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Recovery of salt marsh vegetation after removal of storm-deposited anthropogenic debris: lessons from volunteer clean-up efforts in Long Beach, NY

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Running head: Salt marsh recovery after marine debris removal.

Highlights

The impacts of large wooden debris removal from a New York salt marsh were assessed.

Percent cover and shoot density of vegetation were recorded monthly.

No difference was found in plots with debris removed versus controls after 2 growing seasons.

Timing of debris removal (fall versus spring) did not impact recovery.

Recommended strategies for organizing effective salt marsh clean-ups are presented.

Abstract

Recovery of vegetation on a Long Island, NY salt marsh was investigated after the removal of hurricane-deposited large wooden debris through managed clean-ups involving volunteers. Two years after the removal of the debris, vegetation cover and species composition were not significantly different from controls. There was no significant difference in vegetation recovery among fall and spring debris removal treatments. Initial vegetation cover of the experimental and control plots was 95.8% and 1.2%, respectively; after two growing seasons cover was 78.7% and 71.2%, respectively. The effects of trampling by volunteers during debris removal were monitored and after one growing season, trails used during a single clean-up effort had a mean vegetation cover of 67% whereas those that were used during multiple clean-up efforts had only 30% cover. We use the results of this study to offer guidance for organizing effective salt marsh clean-up efforts.

Key words: clean-ups, *Distichlis*, marine debris, New York, salt marsh vegetation, *Spartina*

Introduction

Salt marshes are vital coastal ecosystems located between land and salt water. Many critical ecosystem services are provided by salt marshes, in part because of their position between the terrestrial and marine habitats (Costanza et al., 1997; Levin et al., 2001; Barbier et al., 2011; Shepard et al., 2011). Salt marshes serve as critical habitats for numerous vertebrate and invertebrate species by providing shelter, feeding grounds, and nursery grounds (Boesch and Turner, 1984; Raposa et al., 2009; Barbier et al., 2011). In addition, they provide substantial indirect and direct benefits to humans including coastal protection, carbon/nutrient sequestration, water purification, and maintenance of commercial fish and shellfish species (Bromberg and Bertness, 2005; Costanza et al., 2008; Gedan et al., 2009; Barbier et al., 2011; Artigas et al., 2015). Globally, salt marsh vegetation has been estimated to sequester about 5-87 teragrams of carbon per year (Barbier et al., 2011; Artigas et al., 2015). In addition, they improve water quality by nutrient and/or pollutant uptake (Casagrande, 1997; Gedan et al., 2009; Barbier et al., 2011). Residential areas also substantially benefit from the role that these ecosystems have in erosion control and coastal protection, particularly during storm events (Casagrande, 1997; Costanza et al., 2008; Morgan et al., 2009; Barbier et al., 2011; Gedan et al., 2011; Shepard et al., 2011). Thus, negative stresses to salt marshes have the potential to cause large economic losses to humans via flooding, erosion, and reduced waste treatment and food production (Gedan et al., 2009; Brisson et al., 2014).

Salt marshes of the mid-Atlantic provide habitat for a wide range of vertebrate and invertebrate species that find shelter and protection from predators (Boesch and Turner, 1984). Migratory and residential birds use salt marshes as foraging and nesting grounds (Levin et al., 2001; Cardoni et al., 2007; Raposa et al., 2009; Conway et al., 2010) and some threatened or endangered species reside on salt marshes (Casagrande, 1997; Neidowski, 2000). Salt marshes are also of great economic, recreational, and educational importance to humans (Barbier et al., 2011). Major fisheries, including shrimp, oysters, clams, and fish are dependent on salt marshes (Boesch and Turner, 1984; MacKenzie and Dionne, 2008; Barbier et al., 2011) and these habitats encourage tourism and recreation activities (e.g., birdwatching) (Johnston et al., 2002; Crossett et al., 2004; Gedan et al., 2009; Moreno and Amelung, 2009; Barbier et al., 2011).

Along the east coast of the United States, salt marsh plant species composition is typically divided into low, mid, and high marsh zones (Niering and Warren, 1980). The low marsh is composed of vegetation that is flooded daily and highly salt tolerant, such as the tall form of native smooth cordgrass *Spartina alterniflora* Loisel. (Mooring et al., 1971; Stalter 1973; Gallagher et al., 1988; Niedowski, 2000; Bertness et al., 2002). The mid marsh and the high marsh are distinguished based on flooding frequency, with the high marsh generally flooding less only during higher tides (Hladik and Alber, 2014). The mid marsh consists of the medium form *Spartina alterniflora* and the high marsh is dominated by the short form of *Spartina alterniflora*, saltgrass *Distichlis spicata* (L.) Greene, and slender glasswort *Salicornia maritima* Wolff & Jefferies (Adams, 1963; Amen et al., 1970; Mooring et al., 1971; Gallagher et al., 1988; Niedowski, 2000; Hladik et al., 2013). Other common plant species in the high marsh are the saltmarsh aster *Symphyotrichum tenuifolium* (L.) G.L. Nesom and lavender thrift *Limonium carolinianum* (Walter) Britton (Redfield, 1972). Salt pans may also be present as shallow depressions that are devoid of vegetation and distributed throughout the mid and high marsh (Sripanomyom et al., 2011; Escapa et al., 2015). The Jesuit's bark *Iva frutescens* L. and common reed (native and non-native) *Phragmites australis* (Cav.) Trin. ex Steud. are two plant species at the high marsh edges (Niering and Warren, 1980; Bart and Hartman, 2003; Silliman and Bertness, 2004; Saltonstall et al., 2014).

A range of natural and human influenced disturbances can impact salt marsh vegetation, leading to die-off and possible regrowth. Wild fires (Baldwin and Mendelssohn, 1998; Conway et al., 2010; Lonard et al., 2012), herbivores (Ellison, 1987; Gedan et al., 2009; Bertness et al., 2014; Coverdale et al., 2014), and accumulation of dead plant material known as wrack (Hartman et al., 1983; Valiela and Rietsma, 1995; Baldwin and Mendelssohn, 1998; Lottig and Fox, 2007) have the potential to damage healthy salt marshes. Additionally, hurricanes and storms cause disturbances to salt marsh vegetation (Burger and Shisler, 1983; Jackson et al., 1995; Valiela et al., 1998; Boose et al., 2001; Costanza et al., 2008; Meert and Hester, 2009; Morton and Barras, 2011). Hurricanes can increase dispersal of wrack on the upper marsh, thus causing damage to plants and at times facilitating colonization by new species (Tolley and Christian, 1999; Bart and Hartman, 2003; Silliman and Bertness, 2004; Lonard et al., 2012). Storms can also transport and deposit anthropogenic materials on top of salt marsh vegetation, potentially crushing and shading the live above ground plant shoots (Valiela et al., 1998; MacLennan, 2005). In this way, human influence (e.g., development and building of structures vulnerable to destructive forces) and storms can have a synergistic and negative effect on salt marshes through deposition of debris.

