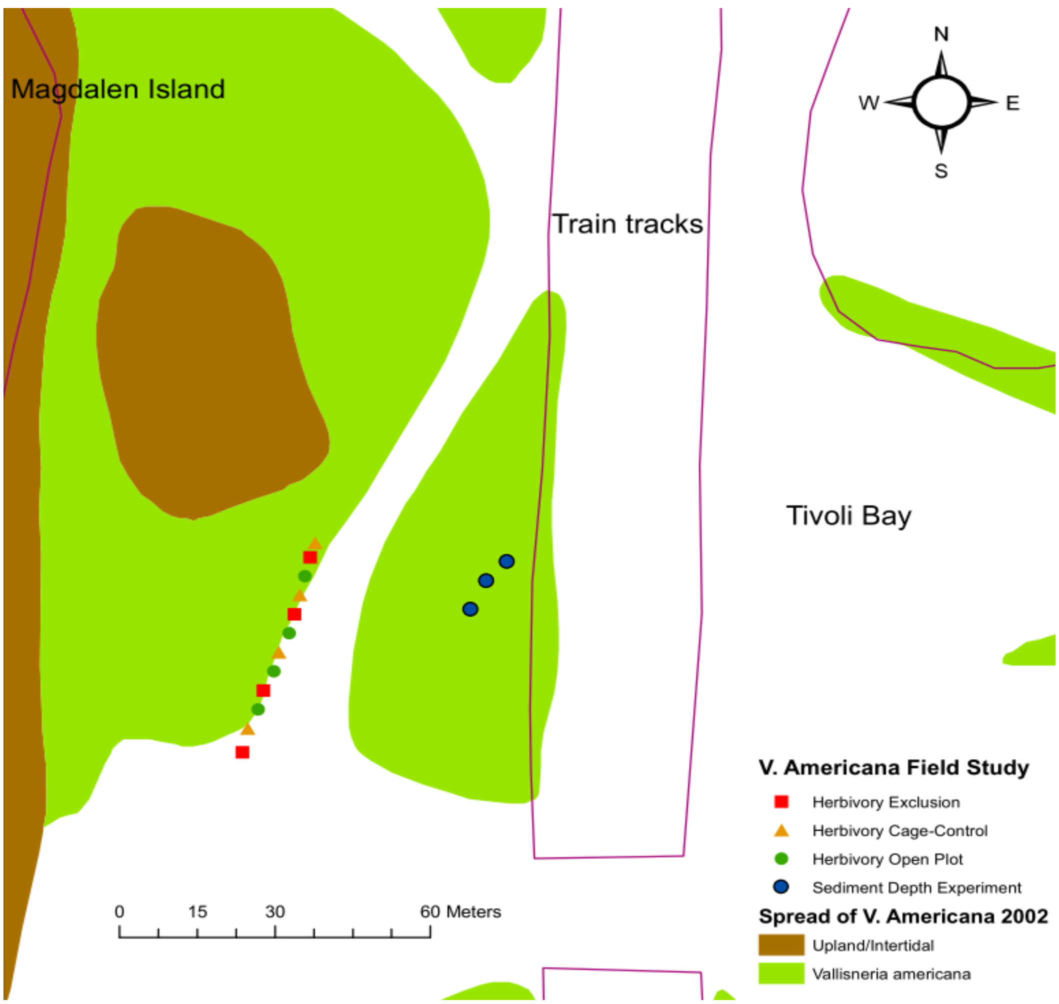


**Figure 1: Map of field experiment site**

**Depth in Sediment - Greenhouse Experiment**

Greenhouse experiments were also conducted in 2014. Forty overwintered *V. americana* tubers were purchased from a nursery for this experiment. Tubers were weighed wet and then buried at 5, 10, 20 and 30 cm, with 10 tubers at each depth. Tubers were buried in sediment taken from the lower Hudson River that had been cleaned of any plant material and then compacted by hand to simulate sediment compaction in the river. PVC pipes were used for pots and 2 tubers were put in each pipe providing 10 cm of sediment below the planting depth. Planting was conducted on 5/16/2014. All 20 pipes were marked and placed in a large plastic tub filled with water from the lower Hudson River and kept aerated. Temperature was controlled by opening and closing window sections of the greenhouse. After two months, plants were harvested and sediment was sieved to try to recover unsprouted tubers.

