National Park Service
U.S. Department of the Interior

National Capital Region Office Washington, D.C.

Effects of Canada Goose Herbivory on the Tidal Freshwater Wetlands in Anacostia Park, 2009-2011

Natural Resource Technical Report NPS/NCR/NCRO/NRTR—2013/001

ON THE COVER
Initially-unvegetated Module 15 in Kingman Marsh in Anacostia Park, Washington, D.C., three years into the herbivory study (August 2011).
Photographed by: R. Hammerschlag

Effects of Canada Goose Herbivory on the Tidal Freshwater Wetlands in Anacostia Park, 2009-2011

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March 2013

U.S. Department of the Interior
National Park Service
National Capital Region Office
Center for Urban Ecology
Washington, D.C.

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Please cite this publication as:
Krafft, C. C., J. S. Hatfield, and R. S. Hammerschlag. 2013. Effects of Canada goose herbivory on the tidal freshwater wetlands in Anacostia Park, 2009-2011. Natural Resource Technical Report, NPS/NCR/NCRO/NRTR—2013/001. United States Department of the Interior, National Park Service, Washington, D.C.

NPS/NCR/NCRO/NRTR—2013/001, March 2013

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Abstract

Herbivory has played a major role in dictating vegetation abundance and species composition at Kingman Marsh in Anacostia Park, Washington, D.C., since restoration of this tidal freshwater wetland was initiated in 2000. The diverse and robust vegetative cover that developed in the first year post-reconstruction experienced significant decimation in the second year, after the protective fencing was removed, and remained suppressed throughout the five-year study period. In June 2009 a herbivory study was initiated to document the impacts of herbivory by resident and nonmigratory Canada geese (*Branta canadensis*) to vegetation at Kingman Marsh. Sixteen modules consisting of paired fenced plots and unfenced control plots were constructed. Eight of the modules were installed in vegetated portions of the restoration site that had been protected over time by pre-existing fencing, while the remaining eight modules were placed in portions of the site that had not been protected over time and were basically unvegetated at the start of the experiment. Exclosure fencing was sufficiently elevated from the substrate level to allow access to other herbivores such as fish and turtles, while hopefully excluding mature Canada geese. The study was designed with an initial exclosure elevation of 20 cm. This elevation was chosen based on the literature, as adequate to exclude mature Canada geese, while maximizing access to other herbivores such as fish and turtles.

Repeated measures analysis of variance (ANOVA) was used to analyze the differences between paired fenced and unfenced control plots for a number of variables including total vegetative cover. Differences in total vegetative cover were not statistically significant for the baseline data collected in June 2009. By contrast, two months after the old protective fencing was removed from the initially-vegetated areas to allow Canada geese access to the unfenced control plots, total vegetative cover had declined dramatically in the initially-vegetated unfenced control plots, and differences between paired fenced and unfenced control plots were statistically significant. These differences have remained steady and significant throughout the remainder of these first three years of the study.

Total vegetative cover has followed a somewhat different path in the initially-unvegetated modules, where cover in the fenced plots did not significantly exceed cover in the unfenced control plots until the August 2010 sampling event. In spite of the slow start in the initially-unvegetated modules, differences between paired fenced plots and unfenced control plots have remained significant and even increased significantly over time. This indicates that total vegetative cover in the initially-unvegetated fenced plots and unfenced control plots is continuing to diverge over time as vegetation increases in the protected plots compared to the basically unvegetated unfenced control plots.

Total vegetative cover has been composed almost entirely of native species during the first three years of the study, with cover by exotics averaging less than 1% during each sampling event.

Species richness did not differ significantly between fenced plots and unfenced control plots during 2009, the first year of the study. Since August 2010, species richness has remained significantly greater in the fenced plots than in the unfenced control plots. These differences have remained relatively steady over time for both the initially-vegetated and initially unvegetated modules.

During the study it became apparent that our elevated fence plots were more accessible to mature geese than we had expected. Even after lowering the exclosure fencing to 15 cm in 2010 and 10 cm in 2011, we documented geese inside exclosures in both years. Nonetheless the data indicate that even at 10 cm, we have limited the numbers of mature geese entering the fenced plots, rather than totally preventing their access through low spots in the uneven substrate surface. At an exclosure elevation of 10 cm and with a soft, mucky substrate, we are assuming that non-goose herbivores such as fish and turtles still have free access to the fenced plots. Annual wildrice (*Zizania aquatica*), known from previous studies to be especially palatable to Canada geese, has seen the greatest impact from partial access to the fenced plots by mature geese, moving from an overwhelming dominant in the initially-vegetated plots to a minor presence there by August 2011. Interestingly, pickerelweed (*Pontederia cordata*), also known to be highly palatable to Canada geese, has so far shown only minor herbivory in the fenced plots. By August 2011, pickerelweed had actually increased to significantly greater cover levels in the fenced plots compared to the unfenced control plots.

In conclusion, the first three years of data document that vegetation exposed to full herbivory by resident and nonmigratory Canada geese for three years in the unfenced control plots showed significantly lower total vegetative cover and species richness compared to the vegetation in the fenced plots, which experienced reduced herbivory by resident and nonmigratory Canada geese. These effects were documented for modules located in both initially-vegetated and initially-unvegetated habitats.

Keywords

Anacostia Park, *Branta canadensis*, Canada goose, Herbivory, Kingman Marsh, Tidal Freshwater Wetland Restoration, Washington, D.C.

Introduction

Kingman Marsh Area 1 (subsequently referred to as Kingman Marsh) is a 16-ha tidal freshwater wetland restoration site located in Anacostia Park, Washington, D.C. Restoration efforts were started by the US Army Corps of Engineers (USACE) at this site in 2000, as the second in a series of four wetland restorations within Anacostia Park, which is managed by the National Park Service (NPS). Although planted and volunteer vegetation produced good cover at Kingman Marsh the first year, the site was decimated by herbivory starting in 2001, after the winter-damaged protective goose fencing was removed (Hammerschlag et al. 2006). A variety of efforts have been used to revegetate portions of Kingman Marsh following this decimation, but with only limited success. As a result, Kingman Marsh currently consists of a mosaic of: fenced exclosures constructed by the Anacostia Watershed Society (AWS) and vegetated with annual wildrice (in this case *Zizania aquatica* var. *aquatica*, the tall, broader-leaved subspecies native to the Atlantic coastal plain) and other native wetland vegetation; fenced and unfenced areas dominated by the relatively goose-resistant species yellow pond-lily (*Nuphar lutea*), green arrow arum (*Peltandra virginica*), or the invasive common reed (*Phragmites australis*); and extensive unvegetated areas that were either not planted or fenced originally or were not refenced and replanted after being decimated by herbivory.

The current study was designed to document the causes and impacts of herbivory on the vegetation at Kingman Marsh using study modules consisting of one fenced plot paired with one unfenced control plot. Since a prior local study had suggested that fish, etc., might be playing a significant role in limiting plant cover in the Anacostia freshwater tidal wetlands (May 2007), the exclosure fencing was elevated to allow access to other herbivores, such as fish and turtles, while excluding mature Canada geese (*Branta canadensis*). Geese causing herbivory impacts to the wetland vegetation would be resident geese that nest in the park from April to July and that are nonmigratory. Historically Canada geese have nested in Canada and Alaska and migrated south in the fall to winter in the conterminous United States and northern Mexico. By contrast, resident and nonmigratory geese nesting in the mid-Atlantic region and throughout the conterminous United States are primarily the result of introductions and translocations by humans since the 1940's (USFWS 2005). Native marsh vegetation in this area is not adapted to herbivory from Canada geese during the growing season.

The data from this study will help NPS with their management of wetlands on the Anacostia. It will provide useful insights into the vegetation response to expect at Kingman if pressure from Canada goose herbivory is reduced. It will also help NPS make better- informed decisions regarding future wetland restorations on the Anacostia River, as well as better informed management decisions for the Kenilworth Marsh, Anacostia River Fringe Wetlands, and Heritage Island Wetland, reconstructed in 1993, 2003 and 2006, respectively. Although most of Kenilworth Marsh has not been affected as severely by Canada goose herbivory, the Anacostia River Fringe Wetlands remain bordered by sheet piling that may be providing some protection from Canada goose herbivory, and the Heritage Island Wetland is still protected by a coir fiber biolog (log made of 100% biodegradable coir fiber and netting that is used to attenuate wave energy and promote stream bank/shoreline revegetation) and peripheral fencing, as well as limited interior fencing and stringing that remain seven years post-reconstruction.

The US Geological Survey (USGS) has taken the lead on the monitoring conducted at all four of the Anacostia Park wetland restoration projects (Hammerschlag et al. 2006; Krafft et al. 2009). USGS also designed the current herbivory study, combining the plot size and shape used for monitoring at the Anacostia River Fringe and Heritage Island Wetlands with the paired fenced plot and unfenced control plot design used for the deer herbivory studies in National Parks throughout the region (Rossell et al. 2007; Hatfield and Krafft 2010). This study was designed to provide herbivory data for the NPS to use in support of the Environmental Impact Statement (EIS) being conducted to sustain and improve NPS efforts in Anacostia wetland management. NPS provided the funding for the research. Preliminary results have already been included in the draft EIS (NPS 2011).

Study Area

Kingman Marsh is one of a series of four tidal freshwater wetland restorations that were undertaken in Anacostia Park along the Anacostia River between 1993 and 2006 (Figure 1). The goal of these efforts was to restore some of the extensive tidal freshwater marsh habitat that existed there prior to the destructive dredge and fill operations and sea wall installation that took place in the early to mid-1900's (Figure 2). These restoration projects were designed and implemented by the U.S. Army Corps of Engineers (USACE) and the District Department of the Environment (DDOE), working in conjunction with NPS, on lands managed by NPS.

Three of the four restorations were constructed by applying hydraulically-dredged sediments to shallow tidal man-made lakes to increase elevations sufficiently to support emergent vegetation. Kenilworth Marsh was constructed in Kenilworth Lake (1993), while Kingman Marsh (2000) and the Heritage Island Wetland (2006) were constructed in Kingman Lake (Figure 1). Unlike the three prior marshes which were reconstructed in low-energy backwater lakes, the Anacostia River Fringe Wetlands (2003) were constructed along the main stem of the Anacostia River by applying sediment to increase the elevation of remnant benches that already existed along the river. Sheet piling was installed along the perimeter of the Anacostia River Fringe Wetlands to protect the new plantings from increased volume and energy of river flow during storm events.

Kingman Marsh, the second in the series, is composed of two areas within Kingman Lake. Kingman Area 1, north of the Benning Road Bridge, consists of 16 ha of tidal freshwater wetland reconstructed in 2000; Kingman Area 2, south of the Benning Road Bridge consists of 2.7 ha. Kingman Marsh performed quite well during its first growing season, with cover in a series of 35×1 m transects averaging approximately 85% total vegetative cover at Kingman Area 1 and 120% at Kingman Area 2 in the fall of 2000 (Hammerschlag et al. 2006). This cover was provided by a variety of volunteer species and the following seven planted species: *P. virginica*, pickerelweed (*Pontederia cordata*), soft-stemmed bulrush (*Schoenoplectus tabernaemontani*), broadleaf arrowhead (*Sagittaria latifolia*), common rush (*Juncus effusus*), common threesquare (*Schoenoplectus pungens*), and *N. lutea*. All of the transects were located in areas initially protected by fencing.

Based on prior experience at Kenilworth Marsh, where only minor herbivory had been sustained, the decision was made to remove the protective fencing at Kingman Marsh in the spring of 2001. In the face of greater herbivory pressure than had been experienced at Kenilworth Marsh, total

vegetative cover averages for the Kingman Marsh transects fell to approximately 67% and 38% for Kingman Areas 1 and 2, respectively, in the fall of 2001. By the fall of 2005, total vegetative cover in the transects averaged approximately 37% for Kingman Area 1 and 12% for Kingman Area 2. Although portions of Kingman were refenced and replanted, either by USACE, or by AWS (in conjunction with their extensive restoration work), a fair amount of the reconstruction was not refenced or replanted and currently remains unvegetated.

Kingman Area 1 was chosen for the location of the herbivory study due to its size, the presence of a mix of habitat types, and prior documented impacts from herbivory (Hammerschlag et al. 2006).

Methods

Sixteen study modules were installed in Kingman Marsh in June 2009. Each module consisted of one fenced plot paired with one unfenced control plot. Fencing was elevated to allow access to herbivores such as fish and turtles, while excluding mature Canada geese. Vegetation data were collected twice each year, once in June and again in August, near the height of the growing season.