With the increase of residential development along the coastal regions, more anthropogenic debris (e.g., wood from buildings and docks, plastics, tires) is entering marine environments (Niedowski, 2000; Worm et al., 2006; Widmer and Hennemann, 2010; Uhrin and Schellinger, 2011; Viehman et al., 2011; Tibbetts, 2015). In addition, derelict fishing gear can be a major source of debris in marine habitats (e.g., NOAA, 2016 and references therein; Scheld et al., 2016). The objective of the present research was to examine the impact that large marine debris (wooden docks dislodged by storms) has on the salt marsh vegetation. Specifically, this study explored how vegetation responded after the removal of such debris and if recovery of these disturbed areas followed the typical pattern of salt marsh succession.

Removal of marine debris through managed clean-ups involving volunteers has been successful in preserving and restoring coastal environments (Niedowski, 2000; Gedan et al., 2009; Uhrin and Schellinger, 2011; Critchell et al., 2015). Many managed clean-ups focus on removing small debris (e.g., plastics) on beaches but other initiatives include removal of large anthropogenic debris (such as derelict crabbing pots and other fishing gear), which have been shown to have positive ecological and economic impacts (NOAA, 2016; Scheld et al., 2016). Less is known about the impacts of removing large pieces of debris from marshes and how to best manage clean-ups in this habitat (Uhrin and Schellinger, 2011; Viehman et al., 2011; Driedger at el., 2015; Lee and Sanders, 2015). Therefore, the present study also tested two factors that should be considered when planning a salt marsh clean-up concentrating on large debris to minimize negative impacts: 1) seasonal timing of debris removal and 2) effects of trampling during removal of debris.

The timing of debris removal was tested because it is unknown whether this factor affects the recovery of salt marsh plants. This study examined whether there was a difference in salt marsh recovery when debris was removed in the early spring (March) versus the mid fall (October). Hurricane season in the western Atlantic coast is from June- November, therefore it is likely that more marine debris, and large debris in particular, is deposited on salt marshes during the fall season (Changnon, 2009).

Ecological succession may be affected by the timing of debris deposition on salt marshes, the timing of clean-ups, and on whether recovery of plants is primarily from seeds deposited during the prior growing season, longer-lived seed banks, or rhizomes. If marine debris is deposited during the fall season and recovery is predominately via seeds from the growing season, then it is possible that delaying debris removal until spring of the following year would delay recovery preventing colonization of the debris removal sites by seeds. If recovery is predominately via seed banks, then spring removal could be lead to a slower recovery due to early season shading and compaction of marsh sediment as a result of the clean-up process. Lastly, if the recovery is predominately via rhizomes then, fall/spring removal plots would likely not show a difference in plant recovery. Rhizomes can stay viable underground for many years even after the death of the above ground biomass, therefore, permitting regrowth of vertical shoots directly from the disturbed areas (Brueggeman et al., 1992). Previous studies of natural disturbances on salt marshes have shown that overall recovery is likely to be dominated by vegetative growth via rhizomes (after initial colonization of *Salicornia* spp.), but less is known about recovery following large debris removal and the consequences of the timing of that removal (Stalter, 1973; Bertness and Ellison, 1987; Bertness and Shumway, 1993; Crain et al., 2008). Examining the effects of timing of debris removal on vegetation recovery could ensure that future clean-ups in this region are planned to maximize beneficial impact.

The effect of trampling on the vegetation during clean-ups was tested to identify damage caused by the volunteers. Large animals that historically grazed on salt marshes had significant effects on the above ground vegetation due to trampling and loss of soil structure (Turner, 1987; Schröder et al., 2002). Impacts of trampling caused humans has been investigated in other marine habitats (Eckrich and Holmquist, 2000; Davenport and Davenport, 2006). However, the effects of human trampling on salt marshes is poorly known, although Martone and Wasson (2008) showed that the percent cover of native marsh plants declined at sites trampled by humans. This could be problematic if invasive species like *Phragmites australis* invade trampled spots because *P. australis* can kill native plants by reducing the available light, reduce habitats for birds, become a source of fire susceptibility, reduce recruitment of some marsh inhabitants, and create large mats of wrack that can create more bare spaces (Egan and Ungar, 2000; Noe and Zedler, 2001; Burdick and Konisky, 2003). Thus, studying the trampling effect of humans on the vegetation during salt marsh clean-ups will help in planning effective conservation efforts and minimizing damage.

Although research on restoration efforts involving salt marshes have been conducted (e.g., Casagrande, 1997; Wolters et al., 2008; Artigas et al., 2015), there are no studies quantifying recovery of eastern coastal salt marsh vegetation after clean-ups of large wood debris with anthropogenic origin. After Hurricane Sandy in 2012, a series of marsh clean-ups utilizing community volunteers were organized from 2013-2015 to remove debris from a salt marsh in Nassau County, NY. The main goal in the clean-ups was to remove the deposited marine debris without causing additional damage to the vegetation. The primary objectives of this study were to: (1) quantify the amount of debris removed and the area cleaned of debris; (2) compare growth of marsh vegetation in plots that had wooden debris removed to control plots that were not affected by debris; (3) compare the impact of removing the debris at different times of the year (spring removal vs. fall removal) and (4) quantify trampling effects on vegetation during clean-ups. Based on these findings, recommendations for the best strategies and supplies helpful for clean-ups of large debris on salt marshes are presented.

Material and Methods

Study Site

Research was conducted on the salt marsh at Lido Beach, New York (40°35'38.03"N, 73°36'51.28"W), along the southern side of Hempstead Bay and the westernmost part of New York's South Estuary Reserve (SSER) (Fig. 1). This location was chosen as the study site because large wooden docks and other marine debris were deposited on the salt marsh vegetation after Hurricane Irene (2011) and Superstorm Sandy (2012).

Salt Marsh Clean-up

Removal of marine debris on this salt marsh was achieved by volunteer based marsh clean-ups coordinated by Hofstra University, the Long Beach School District, and the Town of Hempstead Department of Conservation and Waterways. There were 5 clean-ups with approximately 240 volunteers in total, on 5 October 2013, 19 October 2013, 3 May 2014, 4 November 2014, and 3 May 2015. Medium to large scale debris, including whole wooden dock sections (see description below) were the main focus of debris removal on the 140,000 m^2 salt marsh. Prior to working on the marsh, volunteers were informed of potential dangers (e.g., broken glass, nails and screws protruding from the wood).