In a separate tub a validity experiment was conducted to test if the nursery tuber sprouting was comparable to those taken directly from the river. Fifteen tubers from a nursery were planted at 2 cm depth and two batches of 15 tubers taken from the river near the experiment site were planted at 2 cm and 5 cm and placed in three pots in a tub. DO and temperature readings were taken for each tub using a dissolved oxygen meter (YSI ProODO Instrument, Xylem Inc.) and iButtons. Both tubs were monitored frequently for sprouting, and date of first sprouting was recorded. Six sediment samples taken from the sediment used were dried and then ashed to determine organic content using the loss-on-ignition method (Schumacher 2002).

**Depth in Sediment - Field Experiment**

The field experiment was located outside Tivoli Bays in the main stem of the Hudson River. Thirty unsprouted tubers in good condition were excavated from the river near the experiment site, weighed wet and then replanted in individual pots at 2, 5 and 10 cm, with ten tubers at each depth in sediment. Samples were buried in the same sediment used for the greenhouse experiment. Pots were clustered in threes, with one of each depth in each cluster for a total of ten clusters, and each pot was marked by a small flag. Three poles demarcated the area with three clusters each around two of the poles and four clusters around one of the poles. Tubers and pots were buried on 6/16/2014.

Each pot was monitored for sprouting by feel due to low visibility in the river. This monitoring was conducted on 7/8/2014 and 7/21/2014. At the end of the experiment, on 7/31/2014, pots were taken out of the river and sprouted plants were washed, measured for length and the amount of plantlets and tubers or flowers were counted. The plants were then dried and weighed to the nearest 0.01 g. Three sediment samples were taken from the sediment in pots after harvesting, processed and measured to see if the in-river treatment had changed the organic content of the sediment. All data were continuously recorded in Google Docs (Google Inc.) Statistical analyses were performed in Minitab17 (Minitab Inc.). For the sediment burial experiments, binary logistic regression analyses for plants sprouted per treatment were conducted, with depth as a continuous variable and a two-sided confidence interval.

**Herbivory Experiment**

Twelve plots were chosen and laid out in a North to South pattern (upstreamdownstream) at a depth of between 0.6 and 0.9 m (mean low tide). The plots were square, with each side measuring approximately 1.2 m. Plots were designated either as Open, Exclusion, or Cage-Control. Open plots were marked in each corner with 4 PVC stakes of 1.8 m in length. Exclusion plot cages were made from PVC piping and covered in 2.5 cm metal poultry fencing to a height of 1.2 m with a detachable roof. Each side was constructed with a 'skirt' of 30 cm poultry fence lying flat against the ground to prevent potential herbivores from burrowing under the cage (see Moore et al. 2010). Cage-Control plots were set up just as the Exclusion plots but with one side open, without fencing.

**Figure 2: Exclusion cage at field site**

Plots were maintained, cleaned and repaired once a week. The depth of each cage was measured in the center and adjusted for tide. Light measurements were taken at six plots (two of each type of plot) with HOBO light loggers. Six sediment samples were taken between plots. These were then dried and ashed to determine organic content of the sediment.

Eight peat-pots of sprouted *V. americana*, obtained from a commercial nursery, with two plants in each pot were planted in each plot in a square pattern. Plants had approximately 8 cm of leaf length when planted. Planting and installation of cages were done in summer (6/27/2014) and pots were harvested in three rounds, three pots taken in the first round (7/31/2014), two in the second round (8/28/2014) and the remainder in the third harvest (9/17/2014).

