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Tidal Freshwater Wetland Herbivory in Anacostia Park

Natural Resource Technical Report NPS/NCR/NCRO/NRTR—2010/002

ON THE COVER
Exclosed plot in Kingman Marsh in Anacostia Park, Washington, D.C., after two months of exposure to herbivory.
Photographed by: C. Krafft

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NPS/NCR/NCRO/NRTR—2010/002, November 2010

Contents

Page

Page

Figures

Tables

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. In June 2009 an herbivory study was established to document the impacts of resident Canada goose (*Branta canadensis maxima*) herbivory to vegetation at Kingman Marsh. Sixteen modules consisting of paired exclosed 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 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. Since the experiment was designed to determine the impacts of herbivory by resident Canada geese as opposed to other herbivores, exclosure fencing was elevated 0.2 m to permit access by herbivores such as fish and turtles while excluding mature Canada geese. Repeated measures analysis of variance (ANOVA) was used to analyze the differences between paired exclosure and control plots for a number of variables including total vegetative cover. Differences in total vegetative cover were not significant for the baseline data collected in June. By contrast, two months after the old protective fencing was removed from the initially-vegetated areas to allow Canada geese access to the control plots, total vegetative cover had declined dramatically in the initially-vegetated control plots, and differences between paired exclosed and control plots were significant ($P = 0.0026$). No herbivory by Canada geese or other herbivores such as fish or turtles was observed in the exclosures. These results show that Canada goose herbivory has inflicted significant damage to the native wetland vegetation in the portions of Kingman Marsh that had been refenced and replanted. Significant differences in total vegetative cover were limited to the eight modules installed in areas already vegetated by previous restoration efforts and protected until the start of the study, suggesting that areas of Kingman that are essentially devoid of vegetation would take longer than a growing season to show signs of improvement once goose herbivory impacts have been reduced.

Keywords

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

Introduction

Kingman Marsh Area 1 (hereafter called Kingman Marsh) is a 16-ha tidal freshwater wetland restoration site located in Anacostia Park, Washington, D.C. Restoration efforts were initiated 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 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, 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 *Zizania aquatica* var. *aquatica* (annual wildrice) and other native vegetation; fenced and unfenced areas dominated by the relatively goose-resistant species *Nuphar lutea* (spatterdock), *Peltandra virginica* (green arrow arum), or the invasive *Phragmites australis* (common reed); and large unvegetated areas that were 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 exclosed plot paired with one unfenced control plot. Since another 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), and we were particularly interested in herbivory caused by resident Canada geese (*Branta canadensis maxima*) which are in the region during the growing season, the exclosure fencing was elevated to allow access to other herbivores, such as fish and turtles, while excluding mature Canada geese.

The data from this study should help NPS with their management of wetlands on the Anacostia. It should provide useful insights into what response to expect from vegetation in 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. The Heritage Island Wetland is still protected by a coir biolog and peripheral fencing, as well as limited interior fencing and stringing that remain five years into the project.

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 exclosure and control plot design used for the deer herbivory studies in National Parks throughout the region (Rossell et al. 2007; Hatfield 2010). Results of the study may be used in support of an

Environmental Impact Statement currently being conducted to sustain and improve NPS efforts in Anacostia wetland management.

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 marshes that existed there prior to the dredging and filling 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). By contrast, 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 35x1 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 combination of the seven planted species (*P. virginica*, *Schoenoplectus tabernaemontani* [soft-stemmed bulrush], *Juncus effusus* [common rush], *Pontedaria cordata* [pickerelweed], *Sagittaria latifolia* [broadleaf arrowhead], *Schoenoplectus pungens* [common threesquare], and *N. lutea*) as well as numerous volunteer species. 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 (for simplicity called Kingman Marsh throughout) was chosen for the location of the herbivory study for a variety of reasons, including its size, the presence of a mix of habitat types that would be useful to obtain data on, and 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 exclosed study plot paired with one unfenced control plot. Fencing was elevated 0.2 m to permit access to herbivores such as fish and turtles, while excluding mature Canada geese. Vegetation data were collected twice in 2009, once in June as baseline data, 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 *Lythrum salicaria* (purple loosestrife) 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 and obtaining two elevations per study plot, one at each end. If the average for each study plot fell within the desired range, the study plot orientation and study module were retained. If the average of either study plot fell outside of the desired elevation range, a new random study plot orientation was chosen and tested. 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).

Installation of Modules

Modules were installed in May 2009. Module lay-out is shown in Figure 4. Each module contains two 1x2 m sampling plots, one an exclosed plot and the other an unfenced control plot. Exclosures were constructed of vinyl-coated wire fence with a mesh size of 5x10 cm. 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. This reduction would not be expected to act as a deterrent to most fish, turtles, etc. Exclosures measured 3x4 m, surrounding the 1x2 m study plot and a 1-m buffer that was included to limit possible impacts to the sampling plot from geese stretching their necks to graze under the elevated fence. This also provided samplers room to walk inside the exclosures without impacting the sampling plots. 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, 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 2010. For each sampling event, a 1x2 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 2010).

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, 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.