Impacts of Debris and Spring versus Fall Debris Removal

The vegetation underneath 5 stranded large rectangular wooden docks deposited, specifically, after Superstorm Sandy (2012) was surveyed to measure the impact of stranded wooden dock debris and compare the growth of marsh vegetation in areas that had wooden debris removed to areas that were not affected by debris (Fig. 2A). On 3 October 2013, before the first volunteer-based clean-up, 5 docks were removed and $0.25m^2$ experimental subplots (5-14 per dock, 40 total) were established to monitor vegetation composition, percent cover, and stem density over time (Fig. 2B). Control plots with relatively undisturbed marsh vegetation were set up near the experimental plots and were similarly divided into 0.25m^2 control subplots (5-14 per dock, 40 total) (Fig. 2C). The uneven distribution of the subplots assigned among the docks and controls plots is due to the variation of the dock dimensions that were present on the marsh. The dock dimensions ranged from ~2.1-3.1m x ~0.6-1.2m and were generally composed of 2x8" or 2x10" pressure treated lumber with 5/16" pressure treated decking material, weighing in total ~225-450kg. Docks were oriented so that the framing timbers or Styrofoam pieces were in contact with the marsh surface (i.e., decking faced upwards) so air and water was able to circulate under the docks.

The 5-14 experimental subplots per dock were further divided into two treatments (fall removal and spring removal) to test for the effects of fall (October) removal of debris vs spring (March) removal of debris on the salt marsh vegetation. Each dock was assigned at least 2 subsamples for each season to allow calculation of means. Half of the experimental subplots for each removed dock were randomly selected to act as spring removal plots. The 20 spring experimental subplots had 0.25m^2 plywood squares (1/2 inch plywood, approximately 1.8kg) secured back onto these subplots with steel stakes. On 19 March 2014 the plywood was taken off these spring removal experiment subplots. The other 20 experimental subplots remained free of debris during the entire study following the removal of the wooden docks in October 2013 and therefore represent fall removal plots.

Each of the subplots was marked out with wooden stakes in the four corners using a 0.25m^2 PVC quadrat and marked with tape to uniquely identify it over the course of the experiment. Global Positioning System (GPS) coordinates and the height above sea level elevation measurements of all the subplots were recorded using a Trimble R8 Global Navigation

Satellite System (GNSS) instrument, which is a Real Time Kinematic (RTK) centimeter grade GPS that was getting its base station referencing from a NetRS base station in the nearby Town of Hempstead Department of Conservation and Waterways office with the antenna on its roof. The land elevations (measured in height above sea level) for the control, fall, and spring plots were not significantly correlated with the percent cover of vegetation observed after one year ($r = 0.175$; $n = 10$; $P = 0.629$, two-tailed). The control plots elevation ranged from 0.610 - 0.860 m and the experimental plots elevation ranged from 0.627 - 0.783 m. There was no significant difference between the elevations of the control plots and the experimental plots ($t\ (8) = -\ 0.56$, $P = 0.59$, two-tailed), thus elevation was not considered further as a variable in the statistical analysis.

The 80 subplots were monitored monthly from October 2013 to October 2014, but were not surveyed during the winter months (November 2013-March 2014) because of vegetation die-off. Each month the plant species growing in the subplots were identified and the number of live shoots of all species were counted for both experiment and control subplots. Wrack was removed from all subplots monthly for the first year, in order to count the shoots and because the stakes appeared to be trapping the wrack on the subplots. During each visit, all the subplots were digitally photographed with an Olympus FE-190 camera. A 5x5 transparent grid (25 squares representing $0.05m^2$ each) was overlaid onto the digital pictures of the individual subplots and visually inspected to make estimates of total percent vegetation cover and percent vegetation cover by species. The subplots were revisited in August 2015 to estimate percent cover of vegetation after a second post-debris-removal growing season had elapsed.

Effects of Trampling

Effects of trampling during clean-ups was assessed by setting up 10 experimental $0.25m^2$ subplots on trails trampled by volunteers during the clean-ups; 10 control (no trampling) $0.25m^2$ subplots were established adjacent (<1m) to the trails. Five of the experimental subplots were from a trail used once, during the first clean-up on 5 October 2013 and the other 5 experimental subplots were set up on a trail that was used during the first 3 clean-ups (between 5 October 2013 and 3 May 2014). The estimated trampling during a single clean-up consisted of 30-60 adult volunteers (~45-90kg/volunteer) who moved across the trails multiple times over a 4-hour period. On 24 October 2014, a year after the first clean-up and after a full growing season had elapsed, the percent cover of vegetation and the number of live shoots of each species were counted as indicated above.

Statistical Analysis

One-way ANOVA and Tukey's HSD post hoc tests were used to compare mean vegetation cover, number of shoots, and relative dominance of each of the 4 most common vegetation types (*S. alterniflora, D. spicata, S. maritima*, and all Other species) among the three treatments (control, spring, and fall removal) at each sampling period (i.e. after debris removal, and after the 2014 and 2015 growing seasons). Vegetation cover and stem density among the subplots of each dock and control were averaged to prevent pseudo-replication, resulting in a sample size of n = 5 for each treatment. Within each treatment, a repeated measures ANOVA was used to test for differences in percent cover and stem density among the three time periods (0, 1, and 2 growing seasons). All statistical analyses were performed using the VassarStats statistical analysis platform (Lowry, 2004).

Results

Debris Removal During Clean-ups

In the course of the first two clean-ups (5 October 2013 and 19 October 2013), during which the debris was removed from the experimental plots, a total of 132 volunteers removed 11.0 tons of debris. During the three subsequent clean-ups (3 May 2014, 4 November 2014, and 3 May 2015) a total of 108 volunteers removed an additional 11.1 tons of debris. At each clean-up some additional marine debris was observed to have accumulated, but no large items (e.g., decking, timbers) were deposited on any of the experimental or control plots. Anthropogenic wood, pieces of plastic, Styrofoam, and tires were the most abundant items removed from the vegetation, reflecting its close vicinity to populated areas.

Impacts of Debris on Percent Cover of Vegetation

After the removal of the 5 wooden docks in October 2013, the average underlying percent cover of vegetation in the experimental plots was 1.2 ± 0.4 % (n = 10) and control plots with no debris had an average percent cover of 95.8 ± 1.0 % (n = 5). The control plots had significantly higher percent cover than the experimental plots (Fig. 3; One-way ANOVA, $F_{(2,12)} = 5169.2$; $P < 0.0001$; Tukey's test (control), $P < 0.01$).