Plants were only harvested if its peat-pot could be identified. Any connected runners outside of peat-pots were harvested as well. After harvest, the length of the three longest leaf blades were measured, plantlets and leaf blades were counted, and plants were divided into aboveground and belowground biomass. Any tubers or flowers were counted. In the third harvest, tubers were weighed wet. Plants were dried for a minimum of 24 hours at 60 C° and dry weight measurements were taken. Measurements of dry weight, blade length, amount of blades and amount of plantlets or tubers produced were compared across harvests to look at the effects of herbivory. For the herbivory experiments a one-way ANOVA test was conducted on each response variable separately for each harvest date with each treatment compared pair-wise through a Tukey-Kramer test if ANOVA showed significant differences. The harvested plants from each pot (two original plants per pot) was the unit of measurement.

# RESULTS

## Sediment Burial - Greenhouse Experiment

None of the 40 tubers in the greenhouse sprouted during the experiment phase. The sediment was sieved with no tubers recovered. However, sprouting was recorded in the separate validity trial. First sprouting in the validity experiment was recorded on 5/27/2014, 11 days after planting. Mean organic content of the sediment used was 2.94% ($\sigma = 0.24$).

| Total number of identifiable separate plants | Total number of rosettes | Total dry weight of sprouted plants | Initial tubers | Depth in sediment (cm) | Source |
|---|---|---|---|---|---|
| 2 | 13 | 2.37 | 15 | 2 | Nursery |
| 5 | 10 | 2.2 | 15 | 2 | River |
| 1 | 3 | 1.41 | 15 | 5 | River |

**Table 1. Results of validity trial experiment.**

## Sediment Burial - Field Experiment

Sprouting in the planted pots was observed in the field (by feel) at the first observation, after 23 days. No further sprouting was found in the next observation or during harvest. All pots were recovered at harvest. The area used for the sediment burial experiment had been recorded as an SAV bed earlier in 2002 and 2007. At the time of planting for the experiment no *V. americana* sprouting was observed, however, by the time of the first observation there was dense *V. americana* growth in the area. Planted tubers could be easily discerned from wild due to the pots.

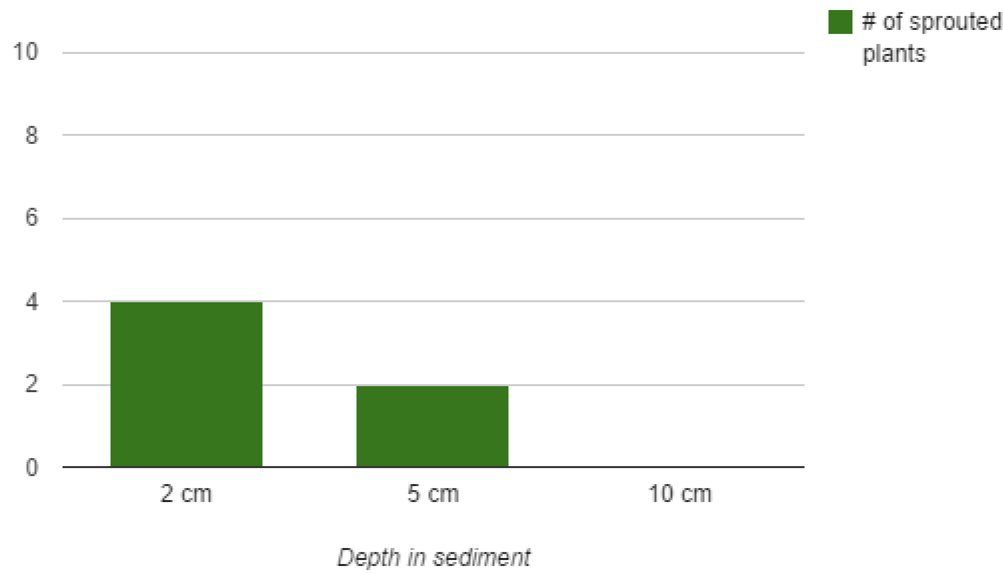


**Figure 3. Total number of sprouted tubers in-river**

There was a significant difference in sprouting by depth, with 40% of plants at 2 cm sprouted, 20% at 5 cm and none at 10 cm ($p$=0.014).Total and average dry weight of the plants sprouting at 2 cm were higher compared to those at 5 cm (see Figure 5). Average numbers of blades and rosettes were also higher at 2 cm than 5 cm. Since there was no sprouting at 10 cm no data could be recorded. The mean wet-weight of tubers, measured before planting, of the six successfully sprouted plants was slightly higher (2.5 g) than that of the twenty four non-sprouted plants (2.1 g), but the difference was not significant (two-tailed unpaired *t*-test $p$-value = 0.3454).