Data Analysis

For total vegetative cover, cover by natives, cover by dominant species, and species richness, differences between paired exclosure and control plots were calculated and analyzed using mixed model repeated measures analysis of variance (SAS, 2003, PROC MIXED) to compare data among months (June and August), habitat types (initially-vegetated or initially-unvegetated), and their interaction. Data were transformed prior to analysis using a natural log transformation to improve normality, as needed. 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 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 exclosed and control plots for each habitat by month interaction (e.g., initially vegetated, August 2009).

Descriptive statistics were generated for the baseline elevation data.

Results and Discussion

Results of the ANOVA's conducted on the differences between paired exclosed and 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 exclosure and control plots behave the same or differently depending on the habitat, the month, or the habitat by month interaction. Of particular importance to this study are the associated least square means and t-tests that indicate the significance of differences between the paired exclosed and control plots. These *P*-values are presented in the discussion for each variable. Significant *P*-values are also displayed in Figures 7 through 12. 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 exclosed and control plots (± 1 standard error) for ease of interpretation.

Descriptive statistics were calculated for the baseline elevation data.

Total Vegetative Cover

At the start of the study in June total vegetative cover for the modules that were initially vegetated averaged 93.1 ± 6.5% in the exclosed plots and 104.4 ± 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 exclosed plots and 1.0 ± 0.6% in the 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 exclosed and control plots for total vegetative cover either for the initially-vegetated modules (P = 0.4380) or the initially-unvegetated modules (P = 0.1782).

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 98.1 ± 3.4% for the exclosed plots compared to 40.5 ± 15.9% for the controls. Differences between the paired exclosed and control plots were significant ($P = 0.0026$). Figure 6 illustrates the impact two months of herbivory exacted on the control plot in Module 11, especially striking when the photographs from June (Figure 6a) and August (Figure 6b) are compared.

Exclosed plots in the modules that were initially-unvegetated did not achieve much cover during Year 1, 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 exclosed and control plots were not significant for the modules that were initially unvegetated ($P = 0.4522$).

Results of the repeated measures ANOVA (Table 1) indicate that the total vegetative cover differences between exclosed and control plots varied significantly depending on month ($P = 0.0025$), which in this case relates primarily to degree of exposure to herbivory rather than phenology. Habitat differences were not significant ($P = 0.0700$). Habitat by month differences were not significant either ($P = 0.0641$), although as sometimes happens, the Tukey test results do indicate a significant difference, with the exclosure-control differences for total vegetative cover in the initially-vegetated modules in August being significantly greater than the exclosure-control differences in June for either the initially-vegetated or initially-unvegetated modules. These Tukey test results make sense, given the relatively small exclosure-control differences observed in June, compared to the relatively large exclosure-control differences observed in August for the initially-vegetated modules (e.g., as illustrated in Figure 6).

The total vegetative cover results from the first year of the herbivory study indicate that the portions of Kingman Marsh that were refenced and replanted by AWS are still highly vulnerable to herbivory pressure. When the old protective fencing was removed, clear signs of herbivory were observed in the newly-unfenced control plots, which experienced a significant decrease in total vegetative cover with respect to the paired exclosure plots, where no herbivory was observed. The use of elevated fencing for the exclosures indicates that this herbivory pressure is associated with Canada geese, rather than fish or other herbivores that could access both the control and exclosed plots.

By comparison, installation of exclosures in areas that were characterized as initially-unvegetated saw no treatment effect during the first growing season of the study. Additional time will be required to determine whether reducing herbivory pressure in these unvegetated areas will be sufficient to allow them to revegetate, or whether additional factors would need to be addressed to insure restoration of these unvegetated areas.

Total Cover by Natives

Of the ten species observed in the herbivory modules during the first growing season of the study, nine were native: *Z. aquatica*, *P. cordata*, *S. latifolia*, *N. lutea*, *Bidens frondosa* (devil's beggartick), *Bidens laevis* (smooth beggartick), *P. virginica*, *Typha latifolia* (broadleaf cattail), and *Polygonum punctatum* (dotted smartweed). The first six species listed were observed only in initially-vegetated modules; the last species was observed only in initially-unvegetated modules. The only native species observed in both habitats were *P. virginica* and *T. latifolia*.

Cover by natives represented 100% of the total vegetative cover in the initially-vegetated modules, where no non-natives were observed during the first growing season (Figure 7). Total vegetative cover in the initially-unvegetated modules was extremely low during the first growing season (2% or less for any treatment in any month). The majority of this cover was provided by native species.

The significance of the exclosure-control repeated measures ANOVA results (Table 1, Figure 7) matched the results for total vegetative cover, with the exception that the habitat by month term was significant for total cover by natives, unlike the situation for total vegetative cover, where habitat by month was not significant (slightly out of synch with the associated Tukey test results, which were significant).

Total Cover by Non-Natives

Only one of the ten species observed in the herbivory modules was a non-native, *Polygonum hydropiper* (marshpepper knotweed). This species was observed only in the initially-unvegetated modules (Figure 8), at very low levels (maximum average of 0.6 ± 0.5% for the control plots in June). *P. hydropiper*, although non-native, has not shown itself to be highly invasive at any of the Anacostia Park tidal freshwater wetland restorations, and is not expected to become problematic in the Kingman herbivory modules. ANOVA's were not run on this variable, since the data are extremely sparse and relatively non-normal. The non-native invasive, *P. australis,* although present at Kingman Marsh, is in areas above the elevation range chosen for the study. No *P. australis* was observed in the study modules during the first growing season. Similarly, *Lythrum salicaria* (purple loosestrife), although present at Kingman Marsh, was not observed in the study modules during the first growing season. *L. salicaria* would also be expected to occur at elevations higher than the range chosen for our study modules (Krafft et al. 2009).