A year following the removal of the wooden docks, in October 2014, the average percent cover of vegetation in the experimental plots increased to 30.2 ± 4.5 % (n = 10); control plots had an average percent vegetation cover of 95.5 ± 0.8 % (n = 5). The percent cover remained significantly higher in the control plots than in the experimental plots in 2014 (Fig. 3; One-way ANOVA, $F_{(2,12)} = 74.32$; $P < 0.0001$; Tukey's test (control), $P < 0.01$).

In August 2015, almost two years from the initial data collection, the average percent cover of vegetation in the experimental plots increased to 71.2 ± 6.1 % (n = 10); control plots had an average percent vegetation cover of 78.7 ± 11.7 % (n = 5). There was no difference between the percent cover of the control and the experimental plots (Fig. 3; One-way ANOVA, $F_{(2,12)} = 0.32$; $P = 0.73$).

Over the two years after the initial data collections, the average percent cover of the vegetation in the control plots stayed relatively consistent from 2013 to 2015 and was not significantly different between years (Fig. 3; Repeated Measures ANOVA, $F_{(2,12)} = 2.09$; $P = 0.19$). However, the percent cover of vegetation in the experimental plots significantly increased each year between 2013 to 2015 in both the fall and spring treatments (Fig. 3; Repeated Measures ANOVA (fall), $F_{(2,12)} = 63.39$; $P < 0.0001$; Tukey's test (2013), $P < 0.01$; (2014), $P < 0.01$; (2015), $P < 0.01$ and Repeated Measures ANOVA (spring), $F_{(2,12)} = 46.16$; $P < 0.0001$; Tukey's test (2013), $P < 0.01$; (2014), $P < 0.01$; (2015), $P < 0.01$).

Comparison of Fall and Spring Debris Removal on Percent Cover of Vegetation

The initial average total percent cover of vegetation after removal of the docks in October 2013, was not significantly different between the experimental plots (Fig. 3; fall and spring removals, 1.5 ± 1.0 % and 1.0 ± 0.2 %, respectively; $t(8) = +0.63$, $P = 0.55$, two tailed). After one (October 2014) and two (August 2015) growing seasons of recovery, the average total percent cover of the fall and spring plots were not significantly different (Fig. 3; (2014): 28.4 ± 5.6 % and 33.0 ± 5 %, respectively; $t(8) = -0.61$, $P = 0.56$, two-tailed; (2015): 73.6 ± 4.8 % and 69.3 ± 7.0 %, respectively; $t(8) = + 0.5$, $P = 0.63$, two-tailed).

Impacts of Debris on Species Composition of Vegetation

Plots in all three treatments (control, fall, and spring plots) were largely dominated by two species: *S. alterniflora* and *D. spicata* (Fig. 3); however, *S. maritima* and other species were also present in low numbers. In 2013, relative dominance of each of the individual species present (*S. alterniflora*, *D. spicata*, *S. maritima*, and other species) were not significantly different between the control, fall, and spring plots (One-way ANOVA: *S. alterniflora* ($F_{(2,12)} = 0.05$; $P = 0.95$), *D. spicata* ($F_{(2,12)} = 0.15$; $P = 0.86$), S. *maritima* ($F_{(2,12)} = 1.36$; $P = 0.29$), and Other ($F_{(2,12)} = 1.22$; $P = 0.33$)). Similar results were seen in 2014; no significant differences found between the control, fall, and spring plots (One-way ANOVA: *S. alterniflora* ($F_{(2,12)} = 0.73$; $P = 0.50$), *D. spicata* ($F_{(2,12)} = 1.82$; $P = 0.20$), *S. maritima* ($F_{(2,12)} = 1.87$; $P = 0.20$), and Other ($F_{(2,12)} = 1.89$; $P = 0.18$)).

S. alterniflora and *D. spicata* dominated the control and the experimental plots after one year (Fig. 3). The main differences in percent cover of the individual species for 2013 and 2014 were seen between the control and experimental plots (fall and spring combined), but not between the fall and spring treatments (Fig. 3). This higher percent cover in the control plots compared to the experimental plots was found in the *S. alterniflora* species for 2013 (One-way ANOVA, $F_{(2,12)} = 12$; $P = 0.001$; Tukey's test (control), $P < 0.01$) and 2014 (One-way ANOVA, $F_{(2,12)} = 6.72$; $P= 0.01$; Tukey's test (control), $P <0.05$) and was also found in the *D. spicata* species in 2013 (One-way ANOVA, $F_{(2,12)} = 6.27$; $P = 0.01$; Tukey's test (control), $P < 0.05$). In 2015, there was not a significant difference in percent cover of any of the individual species between the three treatments (Fig. 3; One-way ANOVA: *S. alterniflora* ($F_{(2,12)} = 0.20$; $P = 0.82$); *D. spicata* ($F_{(2,12)} = 0.10$; $P = 0.91$), *S. maritima* ($F_{(2,12)} = 2.66$; $P = 0.11$); and Other ($F_{(2,12)} = 1.11$; $P = 0.35$)).

In 2013, the shoot densities of *S. alterniflora* and *D. spicata* in the control plots, were significantly higher than in the experimental plots (Fig. 4A; One-way ANOVA (*S. alterniflora*), $F_{(2,12)} = 6.75$; $P < 0.01$; Tukey's test (control), $P < 0.01$ and One-way ANOVA (*D. spicata*), F

(2,12) = 6.04; P = 0.2; Tukey's test (control), P < 0.05). In 2014, *S. alterniflora* had a significant difference in shoot density between at least one of the three treatments, but pairwise differences were not significantly detectable (Fig. 4A; One-way ANOVA; F (2,12) = 4.57; P = 0.03). A year after debris removal in 2014, average shoot densities (shoots/0.25 m^2) were higher in control plots (157.6 ± 61.2 (n = 5) for *S. alterniflora* and 134.7 ± 53.5 (n = 5) for *D. spicata*) than experimental plots (fall plots: 28.4 ± 6.5 (n = 5) for *S. alterniflora* and 69.2 ± 24.5 (n = 5) for *D. spicata*; spring plots: 23.1 ± 4.6 (n = 5) for *S. alterniflora* and 90.6 ± 25.0 (n = 5) for *D. spicata*).

The species composition and shoot densities of the marsh vegetation from October 2013 to October 2014 indicated the beginning of typical salt marsh succession after disturbance (Fig. 4B, C), with *S. maritima* reaching highest densities in experimental plots during June (fall plots: 30.1 ± 18.0 (n = 5); spring plots: 11.2 ± 3.8 (n = 5)), and then plots being dominated by *S. alterniflora* and *D. spicata*. In contrast to control plots where *S. alterniflora* dominated all months, the experimental plots had higher densities of *D. spicata* in all months (Fig. 4B, C). *P. australis* was not recorded in any of the plots and only 2 out of the 5 dock locations had *P. australis* within the vicinity of the bare spot (Fig. 1, docks A & E).