| Average # of rosettes | Average # of blades | Average weight of sprouted plants (g) | Total weight of sprouted plants (g) | # sprouted | # buried tubers | Depth in sediment (cm) |
|---|---|---|---|---|---|---|
| 5 | 20.5 | 0.59 | 2.37 | 4 | 10 | 2 |
| 3 | 11 | 0.31 | 0.62 | 2 | 10 | 5 |
| - | - | - | - | 0 | 10 | 10 |

**Table 2. Comparative data on in-river sediment burial experiment.**

Comparing the wet-weight of the tubers pre-planting to the ones that later sprouted was slightly higher (2.5 g, N = 6) than unsprouted ones (2.1 g, N = 24) but the difference was not significant (two-tailed unpaired *t*-test *p*-value = 0.3454). Pots in the river and in the greenhouse were sieved after the experiment and it was observed that unsprouted tubers did not survive (i.e., no tubers were recovered). It was also observed that most tubers in the river were found at an approximate depth of 0-3 cm. Mean organic content (three samples) of sediment from river pots after harvest was 3.81% ($\sigma = 0.09$), about 1% higher than when buried.

**Herbivory Experiment**

All cages survived the growing season with only minor repairs needed. Accumulation of floating vegetation, mainly water chestnut (*Trapa natans*), was extensive and required weekly cleaning. Eighty-four plants were harvested out of 96 originally planted; plants were not harvested if the peat-pot could not be found. Five Control plot plants, Four Exclusion plot plants and three Open plot plants were not recovered. Two of the plants, one in an Open plot and one in a Cage-Control plot, were observed to have lost most of their growth, seemingly ripped or pulled but with part of their peat-pot remaining, these plants were included in analyses. A blue crab claw was found inside one of the Exclusion cages. It was observed that Exclusion and Cage-Control plots seemed to accumulate more sediment on top of the pots than Open plots, although no controlled measurements were taken.