Habitat Types

Two of the habitat types currently present at Kingman Marsh were chosen for inclusion in this study: initially-vegetated and initially-unvegetated. The initially-vegetated areas had been fenced and seeded with *Z. aquatica* during the period of 2004-2007 (AWS, McKindley-Ward, pers. comm., 2009). These initially-vegetated areas remained fenced until the start of the current study in June 2009. By contrast, areas that were initially-unvegetated had not been fenced and seeded by AWS during 2004-2007, and were characterized as possessing little if any vegetation at the start of the study.

Elevations

Since elevation can play a key role in determining revegetation response parameters such as percent cover, species composition and species richness in a tidal freshwater wetland system, all sampling plot locations were required at the start of the experiment to fall within an elevation range of 0.25 to 0.37 m NAVD88 (1.60 to 2.00 ft NGVD29), which has been shown in previous work on the Anacostia to be high enough to support wetland vegetation, but low enough to reduce the potential for invasion by purple loosestrife (*Lythrum salicaria*) or *P. australis* (Neff 2002; Hammerschlag et al. 2006; Krafft et al. 2009). Elevations were obtained with a laser level pegged to local benchmarks.

Selection of Module Locations

During the winter of 2009 USGS and NPS staff collected elevation data from random point locations at Kingman Marsh. Areas with multiple elevations that fell within the desired elevation range were identified. Within each area, elevations were then tested at a series of random module locations to determine whether they met the elevation criterion. This was done

by choosing a random study plot orientation at the first module location, obtaining one elevation in each half of the first study plot, and then averaging the two elevations. If the average for the first study plot fell within the desired range, elevations were obtained and averaged for the corresponding location of the paired study plot within that module. In cases where the average for each of the paired study plots fell within the desired range, the study plot orientation and study module were retained, and a treatment (fenced or unfenced) was randomly assigned to each of the two study plot locations within the module. If the average of either of the paired study plots fell outside of the desired elevation range, a new random study plot orientation was chosen and tested at that module location. Module locations not meeting the elevation requirement within three study plot configurations were discarded. Locations with a minimum separation distance < 6 m from module center to existing fencing or another study module were also discarded. A total of eight module locations were chosen for each habitat type (Figure 3).

Study Modules

Modules were installed in May 2009. Module lay-out is shown in Figure 4. Each module contained two 1×2 m sampling plots, one plot nested within a fenced exclosure and the other an unfenced control plot. Exclosures were constructed of vinyl-coated wire fence with a mesh size of 5×10 cm. Initially, the 1.2-m high fence was elevated 0.2 m above the sediment for a total height of 1.4 m. A lower elevation height of 0.2 m was chosen rather than the 0.25 m used in the previous studies on the Anacostia and Patuxent (Haramis and Kearns 2007; May 2007) to provide additional deterrence to goose entry. Fence elevations have been lowered twice since 2009 after video footage showed adult Canada geese easily slipping under the fence to browse the *Z. aquatica*. Having lowered the elevation to 0.15 m in June 2010, elevations were lowered again to 0.1 m in June 2011 in response to continued herbivory inside the exclosures and further photo documentation of adult geese inside the exclosures. Given the softness and unevenness of the substrate this reduction would not be expected to act as a deterrent to most fish, turtles, etc.

Exclosures measured 3×4 m, surrounding the 1×2 m sampling plot and a 1-m buffer that was included to limit possible impacts to the fenced sampling plots from geese stretching their necks to graze under the elevated fence. This also provided samplers room to walk inside the exclosures without impacting the sampled area. Horizontal stringing and flagging were used to further deter geese from entering the exclosures from above, although the small size of the exclosures would make this method of entry unlikely. Module orientation was random.

Vegetation Sampling

Baseline vegetation sampling of all the modules was conducted in June 2009, shortly after removal of the old protective fencing from the initially-vegetated areas that now contained study modules. Sampling was repeated two months later, in August 2009, and has been conducted in June and August of each subsequent year, maintaining a balanced design. For each sampling event, a 1×2 m frame constructed of PVC pipe was hooked over the PVC plot markers to delineate the boundary of the sampling plot to insure that the same area would be read during successive sampling events. Ocular estimation was used to record percent cover by species (or nearest identifiable taxon). Estimates were made to the nearest 1% in ranges where it is easier to

accurately estimate cover (0-15% and 95-100%), and in 5% increments between 15 and 95%. Taxonomic nomenclature follows the PLANTS database (USDA 2013).

Total vegetative cover was calculated as the sum of the cover values for all of the taxa. Since species may overlap, total vegetative cover may exceed 100%. Similarly, cover by natives and cover by non-natives were calculated as the sum of the cover values for all native or non-native taxa in the study plot, which has the potential to exceed 100%. Dominant species were defined as species averaging at least 5% for at least one habitat/month/treatment combination (e.g., initially-vegetated, June, unfenced control plots). Species richness was defined as the number of species (or distinct taxa) observed per 2 m^2 sampling plot.

Surveillance and Photo-Documentation

Periodic surveillance was conducted throughout the growing season to confirm that the exclosures were still intact, to look for signs of herbivory inside the exclosures, and to remove debris that was snagged on the fencing or PVC marker poles (to minimize accumulation of sediment as an artifact of the plot structure). Digital photo-documentation was accomplished by taking a set series of photographs from seven prescribed views for each module in conjunction with the sampling events. Video and still cameras equipped with motion detectors were also used as needed in 2010 and 2011 to document the presence of adult Canada geese inside the exclosures.

Data Analysis

For total vegetative cover, cover by natives, cover by dominant species, and species richness, differences between paired fenced plots and unfenced control plots were calculated and analyzed using mixed model repeated measures analysis of variance (ANOVA, SAS 2003, PROC MIXED) to compare data among years (2009-2011), months (June and August), habitat types (initially-vegetated or initially-unvegetated), and their interactions. Data were transformed prior to analysis using a natural logarithm transformation to improve normality, as needed. Since the difference between fenced – unfenced control may be negative, it is necessary to perform the log transformation by taking the difference of the logs rather than the log of the differences. Four variance-covariance structures were modeled (compound symmetry, autoregressive, Toeplitz, and unstructured) and the best model selected via AIC_c comparisons (Littell et al. 1996). Post pairwise comparisons to determine whether the fenced – unfenced control differences varied significantly over time were made using Tukey's Studentized Range Test of Least Squares Means (family-wise error rate with $\alpha = 0.05$). Inspection of the least square means and associated t-tests were used to determine the significance of differences between fenced plots and unfenced control plots for each habitat by month interaction (e.g., initially vegetated, August 2009), with an α of 0.05 after Bonferroni correction.

Results and Discussion

Results of the ANOVAs conducted on the differences between paired fenced plots and unfenced control plots for the variables total vegetative cover, total native cover, cover by individual dominant species, and species richness are provided in Table 1. These *P*-values refer to whether

the differences between paired fenced plots and unfenced control plots behave the same or differently depending on the year, the month, the habitat, or their interactions. Of particular importance to this study are the associated least square means and t-tests that indicate the significance of differences between the paired fenced plots and unfenced control plots. The significance of these differences is displayed in Figures 5 and 8 through 13. Although the statistical tests were conducted on the differences between the paired plots rather than their actual values, the corresponding graphs display the arithmetic means of the fenced plots and unfenced control plots (± 1 standard error) for ease of interpretation. Table 2 provides the Tukey test results, showing the significance of changes in the differences over time. Table 3 provides a list of the species that were observed in the study plots during the three-year study.

Total Vegetative Cover

At the start of the study in June 2009 total vegetative cover for the modules that were initially vegetated averaged 93.1 ± 6.5% in the fenced plots and 103.1 ± 4.4% in the unfenced control plots (Figure 5a). Total vegetative cover for the modules that were initially unvegetated averaged only 0.5 ± 0.4% in the fenced plots and 1.0 ± 0.6% in the unfenced control plots (Figure 5b). Inspection of the least square means and associated t-tests for this baseline sampling event showed no significant differences between paired fenced plots and unfenced control plots for total vegetative cover either for the initially-vegetated modules or the initially-unvegetated modules. Figures 6 and 7 illustrate changes in vegetation over the first three years of the study for a representative initially-vegetated module (Module 11 shown in Figure 6) and a representative initially-unvegetated module (Module 9 shown in Figure 7). The lack of significant differences in total vegetative cover between paired fenced plots and unfenced control plots in the baseline condition in June 2009 is shown in Figure 6a for the initially-vegetated modules and Figure 7a for the initially-unvegetated modules.

In August, two months after the exclosures were installed and the old protective fence was removed, total vegetative cover for the initially-vegetated modules averaged 98.4 ± 3.1% for the fenced plots compared to 40.5 ± 16.0% for the unfenced controls. Differences between the paired fenced plots and unfenced control plots were significant. This is evident visually in the comparison between the June and August 2009 photographs for Module 11 (Figures 6a and 6b), which illustrate the striking impact exposure to two months of herbivory exacted on the initially-vegetated control plots.

Fenced plots in the modules that were initially-unvegetated did not achieve much cover during 2009, averaging only 2.0 ± 1.4% for total vegetative cover in August. Total vegetative cover for the corresponding unfenced control plots averaged 0.1 ± 0.1%. Differences between paired fenced plots and unfenced control plots were not significant for the modules that were initially unvegetated. The general lack of vegetation in the initially-unvegetated fenced plots and unfenced control plots in August 2009 is illustrated by the photograph of Module 9 in Figure 7b. Two months of protection from herbivory starting in June 2009 was insufficient to accomplish significant revegetation of the initially-unvegetated fenced plots. It is unclear whether additional revegetation of these fenced plots might have been achieved during 2009 had the schedule permitted installation of the exclosures earlier in the growing season (prior to the germination of important annuals such as *Z. aquatica*).

In 2010 and 2011, the fenced plots in the eight initially-vegetated modules continued to display significantly greater total vegetative cover compared to the unfenced control plots (Fig. 5a), in spite of the partial exposure of fenced-plot vegetation to goose herbivory during this timeframe. In August 2011 total vegetative cover averaged 61.9 ± 12.3% for the fenced plots, compared to 25.0 ± 13.5% for the unfenced control plots. It should be noted that the bulk of the total vegetative cover in the unfenced control plots reflects the presence of low-palatability plants that were already established in or near three of the unfenced control plots prior to the removal of the protective fencing at the start of the study. No vegetative cover was recorded in any of the remaining five unfenced control plots in August of 2011. The photographs in Figure 6 illustrate the effects of partial exposure to browse in the Module 11 fenced plot, as well as the stark contrast between paired fenced plot and unfenced control plot that persisted in spite of partial exposure to herbivory during 2010 and 2011.

The statistics provided in Table 2 indicate that the fenced plot – unfenced control plot difference in the initially-vegetated modules increased significantly from June to August 2009 as the previously protected control plots received full exposure to Canada goose herbivory, and has not changed significantly since then.

Total vegetative cover in the initially-unvegetated modules, which saw little growth and no significant differences between fenced plots and unfenced control plots in 2009, exhibited a huge increase in cover for the fenced plots during 2010 and 2011, with fenced plot – unfenced control plot differences becoming significant in August 2010 and remaining so during 2011 (Fig. 5b). In August 2011, total vegetative cover in the initially-unvegetated modules averaged 68.6 ± 15.6% for the fenced plots compared to only 0.6 ± 0.3% for the unfenced control plots. The photographs in Figure 7 illustrate the dramatic changes to total vegetative cover exhibited by the initially-unvegetated fenced plots during 2010 and 2011. This is in great contrast to the paired unfenced control plots also displayed in Figure 7, which experienced full exposure to herbivory pressure from Canada geese during this timeframe, and remained essentially unvegetated.

The differences between fenced plots and unfenced control plots have followed different trajectories over time in the initially-unvegetated and initially-vegetated modules. For the initially-vegetated modules the fenced plot-unfenced control plot differences increased significantly by the first sampling event post-baseline and have not changed significantly since (Table 2). By contrast, for the initially-unvegetated modules, the fenced plot – unfenced control plot differences and their significance have gradually increased over time post-baseline.

The total vegetative cover results from the first three years of the herbivory study (2009-2011) indicate that pressure from Canada goose herbivory continues to exert significant negative impacts to native vegetation in the Kingman Marsh wetland restoration constructed in 2000, documented through statistical analysis of the difference in total vegetative cover between paired fenced plots and unfenced control plots. Results were statistically significant in spite of the partial exposure to herbivory experienced by fenced plot vegetation during 2010 and 2011, when we were working to find an optimal fence elevation that would keep out adult Canada geese, but allow access to other potential herbivores such as fish and turtles. Since fish and turtles had access to both the fenced and unfenced plots their component of observed herbivory is reflected

in the total vegetative cover in both types of plots. If the total decimation observed in most of the unfenced control plots were due to herbivory by non-goose herbivores, the same degree of decimation would be expected in the fenced plots, which was not the case. Results were also significant regardless of whether the modules were initially vegetated or initially unvegetated.