Trampling on Trails

A year after being trampled (October 2014), the subplots in the trail used for only one clean-up had an average vegetation percent cover of 67.0 ± 4.6 % (n = 5) (Fig. 5). The trail that was used for multiple clean-ups only showed an average of 30.0 ± 3.5 % (n = 5) vegetation cover after a full growing season from May 2014-October 2014 (Fig. 5). The control subplots for each of the two trails that were never trampled on had a vegetation cover of 100 % (once: n = 5; multiple: n = 5).

Discussion

Impacts of Debris on Salt Marsh Vegetation

This study demonstrates that stranded large marine debris can negatively impact the growth of marsh vegetation. Additionally, it suggests that salt marsh vegetation is resilient and may recover relatively quickly following debris removal, regardless of the time of the year the debris is removed (fall or spring). In this study, the species composition surrounding the plots and marsh elevation did not appear to impact the recovery of vegetation and after two growing seasons the vegetation cover of debris removal areas was not significantly different from areas that were not impacted by debris. In addition, the time required for vegetation to recover from trampling (an unavoidable consequence of most salt marsh clean-up efforts) appears to vary with the intensity of foot traffic. The trail that was used for just one clean-up effort recovered considerably more of its vegetation cover after one growing season than the trail that was used during multiple clean-up efforts.

There was rapid partial recovery (< 1 year) for the vegetation that was impacted by the anthropogenic wooden debris; two years post-impact, the percent cover of the disturbed vegetation was not significantly difference from control plots. The non-significant decrease in percent cover of the control plots in 2015 compared to 2013 and 2014 was most likely because wrack was not removed monthly throughout the second year of the experiment since percent cover was only collected during a single visit in 2015 (Fig. 3). The loss of live above-ground marsh biomass underneath the wood debris was most likely due to the weight and shading effects of the wood material (MacLennan, 2005; Viehman et al., 2011; Uhrin and Schellinger, 2011). There are only a few comparable studies that have focused on the impacts of marine debris on salt marsh ecology. Uhrin and Schellinger (2011) investigated the impacts of tire and crab pot debris on a North Carolina salt marsh vegetation. They found recovery of the marsh vegetation following removal of tires requiring a longer time for regrowth (> 1 year) than needed for the vegetation impacted by stranded crab pots (< 1 year) (Uhrin and Schellinger, 2011). Scheld et al. (2016) estimated that the removal of approximately 34,000 derelict crab pots from the Chesapeake Bay estuary led to gains in fishing efficiency and additional fish harvests valued at more than US $21 million. The authors extrapolated their results to global fisheries and estimated that removing less than 10% of derelict pots would produce more than US $800 million in additional landings annually.

The differences in plant recovery times after impact by different debris types are likely due to the physical impacts of the debris. Wooden docks and tires both have the potential to crush the vegetation or reduce the light levels needed for the vegetation growth. However, the impacts of dock debris may differ from impacts of tires because although wood docks are heavy like tires, the vegetation that is being crushed and compacted by the weight is usually restricted to the perimeter structural members of the dock (Fig. 2A). Middle sections of the docks are usually raised and therefore most of the wood is not touching the marsh plants. The majority of the dock's surface is not adding pressure or burying the vegetation, as is the case for the majority of tire surfaces (Fig. 2A). The wood docks are similar to the crab pots in that there is less physical compression, but unlike the crab pots, the wood shades the vegetation preventing the sunlight needed for photosynthesis. In addition, all three debris types most likely can act as refuges for different organisms that could potentially impact growth (e.g., nesting areas for rodents and burrowing species such as fiddler crabs; Jefferies et al., 1981; Brisson et al., 2014; Escapa et al., 2015; Ehl, pers. obs.).

Salt marsh disturbance has been linked to the invasion of non-native species, but there was no evidence of non-native species invasion of the study plots following debris removal. The dominant species recorded in the experimental plots matched that typically seen during salt marsh succession (Fig. 4). Normally, salt marshes are low in plant diversity and contain *Spartina* spp., *Distichlis* spp., and *Salicornia* spp., with *Salicornia* spp. being the pioneer species during marsh succession (Adams 1963, Amen et al., 1970; Mooring et al., 1971; Ellison, 1987; Gallagher et al., 1988; Niedowski, 2000; Martone and Wasson, 2008; Erfanzaden et al., 2010).

The non-native species *P. australis*, which is invading salt marshes across North America (Niedowski, 2000; Noe and Zedler, 2001; Silliman and Bertness, 2004; Gedan et al., 2009, 2011), is found in the upper parts of the marsh at our study site. We suspect that invasion by this species would have been more likely if debris removal had occurred on the upper marsh, where *P. australis* is common. This invasion happens mostly via clonal expansion (and to a lesser extent through seed dispersal). *P. australis* has been successful in invading North American salt marshes in part because of its high tolerance to disturbed sites, enhanced dispersal of rhizomes as a result of shoreline development activities, increased frequency of reduced salinity due to freshwater runoff from impervious surfaces, and excess nitrogen loading from developed areas (Bertness et al., 2002; Bart and Hartman, 2003; Burdick and Konisky, 2003; Silliman and Bertness, 2004; Gedan et al., 2009, 2011).

The time of the year that the clean-ups took place (spring or fall) did not affect the recovery of the vegetation; there were minimal (and statistically insignificant) seasonal differences in species composition and percent recovery of the experimental plots. This was true despite some differences between the characteristics of the docks (original debris) and the plywood (used to simulate spring debris removal). The docks allowed for some air flow and sunlight penetration due to gaps in the spacing of wood planks and the elevation of much of the underside of the docks above the marsh surface. The plywood, by contrast, limited airflow and sunlight to a greater extent due to its placement directly on the marsh surface. In spite of the plywood treatment not representing a perfect mimic of the dock conditions, no significant differences were observed between spring (dock) and fall (plywood) debris removals.

Other limitations of this study that should be noted for future research, are the unknown residence times of each dock prior to removal, the uneven number of subsamples among the docks (5-14 subplots per dock), and the small sample size. Archived satellite imagery from Google Earth provides evidence that the docks arrived at their present positions following Hurricane Sandy as they are not present in imagery taken earlier that same year, but are present in post-2012 imagery. Because we used docks deposited on the marsh by storms to establish our experiments on recovery, we were constrained in some aspects experimental design. The longer allowable recovery time for the fall treatment subplots compared to the spring treatment subplots could be viewed as a potential limitation, but the majority of the additional potential growing time occurred during the winter months. During the winter months, the marsh plants are dormant and experience very little growth. Therefore, if the additional recovery time for the fall removal subplots had an influence on the results, it is believed to be small.