Cover by Dominant Species

Only three species met the criterion for dominant species status by averaging at least 5% for any habitat/month/treatment combination. They were *Z. aquatica*, *P. virginica*, and *P. cordata*. Of the remaining seven species, only one achieved an average exceeding 1%, and that was *P. punctatum*, which averaged 2.0 ± 1.4% for the initially-unvegetated exclosed plots in August. Given the sparseness of the non-dominant species data, ANOVA's were run only for the dominant species.

Z. 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 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, averaging 63.4 ± 10.6% in the exclosed plots and 68.1 ± 11.9% in the control plots (Figure 9). 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 exclosed and control plots were not significant in June for either the initially-vegetated modules ($P = 0.3186$) or the initially-unvegetated modules where *Z. aquatica* was absent ($P = 1.0000$).

By August, two months after the old protective fencing had been removed from the initially-vegetated areas, the exclosed plots in the initially-vegetated modules averaged 87.9 ± 9.4% cover for *Z. aquatica*, compared to the newly-unprotected control plots, where it averaged only 12.9 ± 11.7%. Differences between the paired exclosed and control plots were significant for the initially-vegetated modules ($P < 0.0001$). They were not significant for the initially-unvegetated modules where *Z. aquatica* was absent ($P = 1.0000$).

Results of the ANOVA for the exclosed-control differences (Table1) indicate that habitat, month, and the month by habitat interaction all play significant roles in determining the exclosure-control differences for *Z. aquatica* cover ($P = 0.0004$, $P < 0.0001$, and $P < 0.0001$, respectively).

Because of its high palatability to Canada geese, *Z. aquatica* has the potential to function as an indicator of herbivory pressure. At the start of the study, *Z. aquatica* exhibited robust growth throughout the initially-vegetated areas that had been fenced and planted by AWS, as reflected in the June *Z. aquatica* cover averages for both the exclosed and control plots. Once the old outer protective fencing was removed, the Canada geese moved in and grazed the newly-accessible *Z. aquatica*. By August, *Z. aquatica* cover had experienced an 81% decline in the initially-vegetated control plots. The *P*-values associated with the *Z. aquatica* data are all more significant than the corresponding values for total vegetative cover, reflecting the strength of *Z. aquatica*'s response to herbivory pressure, which for total vegetative cover is somewhat ameliorated by a lower response from the less palatable *P.virginica*. During the first year of the study no *Z. aquatica* was observed in the initially-unvegetated modules. It is hoped that this will change over time now that *Z. aquatica* seeds dispersing into exclosures in the initially-unvegetated areas will be protected from goose herbivory. This may take some time, however, since *Z. aquatica*'s dispersal range is limited by the fact that seeds are designed to sink and stick in the mud where they fall.

P. virginica

Unlike *Z. aquatica*, which AWS planted as seed throughout most of the area where they performed restoration efforts at Kingman Marsh, *P. virginica* was planted as plants and ended up producing a lower density of plants and a patchier distribution than the *Z. aquatica*. As a result, *P. virginica* was observed in only 6 (38%) of the 16 initially-vegetated sampling plots (located in 8 modules).

At the start of the experiment in June *P. virginica* cover averaged 20.4 ± 13.3% in the initially-vegetated exclosed plots and 19.0 ± 12.0% in the paired control plots (Figure 10). Differences between paired exclosed and control plots were not significant for the initially-vegetated modules (P = 0.7859). *P. virginica* was virtually absent from the initially-unvegetated plots.

In August, following two months of exposure to herbivory, *P. virginica* cover in the initially-vegetated modules averaged 8.6 ± 6.7% for the exclosed plots and 16.5 ± 11.0% for the paired control plots. These averages represent a 58% decline for the exclosed plots and a 13% decline for the control plots with respect to June averages. Competition from *Z. aquatica* undoubtedly played a major role in the large seasonal decline of *P. virginica* observed in the initially-vegetated exclosure plots. *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. *P. virginica* is undoubtedly impacted by increased competition for space, light, and possibly nutrients as *Z. aquatica* undergoes these seasonal increases in height and biomass. Some of the decline observed during the August sampling event for both exclosed and control plots may also be 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). It is also possible that herbivory contributed to the decline observed in the initially-vegetated control plots, since some herbivory of the species (especially seedlings) has been observed in the marsh. Although differences between the paired exclosed and control plots were observed, it should also be noted that these differences were not statistically significant (P = 0.1291).

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

Results of the ANOVA for the exclosure-control differences in *P. virginica* cover (Table 1) indicate no significant differences for habitat, month, or the habitat by month interaction (P = 0.5947, P = 0.2569, and P = 0.2618, respectively).