Total Cover by Natives

Of the 16 species (or unique taxa) observed in the study plots during the first three growing seasons of the study, 13 were native (Table 3). In August 2011, three years into the herbivory study, cover by natives represented 99% of the total vegetative cover in the herbivory study plots.

Since almost all of the vegetative cover in the study plots was native, it is not surprising that the graph and statistical results for cover by natives essentially matched those for total vegetative cover. The pattern of significant differences between fenced and unfenced plots was identical to that displayed for total vegetative cover in Figure 5. Results of the ANOVA and Tukey tests are shown in Tables 1 and 2. Since cover by natives was so similar to total vegetative cover, cover by natives is not shown in a separate graph.

Like the results for total vegetative cover, the fenced plot – unfenced control plot differences for cover by natives were not statistically significant at the start of the study, but became significant over time as vegetation in the unfenced control plots experienced full exposure to Canada goose herbivory, while vegetation in the fenced plots received at least partial protection.

Total Cover by Non-Natives

Only two of the 16 species observed in the herbivory modules were non-natives, marshpepper knotweed (*Polygonum hydropiper*) and wartremoving herb (*Murdannia keisak*). In August 2011, three years into the study, cover by non-natives was still extremely low, averaging less than 1.0% regardless of habitat type or fencing status. No ANOVA was performed on the data for cover by non-natives, due to its low normality even after transformation. Since cover levels for non-natives were so low, they are not shown in a graph.

P. hydropiper and *M. keisak* were both documented at the Kingman Marsh restoration during the course of the original 2000-2004 study (Hammerschlag et al. 2006). Although as non-natives it makes sense to keep an eye on these species, they have not shown themselves to be highly invasive at any of the Anacostia Park tidal freshwater wetland restorations in the past (Krafft et al. 2009, Hammerschlag et al. 2006). The non-native invasives, *P. australis* and *L. salicaria*, although present at Kingman Marsh, were not observed in the study modules during the first three growing seasons. Both of these species would be expected to occur at elevations higher than the range chosen for our study modules (Krafft et al. 2009).

Cover by Dominant Species

Five species met the criterion for dominant species status in 2011 by averaging at least 5% for any habitat/month/treatment combination. They were *Z. aquatica*, *P. cordata*, *P. virginica*, *Polygonum punctatum* (dotted smartweed), and *N. lutea*.

Zizania aquatica

All of the initially-vegetated modules are located in areas that had been fenced and seeded with *Z. aquatica* by AWS after the original marsh restoration (which did not include planting of *Z. aquatica*) was decimated by the herbivory that started in 2001. Although *Z. aquatica* was not the only species AWS planted at Kingman Marsh, it was seeded fairly heavily in the areas where the initially-vegetated modules are located. At the start of the experiment, *Z. aquatica* was observed in all 16 sampling plots (8 modules) located in the initially-vegetated area.

Given this history, it is not surprising that *Z. aquatica* was the overwhelming dominant in the initially-vegetated modules in June 2009, averaging 63.8 ± 10.7% in the fenced plots and 67.0 ± 11.7% in the unfenced control plots (Figures 6 and 8). Given the high palatability of *Z. aquatica* to Canada geese, its absence from any of the initially-unvegetated modules is also not surprising. Differences between the paired fenced plots and unfenced control plots were not significant in June 2009 for either the initially-vegetated modules or the initially-unvegetated modules.

By August 2009, two months after the old protective fencing had been removed from the initially-vegetated areas, the fenced plots in the initially-vegetated modules averaged 88.1 ± 9.1% cover for *Z. aquatica*, compared to the newly-unprotected control plots, where it averaged only 13.0 ± 11.7% (Figures 6 and 8). Differences between the paired fenced plots and unfenced control plots were significant for the initially-vegetated modules. They were not significant for the initially-unvegetated modules, where *Z. aquatica* was absent (Figures 7 and 8).

During 2010 and 2011, the initially-vegetated fenced plots experienced partial exposure to Canada goose herbivory (documented in video footage and still shots). As we worked to optimize fence elevation, cover by the highly-palatable *Z. aquatica* took a big hit during 2010-2011. By August 2011, partial exposure to Canada goose herbivory had sufficiently altered the species prevalence in the fenced plots to the extent that average *Z. aquatica* cover dropped to 1.5 ± 1.2%, and was no longer significantly greater than the 0% present in the unfenced control plots (Figure 8). The photographs in Figure 6 illustrate how this played out for one initially-vegetated module, Module 11. In June 2010, *Z. aquatica* in the fenced plot was clearly shorter than the baseline condition of June 2009, but by August 2010, it was flowering robustly and appeared to have bounced back, reflecting the observation at some point in the growing season if the wildrice has grown tall enough it is no longer as susceptible to damage by Canada goose herbivory. In the June 2011 photograph, *Z. aquatica* in the fenced plot has experienced more extensive herbivory; by the August 2011 photograph there was an absence of flowering *Z. aquatica*, and plot dominance had been taken over by another native, *P. cordata*. In this case it appeared that prolonged exposure to severe Canada goose herbivory of *Z. aquatica* prevented the species from achieving heights sufficient to decrease susceptibility to Canada goose herbivory.

Z. aquatica fared somewhat better in the initially-unvegetated fenced plots over the same timeframe. After an absence of *Z. aquatica* during 2009, the species increased gradually over 2010 and peaked at an average of 20.2 ± 10.2% in June 2011, finally reaching a level significantly greater than in the paired unfenced control plots (Figure 8). By August 2011, *Z. aquatica* averages had decreased to 5.4 ± 2.8% in the fenced plots, however, no longer significantly greater than in the paired unfenced control plots. The photographs in Figure 7 illustrate the changes exhibited by *Z. aquatica* in Module 9, one of the initially-unvegetated modules, over the first three years of the study. The data, photographs, and field notes suggest that when *Z. aquatica* first appeared at somewhat low cover levels in the initially-unvegetated fenced plots in 2010, the Canada geese either didn't notice, or at least did not respond. By June 2011, however, we did observe signs that the *Z. aquatica* in the fenced plots was experiencing partial exposure to Canada goose herbivory, and by August 2011, other native species such as *P. punctatum*, and the *P. cordata* observed in the photograph in Figure 7f, appeared to be outcompeting the remaining browsed *Z. aquatica*.

The results from the first three years of the herbivory study suggest that of the native dominant plant species observed in the study modules at Kingman Marsh, *Z. aquatica* is the most highly palatable to Canada geese. The results to date also indicate that *Z. aquatica* is unable to persist as a dominant at Kingman Marsh at current levels of herbivory pressure unless it receives almost total protection from Canada goose herbivory.

Pontederia cordata

P. cordata was planted at Kingman Marsh during the original plantings in 2000, but this highly-palatable species was hit especially hard by herbivory in 2001 after the protective fencing was removed, decimating its cover levels (Hammerschlag et al. 2006). *P. cordata* was subsequently replanted at Kingman Marsh by AWS in its protected exclosures. Unlike *Z. aquatica*, which AWS planted as seed throughout most of the area where they performed restoration efforts at Kingman Marsh, both *P. cordata* and *P. virginica* were planted as plants and ended up producing lower densities of plants and patchier distributions compared to the *Z. aquatica*. *P. cordata* was planted at much lower numbers than *P. virginica* (AWS, McKindley-Ward, pers. comm., 2010).

In June 2009, *P. cordata* cover averaged 3.4 ± 1.8% in the initially-vegetated fenced plots and 8.8 ± 8.8% in the initially-vegetated unfenced control plots (Figure 9). The magnitude of the standard error associated with the unfenced control plot mean reflects the fact that all of the *P. cordata* cover was concentrated in only one of the initially-vegetated unfenced control plots (in Module 12). Differences between paired fenced plots and unfenced control plots were not significant. *P. cordata* was absent from the initially-unvegetated plots in June 2009, which is as expected based on the relatively high palatability and vulnerability to herbivory pressure demonstrated by this species during the initial decimation observed at the Kingman Marsh restoration in 2001 (Hammerschlag et al. 2006).

In August 2009, *P. cordata* was absent from the fenced plots in the initially-vegetated modules and averaged 10.6 ± 10.6% in the paired unfenced control plots. Differences between the paired fenced plots and unfenced control plots were not significant, reflecting the large standard error associated with the unfenced control plot mean. *P. cordata* remained absent from the initially-unvegetated modules.

By August 2010, highly-palatable *P. cordata* was absent from all of the unfenced control plots regardless of initial habitat status, and remained absent through the August 2011 sampling event. This is in contrast to *P. cordata* in the fenced plots, which increased significantly during the same timeframe. By August 2011, *P. cordata* cover was significantly greater in the fenced plots than in the paired unfenced control plots regardless of initial habitat status (Figure 9). Cover levels in August 2011 averaged 30.6 ± 12.4% in the initially-vegetated fenced plots and 34.0 ± 10.7% in the initially-unvegetated fenced plots, compared to 0% in the paired unfenced plots. *P. cordata* cover increased somewhat more quickly in the initially-unvegetated fenced plots compared to the initially-vegetated, achieving significantly greater cover than in paired fenced plots by August 2010. For the initially-vegetated modules this significance was not achieved until August 2011, a year later. The increased prevalence of *P. cordata* by August 2011 is illustrated in the photographs in Figures 6f and 7f.

Results from the first three years of the study suggest that *P. cordata* is sufficiently palatable to Canada geese that it has difficulty even maintaining a presence at current ambient herbivory levels, but given protection from herbivory by resident and nonmigratory Canada geese, it has the potential to become a dominant species in the marsh. Although *P. cordata* was shown to be highly palatable to Canada geese at Kingman Marsh during the original decimation of vegetation in 2001 (Hammerschlag et al. 2006), data from this study suggest that it is less palatable than *Z. aquatica*. When the initially-vegetated fenced plots were experiencing partial exposure to herbivory during 2010 and 2011, *P. cordata* exhibited few impacts from browsing, compared to severe browsing of *Z. aquatica*. The sharp increase in *P. cordata* cover in the initially-vegetated fenced plots concurrent with the sharp decrease in *Z. aquatica* cover in August 2011 suggests that the heavy browse of *Z. aquatica* reduced the competition experienced by *P. cordata*, and allowed it to become a dominant in these plots.

Peltandra virginica

Like *P. cordata*, *P. virginica* was planted at Kingman Marsh during the original plantings in 2000. Unlike *P. cordata*, its presence was not decimated by Canada goose herbivory when the protective fencing was removed in 2001. In fact, *P. virginica* cover increased at Kingman Marsh over the course of the 5-year study (Hammerschlag et al. 2006). Because of its proven low palatability, *P. virginica* was planted in fairly high numbers in the subsequent AWS protected restoration areas at Kingman that provided the habitat for the current initially-vegetated study modules. Since it was planted as plants rather than the dense seeding that was used for *Z. aquatica*, its distribution in the initially-vegetated modules at the start of the study was patchier and less dense than that of *Z. aquatica*.

At the start of the experiment in June 2009, *P. virginica* cover averaged 20.0 ± 13.1% in the initially-vegetated fenced plots and 18.8 ± 12.0% in the paired unfenced control plots (Figure 10). Differences between paired fenced plots and unfenced control plots were not significant for the initially-vegetated modules. *P. virginica* was virtually absent from the initially-unvegetated plots.

In August 2009, *P. virginica* cover in the initially-vegetated modules averaged 8.8 ± 6.9% for the fenced plots and 16.4 ± 11.0% for the paired unfenced control plots. Competition from *Z.*

aquatica undoubtedly played a major role in the large seasonal decline of *P. virginica* observed in the initially-vegetated fenced plots during 2009. *Z. aquatica* is an annual and experiences a huge increase in biomass over the course of the growing season in natural systems (Whigham et al. 1978). Haramis and Kearns (2007), working at nearby Jug Bay, on the Patuxent River, also documented greater size and density of fenced *Z. aquatica* plants when compared to natural stands of the species. Some of the decline observed during the August 2009 sampling event for both fenced plots and unfenced control plots may also have been caused by natural senescence, since *P. virginica* has been observed to senesce earlier in the growing season than many freshwater tidal wetland species (Whigham et al. 1978; Krafft et al. 2009). Although differences between the paired fenced plots and unfenced control plots were observed, it should be noted that these differences were not statistically significant.

P. virginica remained virtually absent from the initially-unvegetated modules in August 2009.

Inspection of the least square means and associated t-tests for the 2010 and 2011 data from the initially-vegetated modules show that *P. virginica* cover averages were significantly greater in the fenced plots compared to the unfenced control plots during three of the four sampling events during this timeframe (Figure 10). Results of the Tukey tests also show that fenced plot – unfenced control plot means increased significantly from 2009 to 2010 (Table 2). In June 2011 *P. virginica* levels in the initially-vegetated modules averaged 26.2 ± 15.6% in the fenced plots and 20.0 ± 13.4% in the unfenced control plots.