It is not known whether the growth of the dominant salt marsh plants after debris removal were from seeds or from rhizomes. It is likely that seed banks played a role in recovery, but this role could have been masked by growth from existing root networks in or at the edges of the subplots (Burger and Shisler, 1983; Baldwin and Mendelssohn, 1998; Brewer et al., 1998; Michel and Rutherford, 2014). While it is possible that recovery from seed banks and rhizomes may be differentially impacted by debris deposition and removal, the similar (and relatively rapid) rates of vegetation recovery in the fall and spring removal plots in this study suggest that future clean-ups can occur during either season. However, other factors including reproductive season of marsh birds and logistical considerations may influence ideal times for conducting clean-ups (see **Recommendations for Future Salt Marsh Clean-up Efforts** below). The impact of trail trampling by the clean-up crews during the spring (seedling germination period) or fall (shoot die-off period) seasons may be an additional factor to examine in future studies.

In this study, the number of times a trail was used appeared to be important in recovery speed. Trampling damage to the salt marsh vegetation was apparent on all trails used for the clean-ups, but after a growing season, the trail used once exhibited more rapid vegetation recovery than the trail used multiple times. This suggests that using a single different trail for each clean-up instead of the same trail for multiple clean-ups might reduce vegetation recovery time. Martone and Wasson (2008) similarly showed that trampling on marsh vegetation once a week for three months created a visible trail, but there was recovery in the trail if it was not tidally restricted. The estimated area of trampled trails on this study's marsh was 600 m^2 compared to the estimated area of removed debris at 21,000 m^2. Trampling of vegetation by clean-up personnel needs to be managed so that the cleaning effort damage does not outweigh the benefits of debris removal. This should also be considered for other habitats where trampling could have negative impacts (e.g., Eckrich and Holmquist, 2000; Davenport and Davenport, 2006).

The resilience of salt marsh vegetation after removal of wooden docks, a year after they were deposited there, shows that clean-ups can contribute to recovery after large debris accumulates. Unfortunately, humans have played an increasing role in causing disturbance to salt marshes with the increase of anthropogenic structures and marine debris creating about 50 %

deterioration of salt marsh ecosystems globally (Bromberg and Bertness, 2005; MacLennan, 2005; Worm et al., 2006; Barbier et al., 2011; Viehman et al., 2011). Much of the marine debris collects on coastal salt marshes because of large storms and hurricanes that breakup and scatter anthropogenic structures located along the coastlines onto the salt marshes (Cunningham and Wilson, 2003; Krauss et al., 2005; MacLennan, 2005; Ryan et al., 2009; Uhrin and Schellinger, 2011; Viehman et al., 2011). Debris left on salt marshes from storms can damage salt marsh vegetation, which in turn can result in a reduction of ecosystem services including buffering storm waves, absorbing excess nutrients, sequestrating carbon, and providing habitat for wildlife (Gilligan et al., 1992; Uhrin and Schellinger, 2011; Viehman et al., 2011; Brisson et al., 2014; Kulawardhana et al., 2015). Salt marsh loss is a global problem; therefore, it is important to eliminate or reduce any possible human impacts (e.g. accumulation of marine debris) that result in negative ecological and economic consequences of salt marsh die-off (Barbier et al., 2011; Bertness et al., 2014; Coverdale et al., 2014).

Recommendations for Future Salt Marsh Clean-up Efforts

The findings of this study have important implications for organizing successful salt marsh clean-ups while mitigating the potential negative impacts. Although there did not appear to be an effect of season on vegetation recovery, there were advantages and disadvantages noted for clean-ups in the spring and fall seasons. Summer clean-up efforts were not a viable option at our study site because people are not permitted on New York salt marshes during the bird breeding season (late May-early August) to prevent disturbances of marsh bird species. Since many of the damaging storms occur in the fall season, it is suggested that the large debris items are documented and mapped after the storms in the fall and then cleaned up in the early spring (March-early April). It is also advised that, if possible, the debris is not left on the marsh for more than a year because plant growth can entangle debris making it difficult to remove later and heavy debris can compress plants and sink into the marsh (Ehl, pers. obs.) making it more difficult to remove. The longer the large debris is left on the marsh, the more likely it can cause damaging impacts and reduce potential for recovery.

A noted advantage for spring clean-ups was the fact that debris was more accessible during the spring than in fall, when, summer growth covered the debris making it less visible and trapped smaller items (e.g., plastic bottles, bags). Another advantage of having clean-ups during early spring was to avoid poison ivy (*Toxicodendron radicans* (L.) Kuntze) located in the upper marsh lands, which was a problem during the fall (Gladman, 2006; Ehl, pers. obs.). The disadvantage of spring clean-ups was the possible disturbance to the birds that are starting to nest or forage at this time (Cardoni et al., 2007; Raposa et al., 2009; Viehman et al., 2011). In addition, having a late spring (late April-early May) clean-up may have a negative effect on the *Salicornia* spp., which is an early successional species and germinates early in the growing season. During the fall, disturbance of wildlife was less of a problem, but removing debris in the fall near stands of *P. australis* may aid the spread of seeds this invasive plant to bare ground (Martone and Wasson, 2008; Viehman et al., 2011). Weather is also a factor to consider in choosing dates when removals are planned if volunteers are to be the main workers (avoidance of summer/winter due to temperature extremes).

To prevent further loss and deterioration of salt marsh vegetation around heavily populated coastal areas, it is essential to understand the stressors to these ecosystems. It is clear that large debris can inhibit the growth of salt marsh vegetation, but care must be taken in the removal of this debris. One recommendation resulting from this study is to conduct clean-ups of large debris items at most once or twice a year (spring or fall) to minimize the impacts of trampling. A time line of major steps should be developed (see Appendix 1) including advanced preparation (e.g. finding volunteers and funding) and clean-up day logistics (informing volunteers of clean-up goals, hazards, and locations to focus efforts). Required items including tools (e.g. timber carriers, pry bars, drill, circular saws, and carts) and other materials (gloves, boots, etc.) to assist in breaking down and carrying large and heavy debris items should also be organized in advance (see Appendix 2). We advise carefully mapping out a new trail (or system of trails) for each clean-up, in order to: (1) allow recovery of previously trampled trails, (2) to keep volunteers from causing widespread trampling on the marsh, and (3) for the volunteers to avoid hazards (Appendix 1). Potential hazards that volunteers should be made aware of include: tidal creeks, nails and screws left in wood, and broken glass or sharp objects (e.g. syringes or metal). Due to these factors, clean-up organizers should consider providing puncture resistant boot inserts for volunteers and may want to restrict the age of volunteers or perhaps divide groups so young children can stay in safe areas and concentrate on smaller debris. The potential educational benefits of such clean-ups should not be overlooked, as outreach increases awareness of the importance of salt marshes and other ecosystems (Rees and Pond, 1995; Topping, 2000; New England Aquarium, 2002; Critchell et al., 2015; Jacobs et al., 2015).