The lack of any significant differences associated with the *P. virginica* cover data indicates that although evidence of limited herbivory damage was observed in the field, *P. virginica* is relatively robust with respect to herbivory pressure from Canada geese, presumably because it is less palatable to Canada geese than most of the other tidal freshwater wetland species. This relative robustness of *P. virginica* to herbivory had been noted previously at the Kingman Marsh restoration (Hammerschlag et al. 2006).

More time will be needed to determine whether *P. virginica* will be able to establish in the initially-unvegetated exclosed plots without being planted there. In her study conducted at Kingman Marsh in 2000, Neff (2002) did not find *P. virginica* in the seedbank, water trap, or air trap samples, but she did find the species by trawling, suggesting that *P. virginica* has the potential to disperse into these areas.

P. cordata

AWS planted *P. cordata* in their exclosures, but at much lower numbers than *P.virginica* (AWS, McKindley-Ward, pers. comm., 2010). As with *P. virginica*, *P. cordata* is represented by much lower densities and greater patchiness than *Z. aquatica*. *P. cordata* was observed in only four (25%) of the 16 initially-vegetated sampling plots.

In June *P. cordata* cover averaged 3.4 ± 1.8% in the initially-vegetated exclosed plots and 8.8 ± 8.8% in the initially-vegetated control plots (Figure 11). The magnitude of the standard error associated with the control plot mean reflects the fact that all of the *P. cordata* cover was concentrated in only one of the initially-vegetated control plots (12C). Differences between paired exclosed and control plots were not significant ($P = 0.4038$). *P. cordata* was absent from the initially-unvegetated plots in June, 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 *P. cordata* was absent from the exclosed plots in the initially-vegetated modules and averaged 10.6 ± 10.6% in the paired control plots. Differences between the paired exclosure and control plots were not significant ($P = 0.1431$), reflecting the large standard error associated with the control plot mean. *P. cordata* remained absent from the initially-unvegetated modules.

None of the ANOVA results for *P. cordata* were significant (Table 1), again reflecting the large variability associated with the *P. cordata* data. The associated *P*-values for habitat, month, and the habitat by month interaction were 0.7974, 0.0643, and 0.0643, respectively.

Since *P. cordata* proved highly palatable to Canada geese during the initial decimation at Kingman Marsh in 2001, the fact that it persisted in an initially-vegetated control plot through two months of herbivory pressure from June to August 2009 was somewhat surprising. The most likely explanation for this phenomenon was probably the vegetation in the immediate vicinity of the 12C control plot, which included a large expanse of *Z. aquatica* and *P. cordata* newly-available for grazing once the old protective fencing was removed at the beginning of the study. In addition, one end of the control plot borders a patch of *N. lutea*, which is less palatable. It seems most likely that *P. cordata* in the control plot went uneaten in the first growing season because the Canada geese had plenty to eat in the immediate vicinity, and its position next to the unpalatable *N. lutea* provided some deterrence and protection. The absence of *P. cordata* from the initially-vegetated exclosed plots in August is probably the result of competition from the dense *Z. aquatica* as the latter increased in height and biomass over the course of the growing season. Although *P. cordata* remained absent from the initially-unvegetated modules during the first growing season, it is hoped that the species will disperse into the initially-unvegetated exclosures over time. Neff (2002) did identify *P. cordata* seeds in the trawling samples on the Anacostia River, though none appeared in her water trap samples from Kingman Marsh itself.

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 (Figure 12). In June the initially-vegetated modules averaged 2.4 ± 0.2 in the exclosed plots and 2.4 ± 0.3 in the control plots (Figure 12), with no significant differences between them (*P* = 0.9339). Species richness was also quite low in the initially-unvegetated modules, with the average for the exclosed plots (0.5 ± 0.2) being significantly lower (*P* = 0.0343) than the average for the control plots (0.9 ± 0.2).

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

ANOVA results (Table 1) show no significant differences for habitat, month, or the habitat by month interaction.

Species richness values for the study modules during the first growing season of the herbivory study were much lower than those 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). Species richness values at the Heritage Island Wetland restoration three years into that project fell in between the values observed at the Anacostia River Fringe Wetlands and the Kingman herbivory study, averaging 3.7 ± 0.5.

There are a number of possible causes for the low species richness values in the Kingman herbivory modules. One contributory factor may be elevation. Most of the elevations at Fringe B were higher than in the Kingman modules (and therefore more susceptible to invasion by *P. australis* and *L. salicaria*). The 7 plots at Anacostia River Fringe B that fell within the same elevation range as the herbivory modules (22% of total plots) actually only averaged 3 species per plot.

Another contributing factor was undoubtedly the planting technique. The initially-vegetated modules at Kingman were in areas that had been seeded fairly heavily with *Z. aquatica*, which resulted in areas heavily dominated by *Z. aquatica* often to the competitive exclusion of most other species. Having pure stands of *Z. aquatica* in a freshwater tidal wetland is both natural (Odum et al. 1984) and positive from the wildlife standpoint (Haramis and Kearns 2007), but it will result in lower species richness values. The low species richness in these almost-pure stands of *Z. aquatica* is in contrast to Anacostia River Fringe A, where *Z. aquatica* was seeded, but at much lower densities, with a much patchier distribution, and only after the reconstructed marsh vegetation was already established. Under those circumstances, the 8 plots (50% of total) at Anacostia River Fringe A that fell in the same elevation range as the Kingman herbivory modules averaged 9 species per plot. They were able to achieve this by having three strata of vegetation, with *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 *T. latifolia* providing a tall stratum. Given the planting history, species richness may well remain relatively low in the initially-vegetated modules, unless and until their *Z. aquatica* densities decrease.