Additional insights can be gained by a closer inspection of the raw data, which reveals that in the initially-vegetated modules, *P. virginica* cover averages were driven by just two of the eight modules, where the species was present as a dominant in both the fenced and unfenced control plots at the start of the study. Over the first three years of the study, the relatively unpalatable *P. virginica* was able to retain its position as the dominant species in those plots, regardless of whether or not they were fenced, hence the relatively high cover averages for the unfenced control plots during the first three years. Looking beyond these two modules where *P. virginica* was already present as established plants at the start of the study, *P. virginica* was present in five additional fenced plots in 2011 with cover values ranging from 2-5%, compared to two additional unfenced control plots each with a cover value of 0.1%, June only. These data indicate that once *P. virginica* is established, it is fairly robust to Canada goose herbivory, as previously noted at the Kingman Marsh reconstruction (Hammerschlag et al. 2006). The current data also indicate that as a small seedling in an otherwise bare area, however, *P. virginica* is still extremely vulnerable to herbivory.

During 2010 and 2011, *P. virginica* cover levels in the initially-unvegetated plots remained extremely low, not exceeding a 1% average in any of the 2010 or 2011 sampling events. Differences between the fenced plots and unfenced control plots remained insignificant (Figure 10). A closer inspection of the raw data reveals that by August of 2011, five of the eight fenced plots contained *P. virginica*, however, with cover values ranging from 0.5-6%. By contrast, only one of the eight unfenced plots contained *P. virginica* cover, and in the case of this plot, the cover resulted from the expansion of leaves into the plot from a nearby established plant, rather than the result of a new seedling. These data indicate that *P. virginica* has successfully dispersed into the fenced plots in the initially-unvegetated areas. Absent Canada goose herbivory inside

the fenced plots, whether *P. virginica* becomes a dominant in these plots over time should now depend on its ability to compete with other native species such as *P. cordata* and *P. punctatum*, which have already reached dominant status in these plots.

Polygonum punctatum

P. punctatum was never planted at Kingman Marsh, although its presence there as a volunteer was documented during the earlier 5-year Kingman Marsh study (Hammerschlag et al. 2006).

During the first sampling event at the start of the herbivory study in June 2009, no *P. punctatum* was observed in any of the study plots (Figure 11). By August 2009, *P. punctatum* was still absent from all but the initially-unvegetated fenced plots, where it averaged 2.0 ± 1.4%. By June 2010, *P. punctatum* achieved the status of dominant species in the initially-unvegetated fenced plots, and by August 2010 *P. punctatum* cover was significantly greater in the initially-unvegetated fenced plots than in the paired unfenced control plots. *P. punctatum* cover remained significantly greater in the initially-unvegetated fenced plots than in the unfenced control plots during 2011, averaging 23.0 ± 11.2% in August, compared to 0.1 ± 0.1% in the corresponding unfenced control plots.

P. punctatum has performed quite differently in the initially-vegetated modules, exhibiting extremely low levels of cover regardless of fencing status until August 2011, when *P. punctatum* cover averaged 4.9 ± 3.0% in the fenced plots compared to 0% in the unfenced control plots, and achieved a significant difference between the fenced plots and the unfenced control plots.

These results indicate *P. punctatum* is vulnerable to Canada goose herbivory, at least in the context of isolated seedlings in an otherwise bare area. With protection from herbivory, *P. punctatum* was able to fairly quickly become a dominant species in the fenced plots that had started out as unvegetated. In the fenced plots that had started out already vegetated by other species, competition slowed the increase of *P. punctatum* cover, although dominant status was finally achieved in these plots in August 2011.

Nuphar lutea

N. lutea was planted at relatively low numbers at lower elevation locations around the edges of the marsh as part of the original Kingman Marsh reconstruction in 2000 (Hammerschlag et al. 2006). Having proven its low palatability during the herbivory decimation in 2001, *N. lutea* has subsequently been planted by AWS in low-elevation patches around Kingman Marsh.

During the first two years of the study *N. lutea* was present only in the initially-vegetated unfenced control plots, where it attained a maximum average of 1.5 ± 1.5% in June 2010 (Figure 12). In June 2011, *N. lutea* met the dominant species criterion, averaging 5.6 ± 5.6% in the initially-vegetated unfenced control plots, and was also present for the first time in the initially-vegetated fenced plots, with a maximum average of 0.6 ± 0.6% in August 2011. *N. lutea* was not recorded in the initially-unvegetated modules during the first three years of the study. No further statistical analysis was performed on the first three years of *N. lutea* cover data, due to extremely low normality even after transformation.

Although the *N. lutea* cover data was not sufficiently robust to support further statistical analysis, closer inspection of the raw data did provide some additional insight. *N. lutea* has been recorded in only one module (Module 12), an initially-vegetated module where *N. lutea* was present on the margin of the unfenced control plot at the start of the study in June 2009. During 2009, *P. cordata* was the overwhelming dominant in this plot. By 2010, the Canada geese had discovered and decimated this unfenced *P. cordata*, opening up the plot for expansion of the adjacent low-palatability *N. lutea*, which began in 2010 and continued in 2011. In 2011 *N. lutea* also made it into the paired fenced plot, although at much lower levels.

In conclusion, the first three years of herbivory study data indicate that once *N. lutea* is established, its relatively low palatability makes it fairly resistant to Canada goose herbivory, even allowing it to expand into previously protected areas once the protection is removed and the more highly-palatable species is eliminated through herbivory. Why it failed to appear in any of the other modules during the first three years of the study might be a due to a variety of factors including low availability of seeds, vulnerability of seedlings to herbivory, and competition from species already in the plots. Elevation might also play a role in the case of the plots at the higher end of the initial elevation range allowed, since *N. lutea* tends to occupy a lower elevational niche than some of the other wetland dominants, although this would not be expected to play too great a role since elevation was controlled for during site selection, with high marsh elevations excluded.

Species Richness

Species richness, defined as the number of species observed per 2 m^2 sampling plot, was quite low during the first growing season of the study. In June 2009 the initially-vegetated modules averaged 2.4 ± 0.2 in the fenced plots and 2.4 ± 0.3 in the unfenced control plots (Figure 13). Species richness was even lower in the initially-unvegetated modules, where the fenced plots averaged 0.5 ± 0.2, and the unfenced control plots averaged 0.9 ± 0.2. No significant differences in species richness were observed between the fenced and unfenced plots regardless of whether they had been initially vegetated or unvegetated.

By August 2009, species richness had decreased slightly, in the initially-vegetated modules averaging 1.9 ± 0.4 for the fenced plots and 1.1 ± 0.3 for the unfenced control plots, and in the initially-unvegetated modules averaging 0.4 ± 0.2 and 0.4 ± 0.3 for the fenced plots and unfenced control plots, respectively. Differences between paired fenced plots and unfenced control plots were not significant in August 2009 for either habitat type.

During 2010, species richness increased sufficiently in the fenced plots to become significantly greater than in the paired unfenced plots, regardless of initial habitat status. For the initially-vegetated fenced plots this increase in species richness probably reflected the decrease in *Z. aquatica* cover caused by partial exposure to Canada goose herbivory and the opening up of newly-unoccupied space that allowed additional species to come in as a result. In the case of the initially-unvegetated plots, there was basically no pre-existing vegetation occupying the space as it received protection from Canada goose herbivory, so species capable of dispersing into the newly-protected plots would not have been hindered in their establishment by competition from pre-existing vegetation.

The fenced plot – unfenced control plot differences for species richness remained significant through 2011, again regardless of initial habitat status. In August 2011 species richness in the initially-vegetated modules averaged 3.0 ± 0.4 for the fenced plots compared to 0.4 ± 0.2 for the unfenced control plots, while in the initially-unvegetated modules species richness averaged 3.5 ± 0.6 in the fenced control plots and 0.5 ± 0.3 in the unfenced control plots.

Species richness values exhibited by the fenced plots during the third year of the Kingman herbivory study are much lower than the values obtained in the Anacostia River Fringe Wetlands using the same shape and size of sampling plot, where species richness averaged 7.9 ± 0.8 for Anacostia River Fringe A and 8.8 ± 0.8 for Anacostia River Fringe B five years into the reconstruction (Krafft et al. 2009). They are not so dissimilar from the species richness average of 3.7 ± 0.5 obtained for the Heritage Island Wetland three years post-reconstruction, however.

Possible causal factors for lower species richness in the Kingman fenced plots than in the plots at the River Fringe include elevation in the case of Anacostia River Fringe B, and a planting regime in the case of Anacostia River Fringe A that resulted in three well-developed strata of vegetation. Most of the elevations at Anacostia River Fringe B were higher than the range set for the Kingman modules (and therefore more susceptible to invasion by *P. australis* and *L. salicaria*). The seven plots at Anacostia River Fringe B that fell within the same elevation range as that used for the herbivory modules (22% of total plots) actually only averaged 3 species per plot. In the case of Anacostia River Fringe A, the eight plots that fell in the same elevation range as that set for the Kingman herbivory modules (50% of total) averaged 9 species per plot. This was achieved by the presence of three strata of vegetation, with floating primrose-willow (*Ludwigia peploides*) in some cases providing a prostrate stratum, *P. virginica* with or without *S. latifolia* providing a middle stratum, and *Z. aquatica* with or without broadleaf cattail (*Typha latifolia*) providing a tall stratum. It is unclear what led to three strata of vegetation, although it seems possibly related to the planting history, which involved seeding of *Z. aquatica*, but at much lower densities than were used in the Kingman AWS exclosures, with a much patchier distribution, and only after the reconstructed marsh vegetation was already established. It is also unclear whether those three strata of vegetation and related high levels of species richness were transient or able to persist beyond the first five years post-reconstruction (when monitoring ended).

In conclusion, over the course of the first three years of the study Canada goose herbivory has had a clear negative impact on vegetation in the unfenced control plots by reducing its species richness relative to that exhibited by vegetation in the paired fenced plots, regardless of initial habitat.

Elevation

Sample plot elevations measured in May 2009 during the module location phase of the study ranged from 0.25 to 0.37 m NAVD88, and averaged 0.31 ± 0.1 m for the initially-vegetated unfenced controls and initially-unvegetated fenced plots, and 0.32 ± 0.1 m for the initially-vegetated fenced plots and initially-unvegetated unfenced controls. Controlling for elevation in this way should insure (based on previous elevation work in the Anacostia Park wetland restorations) that all of the sampling plots started the experiment at elevations high enough to

support emergent vegetation and low enough to reduce vulnerability to invasion by non-natives (Neff 2002; Hammerschlag et al. 2006; Krafft et al. 2009). Areas dominated by the non-native invasive, *P. australis*, were characterized by elevations above the elevation range chosen for the study.

Conclusions

The goal of this study was to document the impacts and primary source of herbivory to the tidal freshwater vegetation present in the wetland restorations in Anacostia Park. Early results were factored into the draft Wetland Management Environmental Impact Statement (NPS 2011) prepared by NPS, allowing them to make better informed decisions regarding policies for and management of the wetlands within Anacostia Park.

Total vegetative cover in the initially-vegetated modules (located in areas that AWS had over recent years planted with natives and protected by fencing until the start of our study) showed no significant difference between the fenced and unfenced control plots in June 2009 under the baseline conditions present immediately after the old AWS protective fencing was removed from the initially-vegetated habitat. By August 2009 and throughout the subsequent sampling events in 2010 and 2011, total vegetative cover in the fenced plots was significantly greater than in the unfenced control plots. The results indicate that the significant negative impacts to total vegetative cover in the unfenced control plots are due to herbivory by resident and nonmigratory Canada geese, since negative impacts from other herbivores such as fish and turtles which had access to the elevated fenced plots as well as the unfenced control plots should have been experienced by vegetation in both plot types. Results remained significant during 2010 and 2011, in spite of the fact that vegetation in the fenced plots only received partial protection from resident and nonmigratory Canada goose herbivory during this time, as it became apparent through motion-sensor video surveillance and still photos that some of the adult geese were able to slip under the exclosure fences in order to browse. Given the unconsolidated and uneven substrate, we assume that the 10 cm fencing elevation set in the spring of 2011 did not prevent access by the non-goose herbivores such as fish and turtles.

The initially-unvegetated modules were located in areas that had not been replanted and protected by AWS following the initial restoration and the decimation which began in 2001. They were essentially devoid of vegetation at the start of the experiment in June 2009, and exhibited little plant establishment over the course of the first growing season. By August 2010, however, total vegetative cover in the fenced plots had increased to the extent that it was significantly greater than that in the unfenced control plots. In 2011 total vegetative cover continued to increase, and remained significantly greater than in the unfenced control plots, in spite of partial exposure of the initially-unvegetated fenced plot vegetation to herbivory during this time. This in effect was the purpose of establishing modules in unvegetated areas, to demonstrate that over time with reduced goose herbivory there could be natural marsh regeneration.