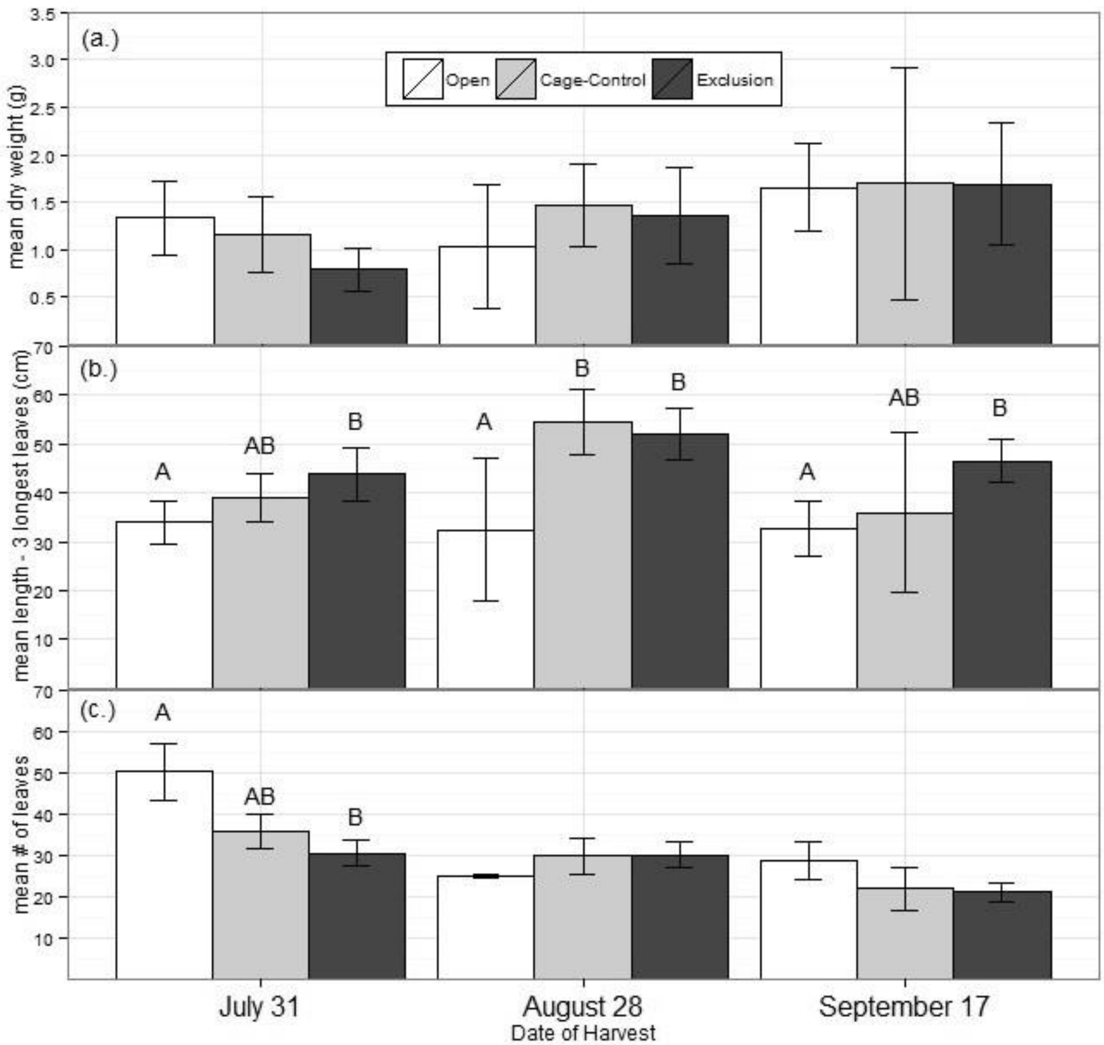


**Figure 4. Mean dry weight (a), mean length of three longest leaves (b) and number of leaves per pot (c). Error bars as 95% confidence interval. Differences**

**between treatments at same harvest date as per ANOVA post-hoc Tukey-Kramer method noted above bars if significant (95% C.I.).**

The difference between Open plots and Exclusion plots was statistically significant in the first harvest for blade length, number of blades, number of rosettes, but not for dry-weight. There was no statistically significant difference between Exclusion and Control (one side open) indicating a lack of herbivory. Average blade length was the only factor that differed significantly between Open plots and Exclusion plots through all three harvests. Blade length did not differ significantly between Control plots and Exclusion plots.

In the third harvest 20 out of 24 pots had produced tubers, as compared to one pot in the second harvest and none in the first. Neither the weight nor number of tubers differed significantly between the three treatments. Plants were buried in peat-pots but plants sent runners outside the potted area. Mean organic content of sediment between plots was 6.27% ($\sigma$=1.03). Light meter readings were taken over three days but were inconsistent and yielded no dependable results, potentially due to coverage by plants or sediment. There were no correlation between growth and relative north-south position of cages.


**Figure 5. North-south comparison of dry weight of plants.**

# DISCUSSION

## Sediment Burial

The results of the sediment burial experiment lend support to the hypothesis that increased depth in sediment will decrease the likelihood of sprouting for *V. americana* tubers in the Hudson River. Although lack of sprouting in the greenhouse could potentially be attributed to lack of flow or to excessively high temperatures, the tubers in the validity experiment in the same greenhouse room and similar conditions did sprout successfully at 2 cm depth.