With species richness values in the initially-unvegetated modules starting basically from zero, it is hoped that species richness will increase over time in the exclosed plots, as seeds disperse into these newly-protected refugia from adult goose herbivory. Since these exclosed plots have not been seeded heavily with *Z. aquatica*, lower competition may actually cause species richness in the initially-unvegetated exclosed plots to exceed that in the initially-vegetated exclosed plots over time.

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 controls and initially-unvegetated exclosures, and 0.32 ± 0.1 m for the initially-vegetated exclosures and initially-unvegetated 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.

Surveillance

The exclosures remained intact throughout the first growing season. No herbivory from Canada geese or other herbivores was observed inside the exclosures.

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. The results are to be factored into the Wetland Management Environmental Impact Statement being prepared by NPS, allowing them to make better informed decisions regarding policies for and management of the wetlands within Anacostia Park.

Data from the first year of the herbivory study showed that for initially-vegetated modules (located in areas that AWS had over recent years planted with natives and protected by fencing until the start of the experiment) total vegetative cover in the unfenced control plots was significantly lower than that in the paired exclosed plots following two months of exposure to herbivory. Since the fence exclosures were elevated 0.2 m above the substrate, the results indicate that the observed herbivory impacts were due to the adult Canada geese that were able to access only the control plots, rather than other herbivores such as fish and turtles, which were able to access both the control and exclosed plots.

Vegetation in the initially-vegetated modules was composed entirely of native species. The main dominant was *Z. aquatica*, an annual species that is at the same time 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 such as soras (*Porzana carolina*), bobolinks (*Dolichonyx oryzivorus*), red-winged blackbirds (*Agelaius phoeniceus*) and numerous ducks; and highly palatable to Canada geese (Thunhorst 1993; Haramis and Kearns 2007). Because of its extreme palatability to Canada geese, *Z. aquatica* is a good indicator of herbivory pressure. *P. virginica*, another native present at dominant levels in at least some of the initially-vegetated modules, did not show a significant herbivory effect, in line with the lower palatability already exhibited by this species earlier in the history of the Kingman Marsh restoration (Hammerschlag et al. 1996). Species richness was relatively low in the initially-vegetated modules reflecting *Z. aquatica*'s planting history at the site, its ability to form pure as well as mixed stands (Odum et al. 1984), and its tendency to achieve increased height and density when grown in exclosures (Haramis and Kearns 2007).

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, and exhibited little plant establishment over the course of the first growing season. This delay in treatment response should not be due to elevation, since the elevations of all the modules fell within a range shown in previous work in the Anacostia restorations (including Kingman Marsh) to be sufficient to support emergent vegetation (Hammerschlag et al. 2006; Krafft et al. 2009). Additional years of monitoring should reveal whether the initially-unvegetated exclosure plots just need more time to fill in with vegetation, or whether some other factor is at work.

The first year of the Kingman Marsh herbivory study indicates that herbivory pressure from 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 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). Since the level of herbivory pressure that might be experienced by the wetland vegetation if the peripheral sheet piling and coir biologs are removed from the nearby Anacostia River Fringe and Heritage Island wetland restoration sites, respectively, is unknown, it seems advisable to retain these structures that may be providing protection from Canada goose herbivory unless and until that herbivory pressure is mitigated.

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

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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 (National Park Service, National Capitol Parks East), who arranged NPS funding and personnel for the project, as well as providing field and GIS support; T. Doan (District Department of the Environment), who was a reliable presence for all components of the field work; and S. McKindley-Ward (Anacostia Watershed Society), who recruited volunteers to take down the old fencing, and provided insights into the planting history of the initially-vegetated areas. Additional field assistance was provided by 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).