The total vegetative cover results show that although the elevated exclosures provided full access to non-goose herbivores, herbivory in the fenced plots was not as great as in the unfenced plots. If non-goose herbivores were a primary force, the vegetation in the elevated-fence plots should

have been decimated. The raised exclosures did provide partial protection from geese, but not non-goose herbivores.

Thirteen of the 16 species observed in the Kingman herbivory study plots were native, and 99% of the cover observed in August 2011, three years into the study, was contributed by natives. These data indicate that protection from goose herbivory provided at these elevations can be expected to result in revegetation by desirable native wetland species. All five of the species that met the dominant species criterion in 2011 by achieving at least 5% total vegetative cover in at least one sampling event/habitat/fencing treatment combination were native. Prevalence of individual dominant species varied with initial habitat status, palatability, ongoing protection status, and time since the start of the study.

In the initially-vegetated modules, *Z. aquatica*, a common component of natural tidal freshwater systems (Odum et al. 1984; Whigham et al. 1978; Haramis and Kearns 2007), a good source of food for wildlife, and of known high palatability to Canada geese (Thunhorst 1993; Haramis and Kearns 2007), started the study as the overwhelming dominant, but decreased in prevalence there over time as the result of full exposure to Canada goose herbivory in the unfenced control plots and unplanned partial exposure in the fenced plots. As the cover of the highly-palatable *Z. aquatica* decreased in the fenced plots, the somewhat less palatable *P. cordata* was able to increase its cover dramatically, achieving dominant status. *P. punctatum* was also able to achieve dominant status in these plots, although later and at lower levels of cover. Low-palatability *P. virginica* was able to retain dominant species status throughout 2009-2011, by dominating two plots where it was present in the baseline condition.

After the initial decimation of *Z. aquatica* in the newly-unfenced control plots, only two species have been able to retain or achieve dominant species status in the initially-unvegetated unfenced control plots, *P. virginica* and *N. lutea*. Both of these species are of known low palatability to Canada geese, and both existed as established plants either in study plots (*P. virginica*) or near study plots (*N. lutea*) at the start of the study. Although limited numbers of seedlings have been observed in the unfenced control plots during the June sampling events, none have survived until the August sampling events in the face of total exposure to herbivory by resident and nonmigratory Canada geese.

In the initially-unvegetated modules, very little vegetation was observed in 2009, the first year of protection, but during 2010 two species were able to achieve sufficient cover in the fenced plots to meet the dominant species criterion, *Z. aquatica* and *P. punctatum*. In 2011, *P. cordata* saw a marked increase in cover and exceeded the dominant species threshold as the more highly-palatable *Z. aquatica* declined by August 2011 after partial exposure to herbivory by resident and nonmigratory Canada geese. A number of additional species have been observed in the initially-unvegetated fenced plots at sub-dominant levels, including *P. virginica*. This indicates that with protection from herbivory by resident and nonmigratory Canada geese, all of the 2011 dominant species were able to disperse into the initially unvegetated fenced plots and persist during the first three years of protection, except *N. lutea*. It is worth noting that Neff, during her 2000-2001 studies of seed dispersal at/into Kingman Marsh found seeds of all of the current dominants except *N. lutea* (and *Z. aquatica*, which was not present at Kingman in that timeframe) through water traps or seedbank samples in Kingman, and/or trawling on the Anacostia (Neff 2002).

This suggests that *N. lutea* may be one of the many perennial emergent macrophytes that relies more on asexual reproduction, unlike *P. virginica*, which was shown by Whigham et al. (1979) to be dispersed almost exclusively by seed. Apparently *P. cordata*'s reproduction strategy is similar to that of *P. virginica*, relying on dispersal by seed rather than spreading vegetatively (USDA 2013).

Although seedlings of a number of species have been observed in the initially-unvegetated unfenced control plots during June sampling events, only two of those species have persisted to be observed during the subsequent August sampling events, marshpepper knotweed (*Polygonum hydropiper*), a non-native, and *P. punctatum*, a native, both observed at extremely low cover levels.

Three years into the herbivory study, species richness averages in both the initially-vegetated and initially-unvegetated fenced plots were still somewhat low, but comparable with values from the Heritage Island Wetland restoration and plots from the Anacostia River Fringe B that were positioned in a similar elevation range. Most importantly, species richness averages were significantly greater in the fenced plots than in the unfenced control plots, regardless of whether the plots started the study vegetated or unvegetated.

Vegetation data from the first three years of the Kingman Marsh herbivory study indicate that herbivory pressure from resident and nonmigratory Canada geese is still a controlling factor in determining species composition and abundance at this tidal freshwater marsh restoration. The data also indicate that if the goal is for Kingman Marsh to consist of a mosaic of native emergent species beyond the small number that over the years have shown a relatively low palatability to Canada geese (e.g., *N. lutea*, *P. virginica*, and *T. latifolia*), it will be necessary to reduce herbivory pressure from resident and nonmigratory Canada geese, or rely on the unnatural situation of needing fencing to provide refugia for the wide array of valuable native plants that have shown their vulnerability to herbivory at this site (Hammerschlag et al. 2006).

Additional years of monitoring are recommended for the herbivory study to track the treatment response to continued protection from herbivory in the fenced plots, as well as the ability of the unfenced control plots to revegetate over time, in the event that control measures are undertaken to reduce herbivory pressure from resident and nonmigratory Canada geese.

Acknowledgements

Individuals from three partner entities worked with USGS to insure the successful implementation of this herbivory study. Critical contributions were made by S. Syphax and M. Milton (NPS, National Capitol Parks East), who arranged NPS funding and personnel for the project, as well as providing field and GIS support; D. Pavek (NPS Center for Urban Ecology), who has provided guidance in obtaining funding; T. Doan (District Department of the Environment), who was a reliable presence for all components of the field work; P. Hill (DDOE), who has continued to provide personnel support; S. McKindley-Ward, who when he worked with the Anacostia Watershed Society, recruited volunteers to take down the old fencing, and provided insights into the planting history of the initially-vegetated areas; and Jorge Bogantes Montero (AWS), who has recruited volunteers for goose monitoring at the site. Additional field assistance was provided by USGS (D. Krafft), NPS (J. Rosenstock, J. Hemsley, E. Harris, K. Barry, J. Reardon, G. Battel, A. Reuter, and K. Syphax) and DDOE (P. Hill, J. Burch, M. Ryder, and D. Ossi). We are grateful to XXX and YYY for reviewing a previous version of this report.

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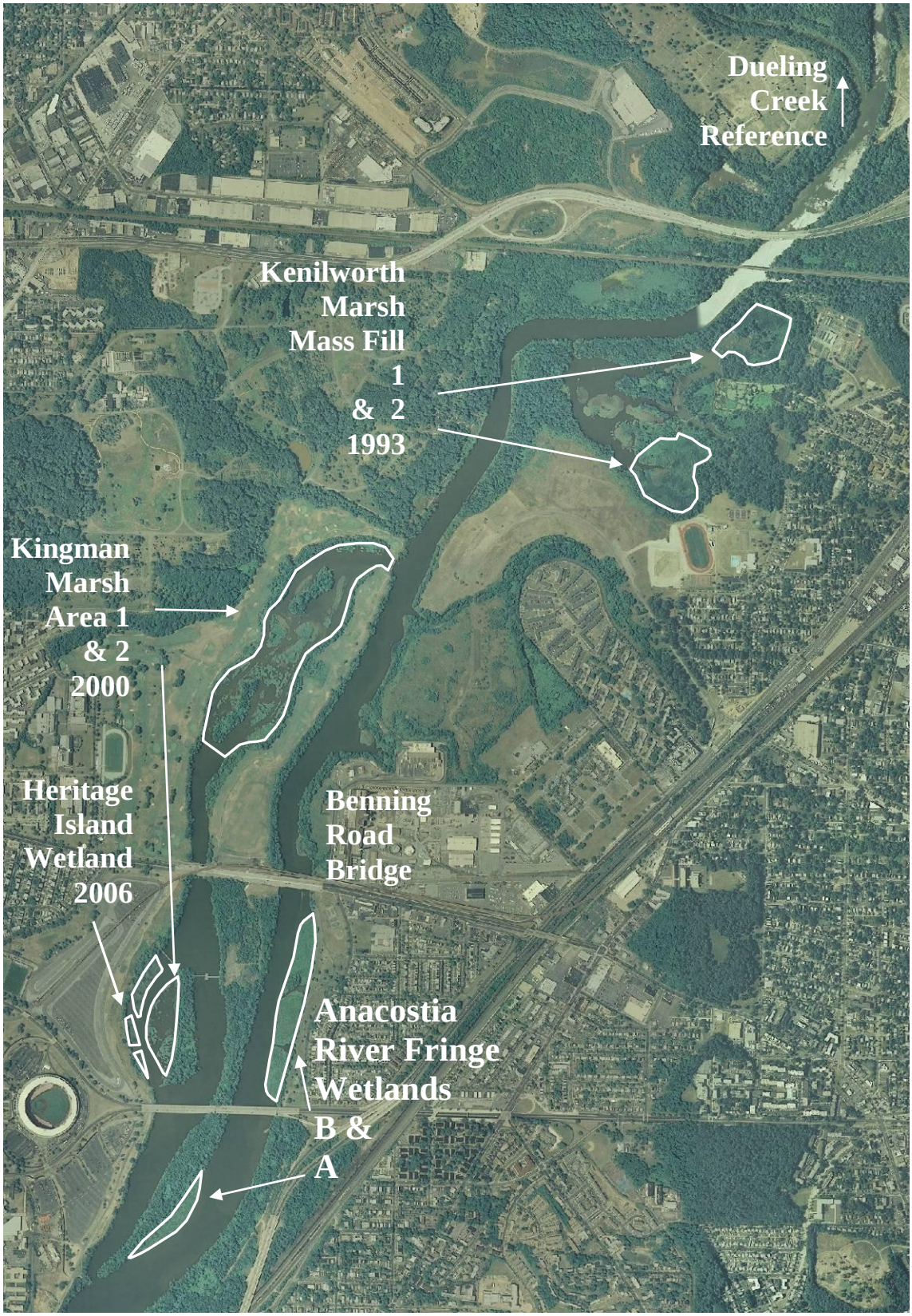

Figure 1. Anacostia Park tidal freshwater wetland restoration sites and reference wetland in 2007. Kingman Marsh Area 1 was the focus for this study. Dates reflect year of reconstruction. Photo courtesy of the National Agricultural Imagery Program.

Figure 2. Historical (1929) photograph of the Anacostia River showing extensive wetlands and the excavation of the northern end of Kingman Lake north of the Benning Road Bridge. In the photograph, the dredge can be seen in the area that would later become Kingman Marsh Area 1. Photograph courtesy of the US National Arboretum.

Figure 3. Location of the 16 study modules (8 initially-vegetated and 8 initially-unvegetated) at Kingman Marsh in Anacostia Park. Photo courtesy of the National Agricultural Imagery Program.