The field experiment further showed a clear correlation between depth in sediment and sprouting (see Figure 3) with 40% sprouting at 2 cm, 20% at 5 cm and no sprouting at 10 cm. Following the estimates by Ralston et al. (2013) new sediment in the lower Hudson River may have added 3 cm in depth if spread evenly, and potentially more than that in active SAV beds due to sediment trapping (Findlay et al. 2006). The in-river experiment shows a clear effect of increased depth in sediment on sprouting. If sediment depth of tubers changed from 2 to 5 centimeters, the experiment indicates a halving of successful sprouting, which could be a potentially river-wide effect. During excavation for tubers to be used in the experiments, it was observed that tubers were found mostly in the top 1-2 cm layer of the sediment. Three more centimeters added on to the depth (to 5 cm) may have drastically reduced and potentially slowed sprouting in the season after Irene and in turn affected the available stock to produce tubers for coming seasons; however, this may not solely explain the > 90% loss witnessed in 2012 as compared to 2011.

The depths chosen at the beginning of the experiment were based on a study in the Potomac River by Rybicki and Carter (1986) where the tubers were planted from 10 to 35 centimeters. These authors found that sprouting declined from about 90% at 10 cm to 0-25% at 25 cm, depending on sediment composition. The difference between Rybicki and Carter's (1986) results and the present experiment could potentially be attributed to the high turbidity of the Hudson River or the more northern latitude, as compared to the Potomac, decreasing light and heat signals for the tubers (Jarvis and Moore 2008; McFarland and Shafer 2008) or a difference in sediment composition. Jarvis and Moore (2008), in a similar experiment in Chesapeake Bay chose 5 depths between 0.2 and 10 centimeters for *V. americana* seeds and found a large difference in oxidation-reduction potential above versus below 2 cm, but they did not find a significant difference in sprouting success.

In the same paper, Jarvis and Moore (2008) reported that higher amounts of organic matter correlates negatively with germination success of *V. americana* seed, and that germination decreased by approximately half between 1.5% and 3% of organic content. Although seed germination and tuber sprouting are different, the high organic content (2.94%) in the sediment used for the greenhouse experiment may have still have affected the tubers. How the sediment burial effect would affect other rivers would depend on the geomorphology of the system and its tributaries; the Hudson River had much of its sediment supplied from easily suspended sediment in the Mohawk River tributary (Ralston et al. 2013), this may not be the case in other systems.

**Herbivory**

The results from the herbivory experiment in the river provided little to no evidence that herbivory from larger herbivores was impeding *V. americana* regrowth in the area. This may be due to the Hudson River supporting lower density of herbivores than Chesapeake Bay. For comparison, Chesapeake Bay has a large commercial blue crab fishery (Chesapeake Bay Foundation 2008), as compared to a small (and diminishing) population of the species in the Hudson River (NYSDEC 2015). Low blue crab numbers were reported by local fishermen (personal communication - Stuart Findlay, 2014) and it may be that the drastically lowered stock of SAV in 2012 and 2013 meant that herbivores and animals reliant on SAV have already decreased or changed migration patterns by 2014, as has been shown to happen with both waterfowl (Hansson 2010) and with fish (Winemiller and Jepsen 1998).

The experiment did not test for herbivory from herbivores smaller than 1 inch in body width, such as small fish or invertebrates. There could also potentially be herbivory of the overwintering buds during the fallow season as has been observed by swans and other waterfowl in lakes and rivers in North America (Sponberg and Lodge 2005, Stafford et al. 2012). Plants were observed to have more rosettes in the first harvest (see Figure 6), especially outside the pot. This could be due to quick spread in the beginning of the season and subsequent deterioration of runners from the original rosettes. In the later harvests, more deteriorated and broken connections were observed.

The high organic content in the area around the herbivory experiment would only have a limited effect on the potted plants as most of the underground growth was centered in the peat-pot.

**Storm Impact and Restoration**

Perhaps one of the more important outcomes of the herbivory experiments is to show that plants from nursery stock can survive and grow in the river with low mortality, rapid spread, and with production of tubers. The apparent lack of a need for herbivory protection may be beneficial as it would decrease costs for any future restoration efforts in the Hudson River.