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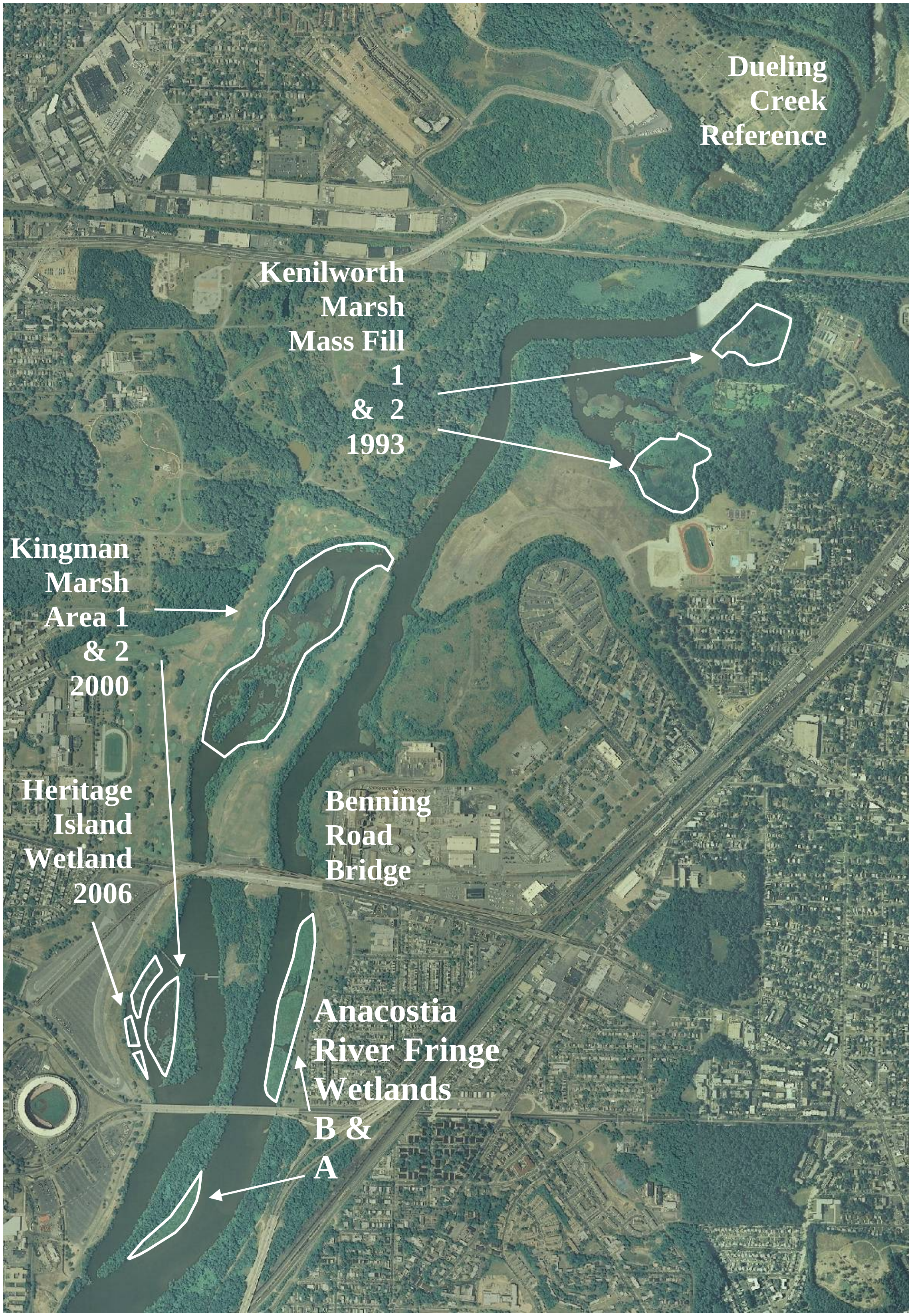

Figure 1. Anacostia Park tidal freshwater wetland restoration sites and reference wetland in 2007. Kingman Marsh Area 1 was the focus for this study. Dates reflect year of reconstruction. Photo courtesy of the National Agricultural Imagery Program.

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 at Kingman Marsh in Anacostia Park. Photo courtesy of the National Agricultural Imagery Program.