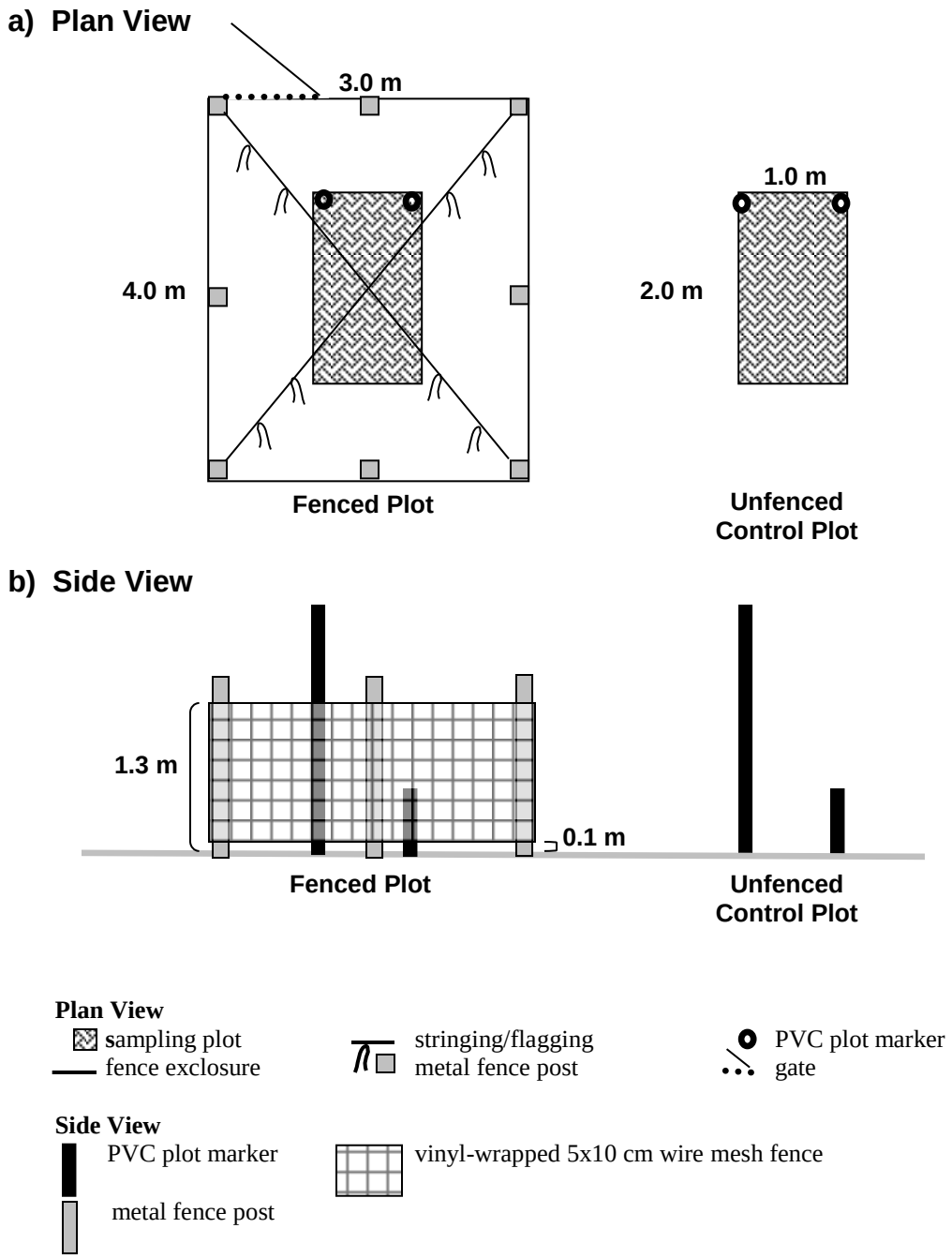

Figure 4. Schematic diagram of the study modules used in the herbivory study at Kingman Marsh. Each module consists of two 3x4 m study plots, one of which is a fenced plot (exclosure elevated 0.1 m) and the other an unfenced control plot. A 1x2 m PVC frame was hooked over the PVC plot markers to delineate the same sampling plot boundaries within each study plot during repeated sampling events.

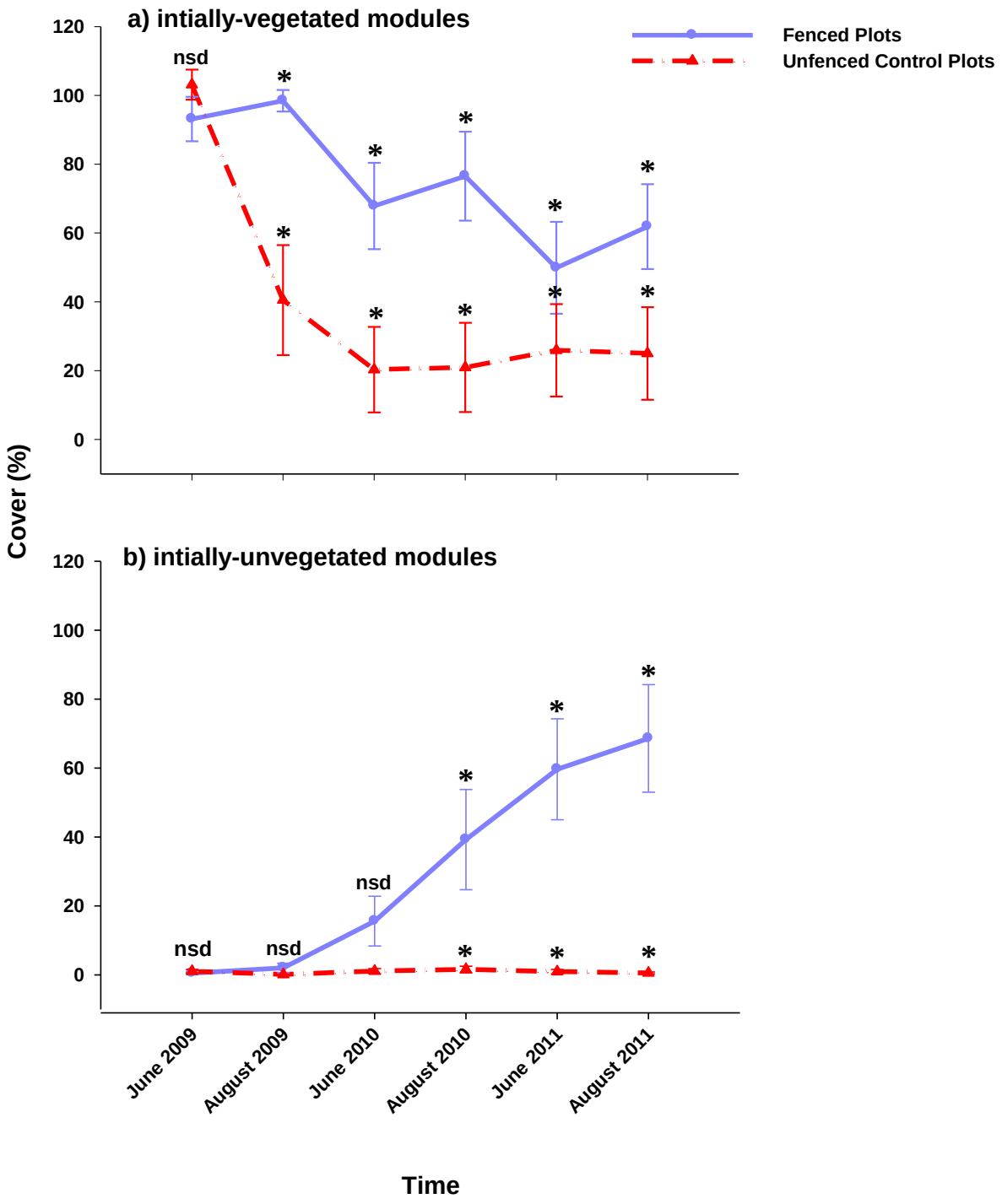

Figure 5. Total vegetative cover during the first three growing seasons of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Total vegetative cover represents the sum of cover values for all individual species, and may therefore exceed 100%. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

▲ a) June 2009

▲ b) August 2009

▲ c) June 2010

▲ d) August 2010

▲ e) June 2011

▲ f) August 2011

Figure 6. Initially-vegetated Module 11 illustrating changes in vegetation over time, from a) in June 2009, prior to exposure to herbivory and b) again in August, after two months of exposure to herbivory through f) in August 2011. The prevalent broad-leaved emergent shown inside the exclosure in f) is pickerelweed (*Pontederia cordata*). Photographed by R. Hammerschlag and C. Krafft.

▲ a) June 2009

▲ b) August 2009

▲ c) June 2010

▲ d) August 2010

▲ e) June 2011

▲ f) August 2011

Figure 7. Initially-unvegetated Module 9 exhibiting changes in vegetation over time, from a) in June 2009 through f) in August 2011. The prevalent broad-leaved emergent shown in f) is pickerelweed (*Pontederia cordata*). Photographed by R. Hammerschlag and C. Krafft.

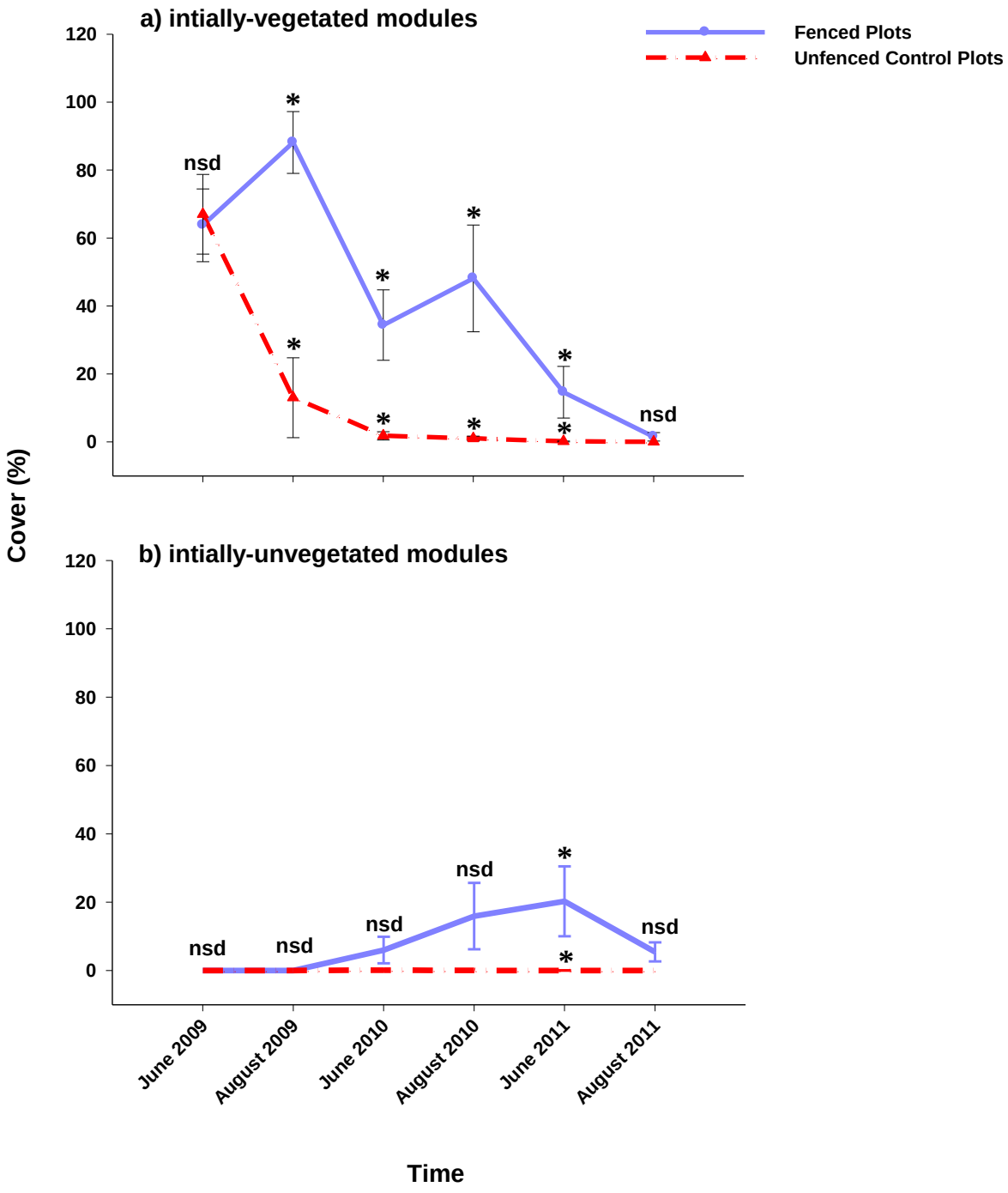

Figure 8. Cover by annual wildrice (*Zizania aquatica*) during the first three growing seasons of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