'Tuber banks' have been discussed as being a source from which *V. americana* could recover after a disturbance (Harwell and Havens 2003), but from the results of this experiment, *V. americana* tubers that do not sprout appear to deteriorate and do not create a tuber bank that could last more than one season. This means that the season after the disturbance the potential tuber bank would have to have good enough conditions to sprout and establish a new set of viable tubers. Establishment after a storm event that removes tubers or creates negative conditions lasting more than a season (e.g., increased settled sediment or worsened light conditions) may therefore have to come from sources such as seeds banks, surviving *V. americana* beds in the river and from other nearby populations or via animals, as has been observed in similar species (Harwell and Orth 2002; Rybicki et al. 2001).

From the herbivory experiment it was also observed that almost all tubers were produced at the end of the season between 8/28/2014 (second harvest) and 9/17/2014 (third harvest). This timing corresponds to when the storm would have caused high turbidity in the river (Ralston et al. 2013).  This may have led to lower light availability for plants going into the reproductive stage and producing smaller tubers that would have had an even more difficult time sprouting when buried. These "death spirals" with *V.*

*americana* have been recorded before (Titus and Hoover 1993) as each stage negatively reinforces the next, so that the second year's crop may not have had enough energy reserves to re-establish quickly.

Hurricane season on the Atlantic seaboard coincides with the growing season in the Hudson River (NOAA/NWS 2014) which means most hurricanes affecting the Hudson River would cause both light-extinction and sediment burial issues for SAV. It may be that both effects combined to decrease re-sprouting in the next year, with small tubers, due to low light during the earlier growing season, having to sprout out of deeper sediment, due to sediment burial. The only time this would not have had any effect would be if a storm occurred after or before the growing season but before the river froze over.

Hurricanes can have serious and long-lasting effects on rivers (Strayer et al. 2014) and with climate change predicted to increase the strength of hurricanes and the amount of precipitation over the U.S. Northeast (IPCC 2013), it is important to figure out how hurricanes may affect SAV in the long run. Strayer et al. (2014) proposed a framework for describing disturbances and stresses that lead to long-term change in the river, and a hurricane would represent an abrupt, brief, fast and severe driver. That said, the response may be a long, gradual and slow recovery. Since not much can be done to stop hurricanes, and restoration, as stated before, may be undone easily by the next storm, it is also important to focus on how to make the recovery a little less slow, long and gradual. Rybicki et al. (2001) identified storms as being the reason for loss of SAV in the Potomac, the reason for its slow regrowth was argued to be the low water quality (high nutrient load and high turbidity). Although water quality has improved in the Hudson River in the last few decades (Miller 2013) there is still room for improvement. Lowering turbidity generally would mean that light extinction and sediment deposition would be less severe during a storm event and recovery could proceed faster due to higher light penetration in successive seasons unless offset by higher growth of phytoplankton. This could create a positive cycle with more SAV, and especially, *V. americana*, in turn also improving water quality (Findlay et al. 2006).

Any future restoration of SAV would have to consider that restoration efforts may be temporary and gains in plant stock from restoration could be wiped out by the next storm. Restoration, even without the need for herbivory protection in the Hudson, may be considered an expensive option if the reality is that the job will be undone in short time. On the other hand, if restoration is not done, multiple storm events returning at close intervals could potentially extirpate the stock of *V. americana*, and SAV in general. If a storm event of the same magnitude as Irene and Lee were to occur in the Hudson Valley in the next few years, the remaining SAV may well be gone. Extirpation of SAV has happened in other systems (Rybicki et al. 2001) and in the Hudson River extirpation of SAV may also affect fish populations and general water quality. Assisted restoration may bring SAV back much more quickly than natural regrowth and limit any effects on important fish species in the river but the cost of restoration should be calculated and weighed against the potential gains both environmentally and economically for the river, its biota and the people that rely on it.

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