In conclusion, this study shows clear negative impacts of stranded anthropogenic debris, on eastern coastal salt marshes and the positive impacts from its removal. A well-planned clean-up during the spring or fall, involving 50 - 100 volunteers can remove ~ 2 - 4 tons of debris, clear an area of ~ 2,000 – 3,000 m^2, and have significant benefits in terms of salt marsh recovery Negative impacts from trampling can be minimized by using trails a single time rather than reusing the same trails for multiple clean-ups. Although the total economic value of salt marshes per m^2 is difficult to quantify, there are monetary estimates for ecosystems services provided by salt marshes (Gedan et al., 2009; Barbier et al., 2011). For example, coastal protection provided by the salt marsh vegetation has been estimated to reduce hurricane damages by approximately US$8,000 ha-1/yr-1 (Costanza et al. 2008). In addition, salt marshes are estimated to save US$700-15,000/acre by aiding in water purification (Breaux et al. 1995) and US$6,000/acre gained in terms of support for recreational fishing along the east coast of the United States (Bell, 1997). Thus, conservation efforts on salt marshes have clear economic benefits and at the same time support the ecological and societal values of salt marshes (e.g. educational, recreational, and aesthetic). This study highlights the importance of annual clean-ups to help protect this vital, but declining ecosystem.

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Figure Legends

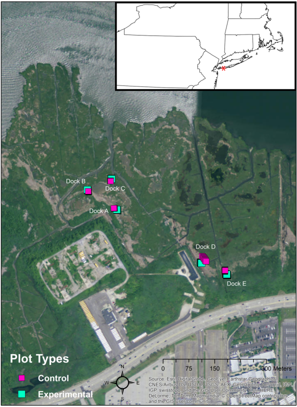
Fig. 1. Location of salt marsh study site in Lido Beach, New York (40°35'38.03"N, 73°36'51.28"W). Inset shows its position on the south shore of Long Island and the position of the docks (experimental plots) plus control plots on the marsh.

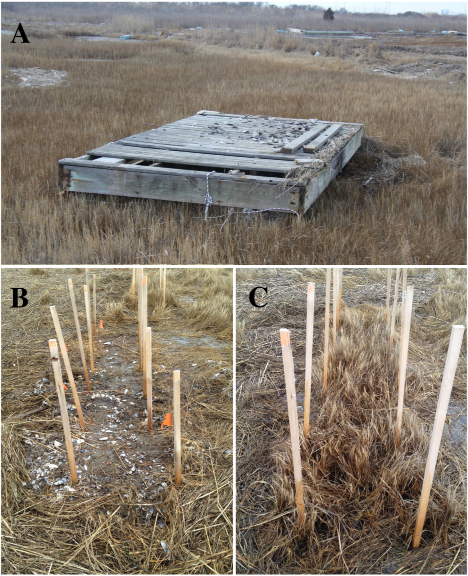
Fig. 2. Representative photographs of the study site prior to dock removal and experimental subplots after removal of dock. **A,** one of the 5 large rectangular wooden docks (dock B) that was stranded on top of the salt marsh vegetation after Superstorm Sandy and removed from the marsh on 3 October 2013. **B,** example $0.25m^2$ experimental subplots that were surveyed in the area where dock B was removed. Most of the vegetation underneath the dock was dead; photographed on 3 October 2013. **C,** example $0.25m^2$ control subplots near dock B whether the dominant species was *D. spicata*; photographed on 3 October 2013.

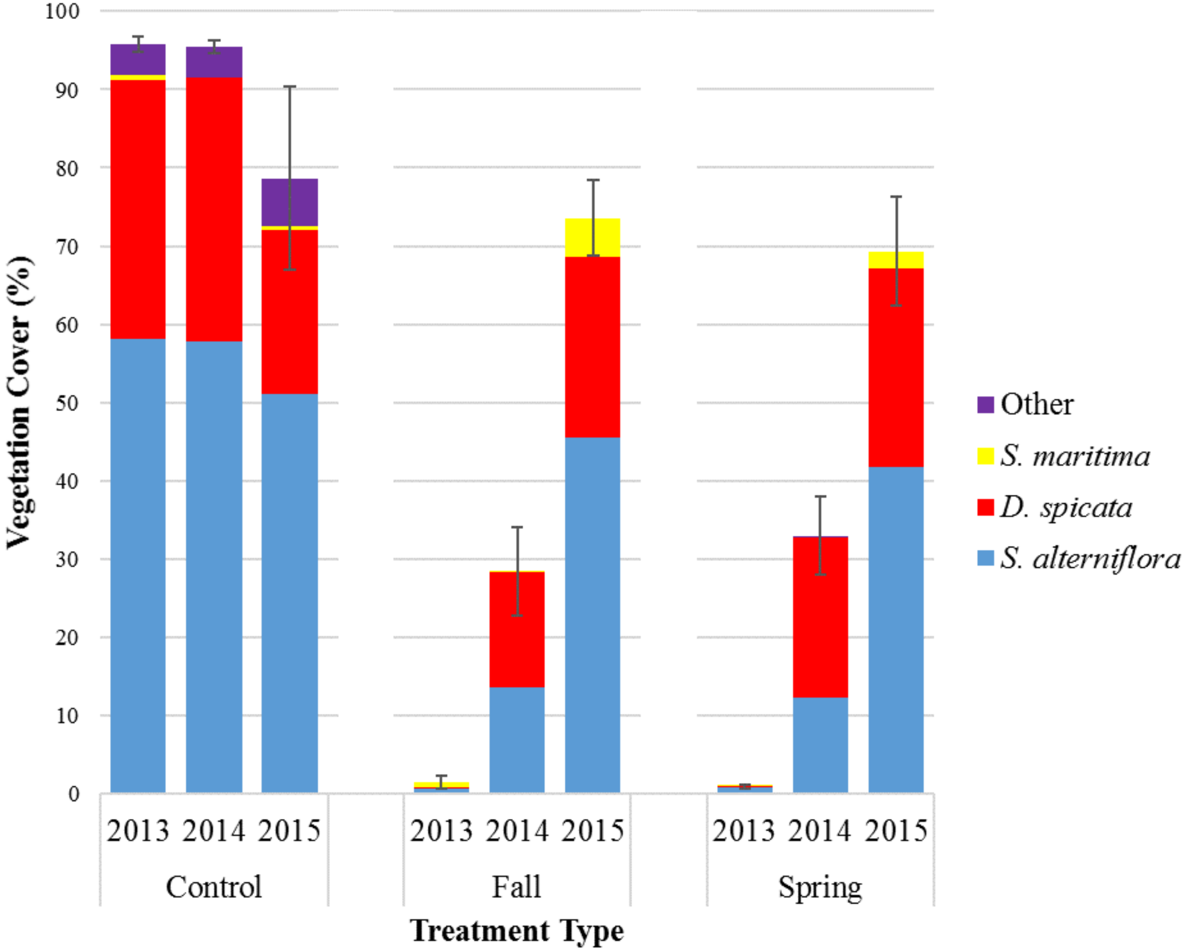
Fig. 3. Percent cover of total vegetation (mean ± SE) for the three treatments (control, n = 5; fall debris removal, n = 5; and spring debris removal, n = 5) at the start of the study on 3 October 2013, a year later on 24 October 2014, and after a second growing season on 25 August 2015. The bars are stacked to show the individual mean percent cover of vegetation of the 4 most common vegetated species found within the plots (*S. alterniflora*, *D. spicata*, *S. maritima*, and other).