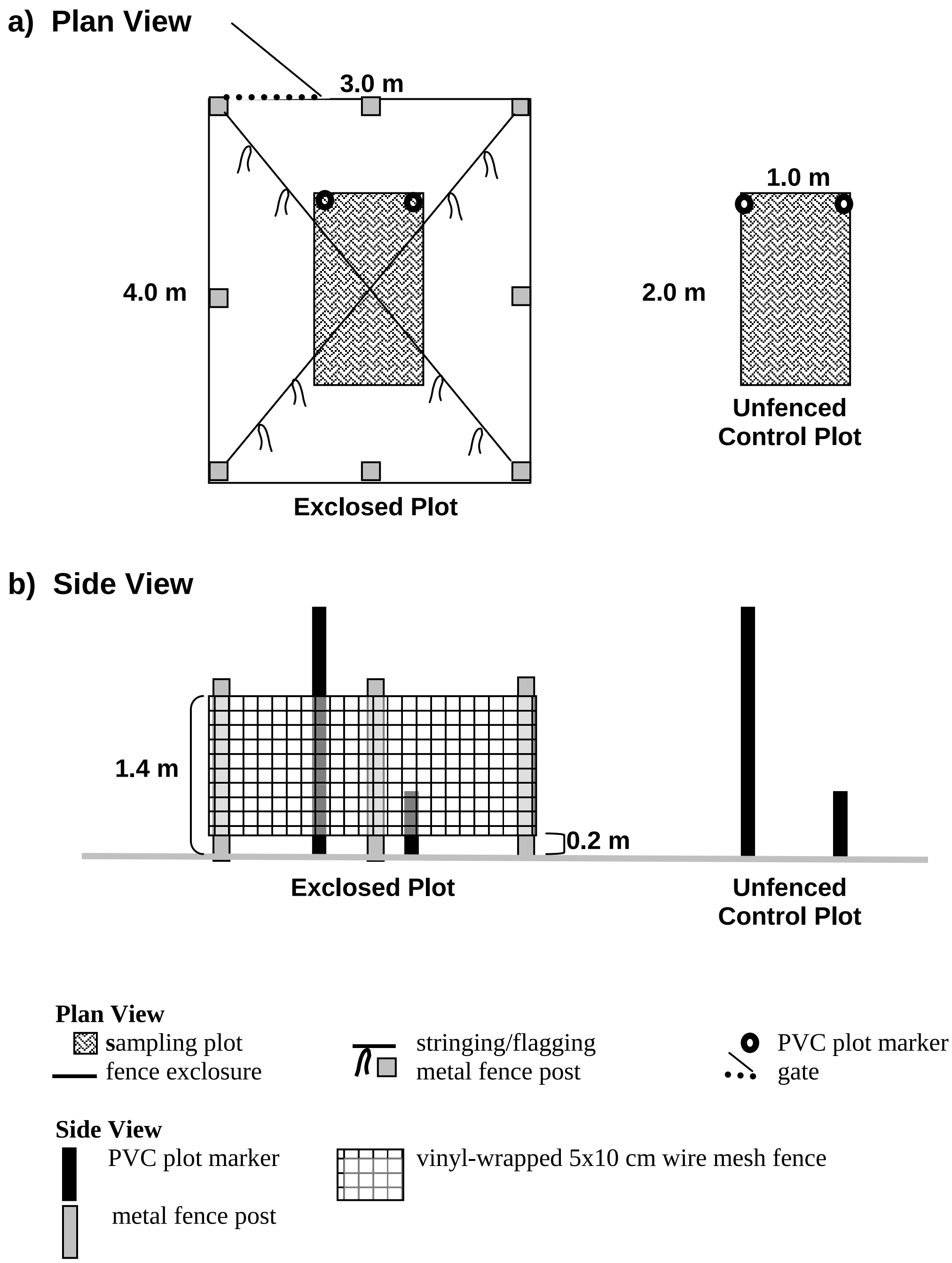

Figure 4. Schematic diagram of the study modules used in the herbivory study at Kingman Marsh. Each module consists of one fenced exclosed plot elevated 0.2 m and one unfenced control plot. A 1x2 m PVC frame was hooked over the PVC plot markers to delineate the same sampling plot boundaries during repeated sampling events.