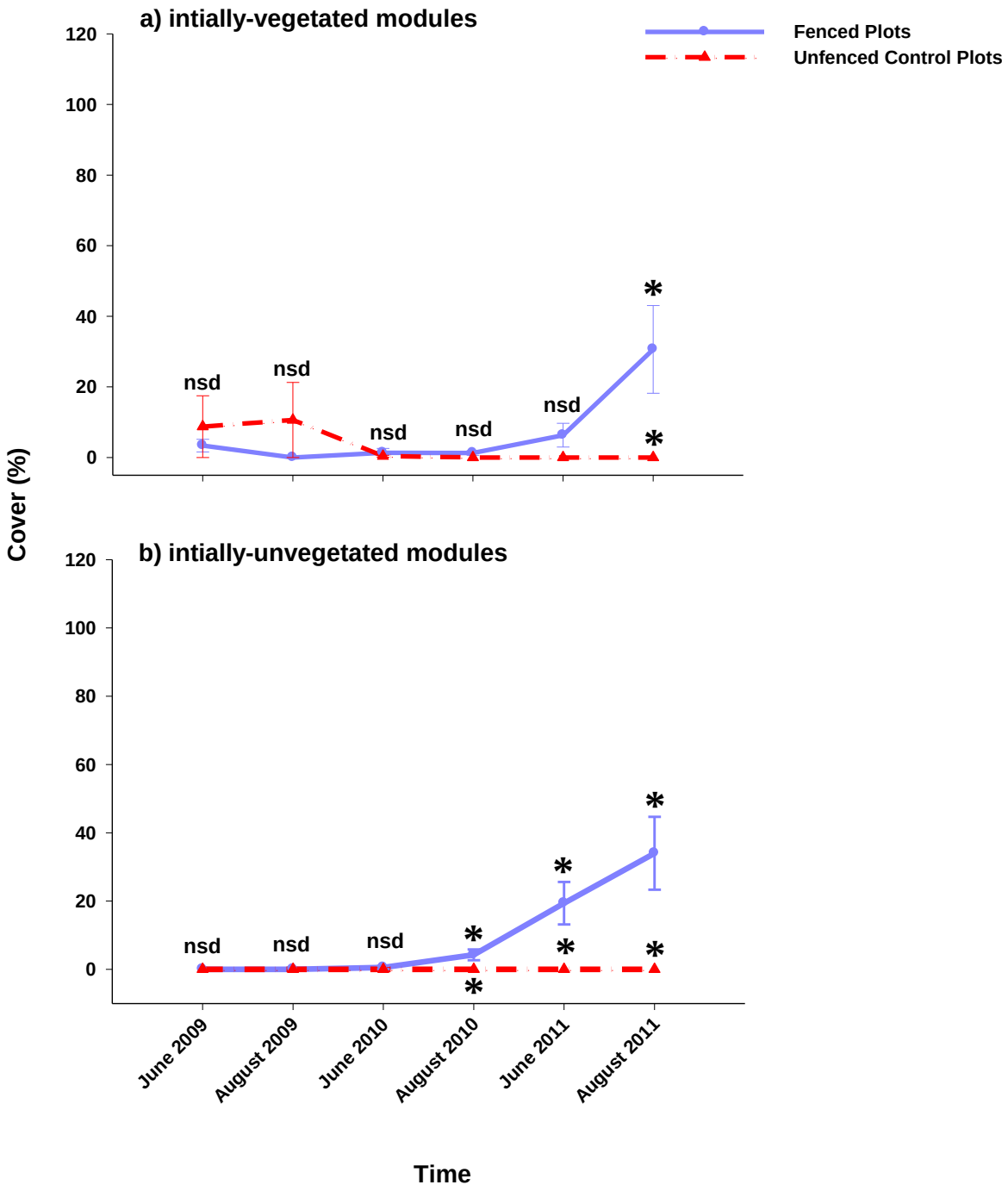

Figure 9. Cover by pickerelweed (*Pontederia cordata*) during the first three growing seasons of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

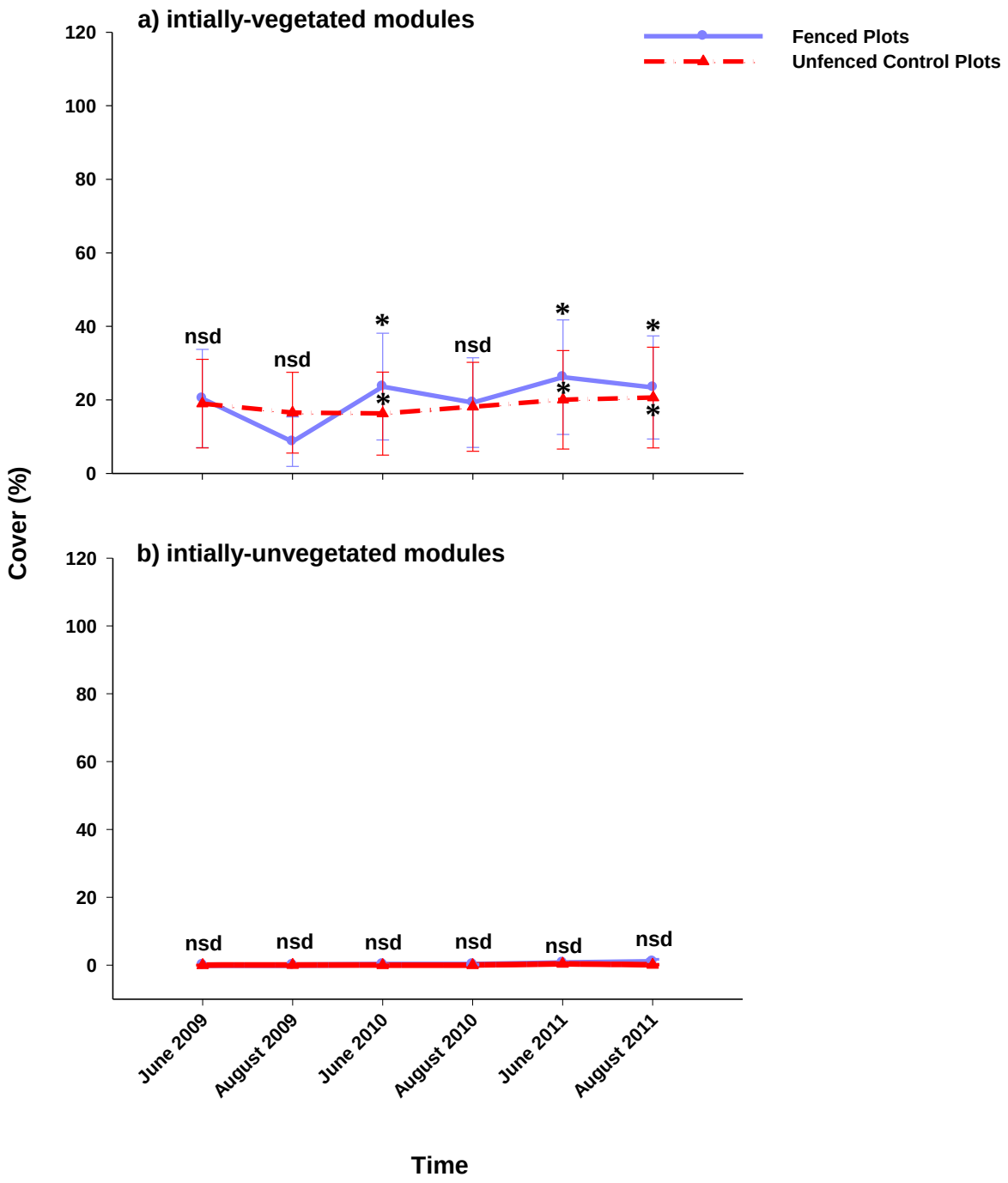

Figure 10. Cover by green arrow arum (*Peltandra virginica*) during the first three growing seasons of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

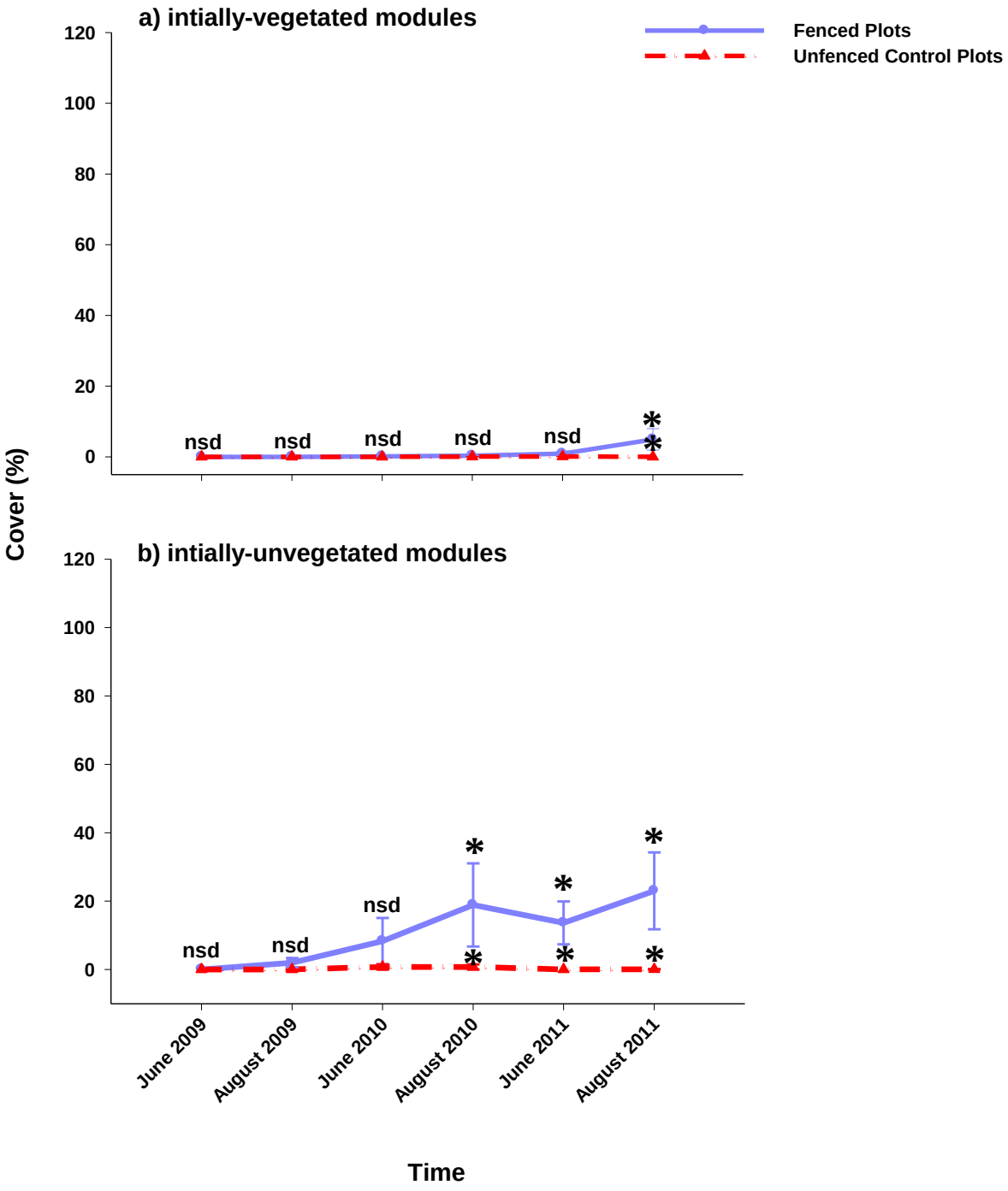

Figure 11. Cover by dotted smartweed (*Polygonum punctatum*) during the first three growing seasons of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

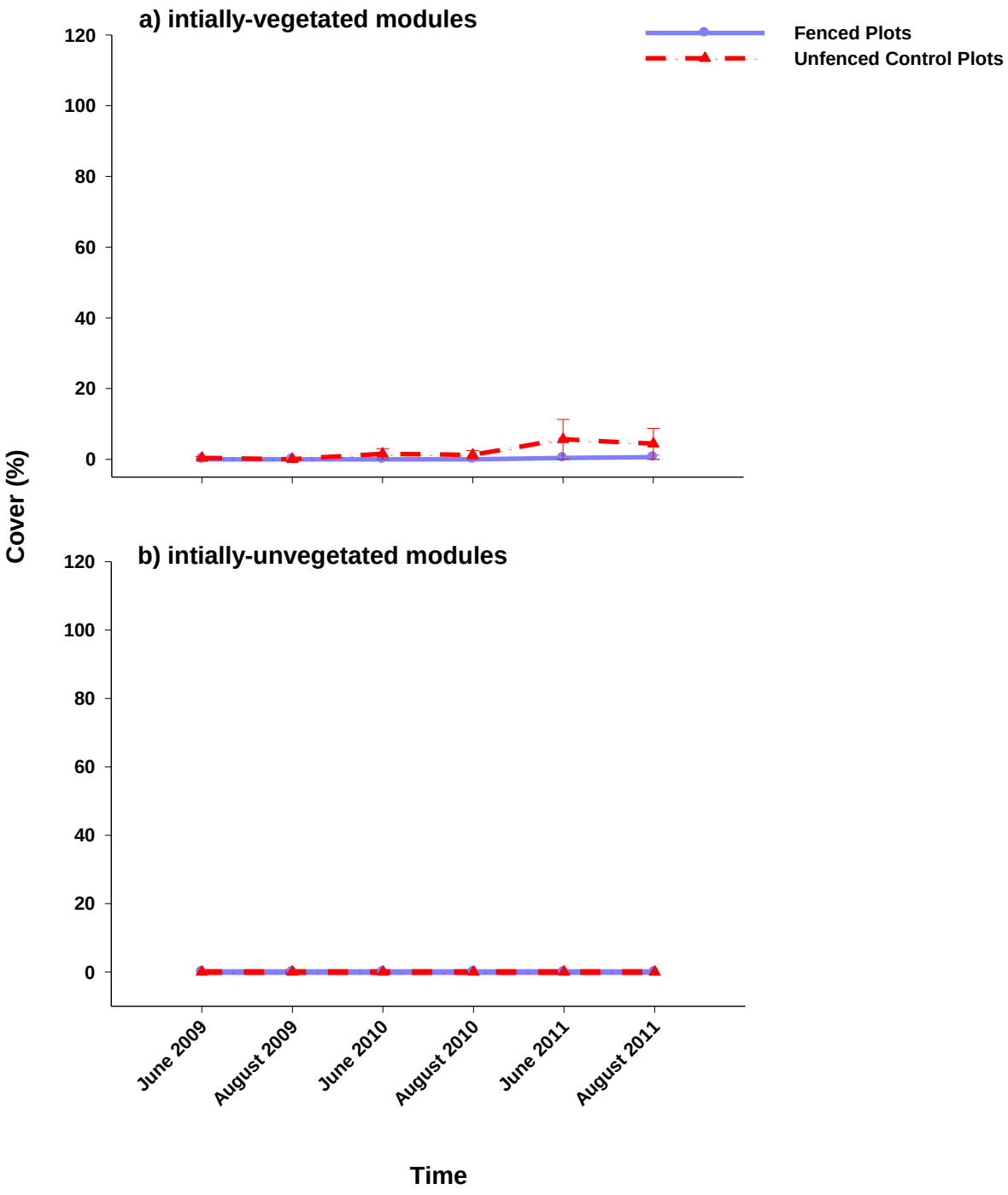

Figure 12. Cover by yellow pond-lily (*Nuphar lutea*) during the first three growing seasons of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