Fig. 4. Species composition over time in the three treatments from October 2013 to October 2014 (means ± SE, winter-die off of stems is observed during November 2013 - March 2014 and the start of a new growing season is observed April 2014). **A,** individual shoot density counts of the most common species (*S. alterniflora*, *D. spicata*, *S. maritima*, and other) in the control plots (n = 5). **B,** individual shoot density counts of the common species in the fall plots (n = 5). **C,** individual shoot density counts of the common species in the spring plots (n = 5).

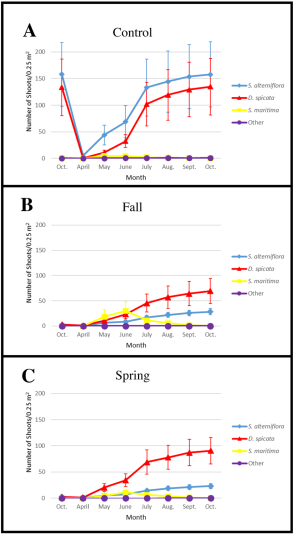
Fig. 5. Average percent vegetation cover observed for the subplots of the untrampled controls (n = 5 each) and the 2 experimental trail treatments (trail used for one clean-up (n = 5) and trail used multiple clean-ups (n = 5) on 24 October 2014). The bars are stacked to show the individual percent cover of the most common vegetated species found within the subplots (*S. alterniflora*, *D. spicata*, *S. maritima*, and other).

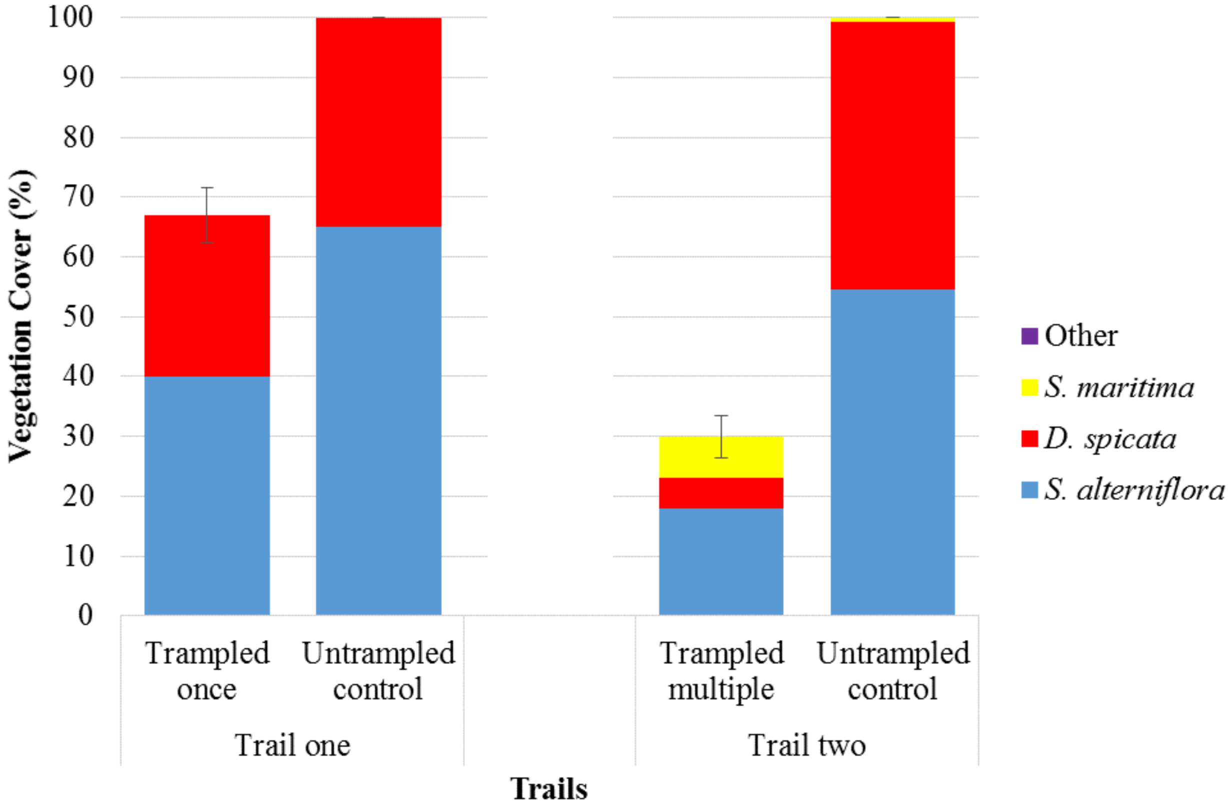

Dock B
Dock C
Dock A
Dock D
Dock E
Plot Types
Control
Experimental
N
W
E
S
0
75
150
300 Meters
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS user community


A
B
C



Vegetation Cover (%)
100
90
80
70
60
50
40
30
20
10
0
2013 2014 2015
Control
2013 2014 2015
Fall
2013 2014 2015
Spring
Treatment Type
Other
S. maritima
D. spicata
S. alterniflora


A
Control
B
Fall
C
Spring
Number of Shoots/0.25 m²
200
150
100
50
0
Oct.
April
May
June
July
Aug.
Sept.
Oct.
Month
S. alterniflora
D. spicata
S. maritima
Other



Vegetation Cover (%)
100
90
80
70
60
50
40
30
20
10
0
Trampled once
Untrampled control
Trail one
Trampled multiple
Untrampled control
Trail two
Trails
Other
S. maritima
D. spicata
S. alterniflora