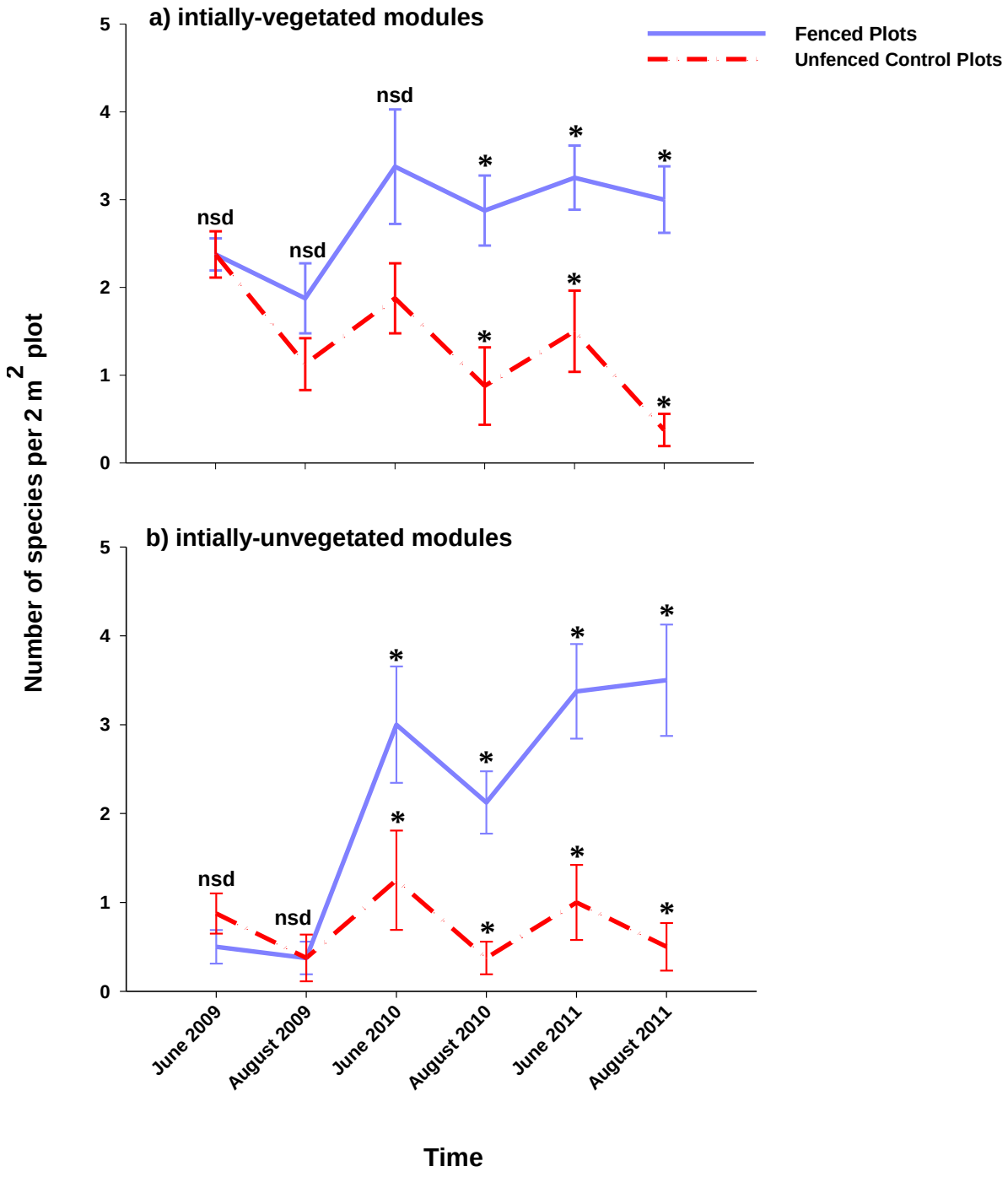

Figure 13. Species richness (number of species per 2-m^2 sampling plot) during the first three growing seasons of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

Table 1. Summary statistics (*F*-values and *P*-values) from the repeated measures analysis of variance (ANOVA) that was performed on the fenced plot – unfenced control plot difference for each variable. See text for descriptions of the vegetation variables and for details concerning the ANOVA models.

	Fixed Effects Terms in ANOVA Model													
	Year [1]		Month [2]		Year*Month		Habitat [3]		Year×Habitat		Month×Habitat		Year×Month×Habitat	
Variables: [4]	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Difference (Fenced – Unfenced Control) in:														
Log Total Vegetative Cover (%)	25.68	< 0.0001	20.84	0.0004	3.16	0.0762	0.01	0.9047	8.52	0.0043	1.32	0.2699	3.19	0.0745
Log Total Native Cover (%)	25.53	< 0.0001	24.16	0.0002	2.26	0.1441	0.03	0.8660	9.29	0.0031	1.39	0.2577	3.95	0.0456
Log *Zizania aquatica* Cover (%)	3.66	0.0548	4.38	0.0551	53.88	< 0.0001	4.55	0.0512	8.73	0.0039	5.03	0.0416	30.54	< 0.0001
Log *Peltandra virginica* Cover (%)	16.17	< 0.0001	0.44	0.5097	0.27	0.7673	1.79	0.2018	5.66	0.0053	0.77	0.3822	0.42	0.6616
Log *Pontederia cordata* Cover (%)	13.11	0.0008	10.49	0.0060	7.24	0.0077	0.86	0.3704	0.20	0.8202	0.69	0.4209	1.79	0.2050
Log *Polygonum punctatum* Cover (%)	6.60	0.0023	8.41	0.0051	0.52	0.5949	4.52	0.0474	0.98	0.3783	0.43	0.5136	1.13	0.3290
Species Richness	42.63	< 0.0001	14.68	0.0003	0.05	0.9503	0.00	0.9939	2.48	0.0914	1.55	0.2170	0.24	0.7854

[1]Three years (2009-2011).

[2]Two months for vegetation (June and August).

[3]Two habitats (Initially-Vegetated and Initially-Unvegetated).

[4]The transformation natural log (variable+1) was used to improve normality where indicated.

Table 2. Results of Tukey's multiple comparison procedure for least square means (standard error in parentheses) from repeated measures analysis of variance (ANOVA). Within each row, means with the same lower case letter superscript are not significantly different among years ($P > 0.05$). Species richness estimates represent the difference of fenced – unfenced control. Cover data were transformed using natural logs to improve normality. The back-transformation of these estimates results in the ratio of (fenced + 1)/(unfenced control + 1).

	2009				*2010*				*2011*			
	June		August		June		August		June		August	
Variables:	Initially-vegetated	Initially-unvegetated	Initially-vegetated	Initially-unvegetated	Initially-vegetated	Initially-unvegetated	Initially-vegetated	Initially-unvegetated	Initially-vegetated	Initially-unvegetated	Initially-vegetated	Initially-unvegetated
Plant Cover (%)												
Total Vegetative Cover[1]	0.89^{ce} (1.17)	0.80^{de} (1.17)	10.09^{ab} (1.87)	1.62^{bcd} (1.87)	9.95^{ab} (1.64)	4.47^{bcd} (1.64)	14.31^{ab} (1.84)	10.20^{abc} (1.84)	7.35^{abd} (1.73)	27.45^{a} (1.73)	9.65^{ab} (1.73)	36.84^{a} (1.73)
Native Cover[1]	0.89^{e} (1.07)	0.98^{de} (1.07)	10.09^{abd} (1.88)	1.64^{bcde} (1.88)	10.30^{ab} (1.69)	4.80^{bde} (1.69)	14.29^{ab} (1.88)	13.69^{ac} (1.88)	7.05^{abde} (1.78)	33.70^{a} (1.78)	9.50^{ab} (1.74)	45.72^{a} (1.74)
Zizania aquatica Cover[1]	1.01^{d} (1.10)	1.00^{d} (1.10)	30.59^{a} (1.48)	1.00^{cd} (1.48)	12.74^{ab} (1.57)	2.53^{bcd} (1.57)	15.75^{abc} (1.96)	4.91^{abcd} (1.96)	6.24^{abcd} (1.75)	6.39^{abcd} (1.75)	1.60^{d} (1.48)	3.05^{bcd} (1.48)
Peltandra virginica Cover[1]	0.75^{b} (1.21)	0.99^{ab} (1.21)	0.77^{b} (1.21)	0.95^{ab} (1.21)	2.02^{a} (1.21)	1.12^{ab} (1.21)	1.42^{ab} (1.21)	1.15^{ab} (1.21)	2.23^{a} (1.21)	1.24^{ab} (1.21)	1.99^{a} (1.21)	1.34^{ab} (1.21)
Pontederia cordata Cover[1]	1.37^{abc} (1.40)	1.00^{bc} (1.40)	0.57^{c} (1.48)	1.00^{abc} (1.48)	1.13^{abc} (1.34)	1.29^{abc} (1.34)	1.73^{abc} (1.39)	3.41^{abc} (1.39)	3.02^{abc} (1.78)	8.53^{abc} (1.78)	12.08^{ab} (1.88)	15.69^{a} (1.88)
Polygonum punctatum Cover[1]	1.00^{b} (1.45)	1.00^{b} (1.45)	1.00^{b} (1.45)	1.72^{ab} (1.45)	1.09^{b} (1.45)	2.01^{b} (1.45)	1.15^{b} (1.45)	3.20^{ab} (1.45)	1.31^{ab} (1.45)	5.03^{ab} (1.45)	2.94^{ab} (1.45)	7.21^{a} (1.45)
Species Richness	0.01^{def} (0.18)	-0.22^{e} (0.18)	0.32^{bcde} (0.18)	0.04^{cef} (0.18)	0.40^{bcde} (0.18)	0.69^{abcd} (0.18)	0.87^{abc} (0.18)	0.83^{abd} (0.18)	0.63^{abcd} (0.18)	0.88^{ab} (0.18)	1.10^{a} (0.18)	1.12^{ab} (0.18)

[1]Back-transformed from natural log (fenced + 1) – natural log (unfenced control + 1).

Table 3. Species list for Kingman Marsh herbivory study plots during the first three years of the study, 2009-2011.

Scientific name [1]	***Common Name*** [1]	***Acronym***	***Origin*** [1]
Amaranthus cannabinus (L.) Sauer	tidalmarsh amaranth	AMACAN	native
Bidens connata Muhl. Ex. Willd.	purplestem beggarticks	BIDCON	native
Bidens frondosa L.	devil's beggartick	BIDFRO	native
Bidens laevis (L.) Britton, Sterns & Poggenb.	smooth beggartick	BIDLAE	native
Juncus L.	rush	JUNSPP	unknown
Murdannia keisak (Hassk.) Hand.-Maz.	wartremoving herb	MURKEI	non-native
Nuphar lutea (L.) Sm.	yellow pond-lily	NUPLUT	native
Peltandra virginica (L.) Schott	green arrow arum	PELVIR	native
Phalaris arundinacea L.	reed canarygrass	PHAARU	native
Polygonum hydropiper L.	marshpepper knotweed	POLHYD	non-native
Polygonum punctatum Elliot	dotted smartweed	POLPUN	native
Pontederia cordata L.	pickerelweed	PONCOR	native
Sagittaria latifolia Willd.	broadleaf arrowhead	SAGLAT	native
Typha latifolia L.	broadleaf cattail	TYPLAT	native
Zizania aquatica L. var. *aquatica*	annual wildrice	ZIZAQU	native

[1] Taxonomic nomenclature and origin information follow the PLANTS database (USDS 2013).

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