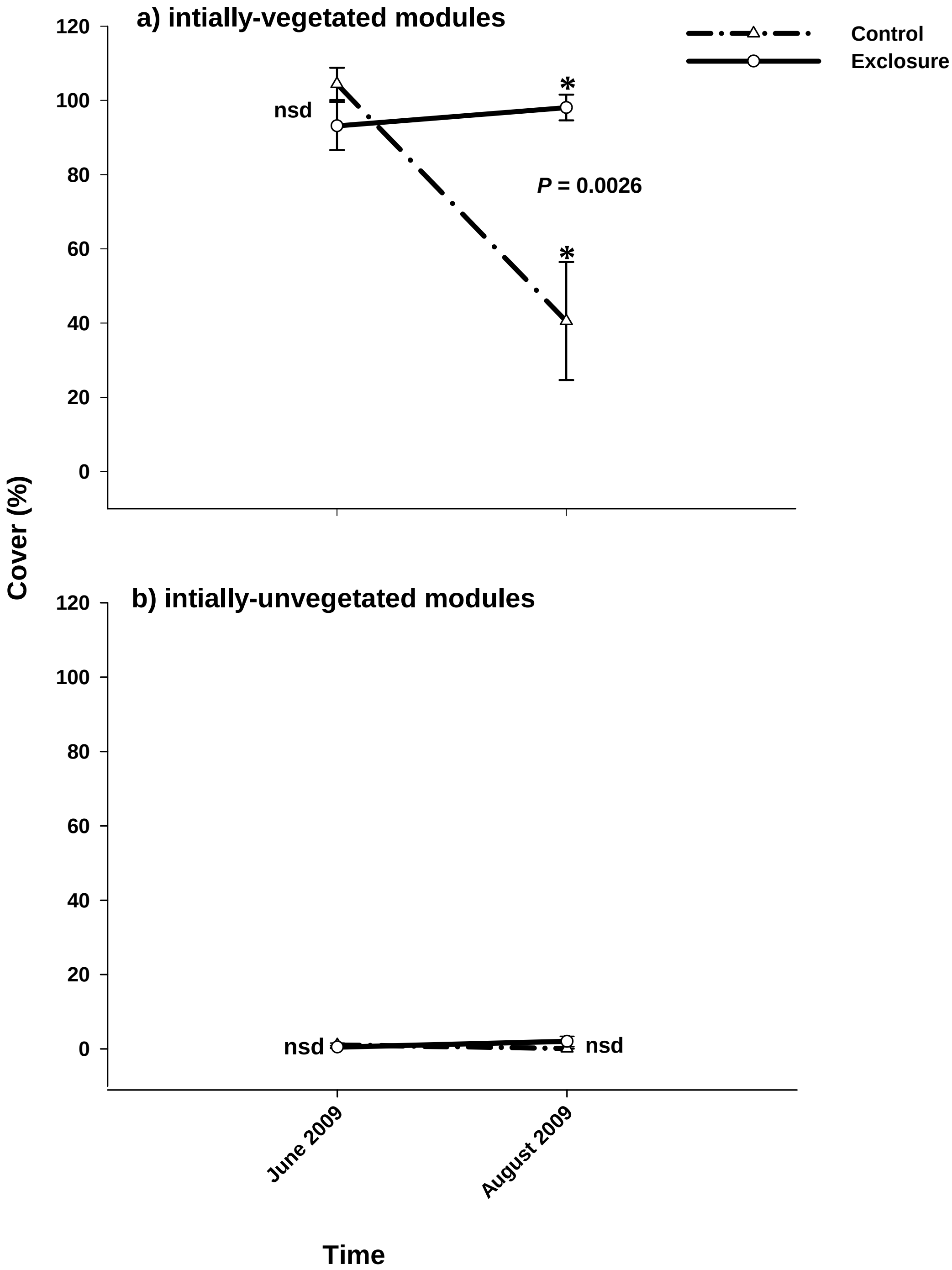

Figure 5. Total vegetative cover during the first growing season of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Total vegetative cover represents the sum of cover values for all individual species, and may therefore exceed 100%.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

a)

b)

Figure 6. Initially-vegetated Module 11 a) in June 2009, prior to exposure to herbivory, and b) again in August, after two months of exposure to herbivory. Photographed by R. Hammerschlag.

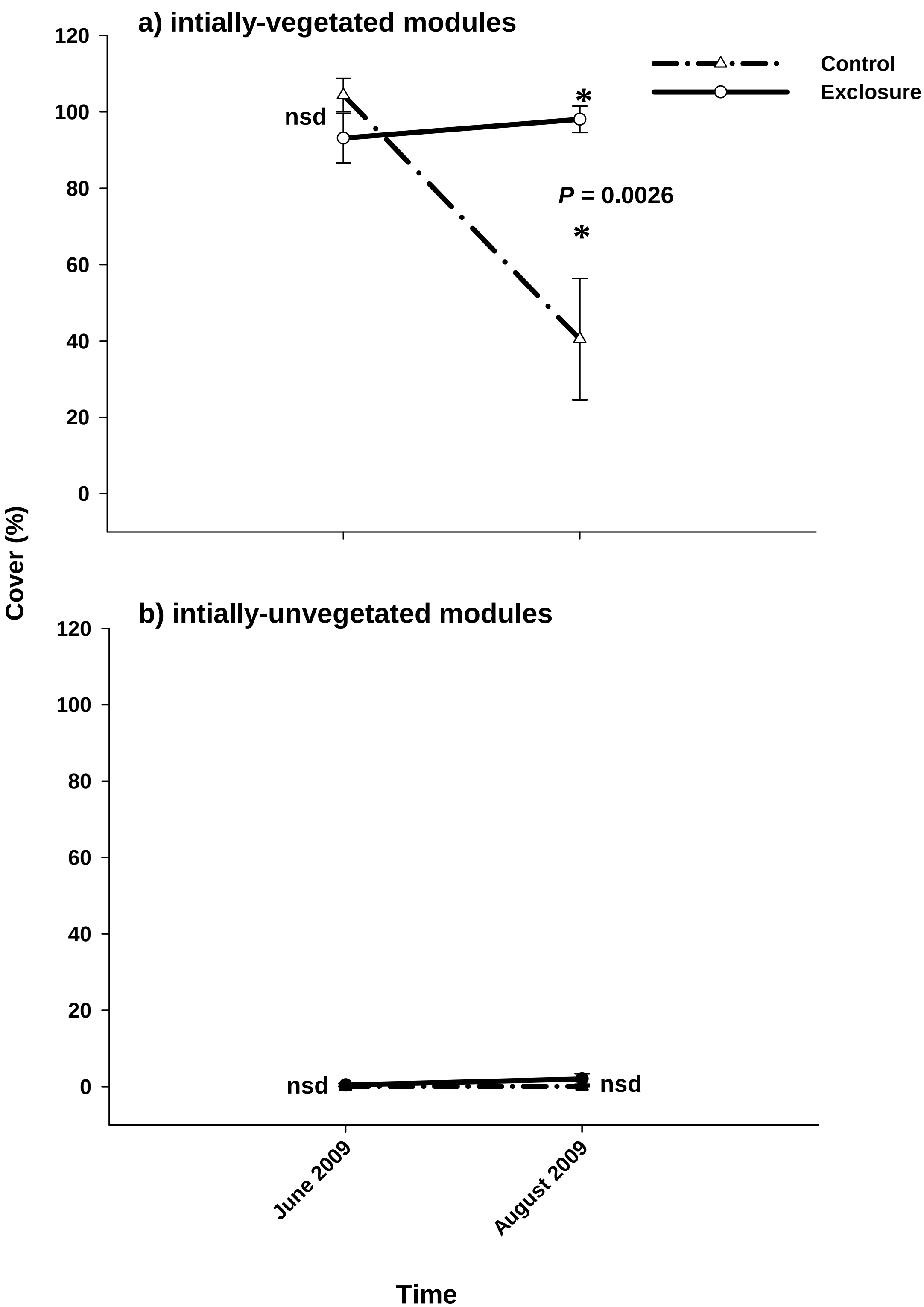

Figure 7. Total cover by natives during the first growing season of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Total cover by natives represents the sum of cover values for all individual native species, and may therefore exceed 100%. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

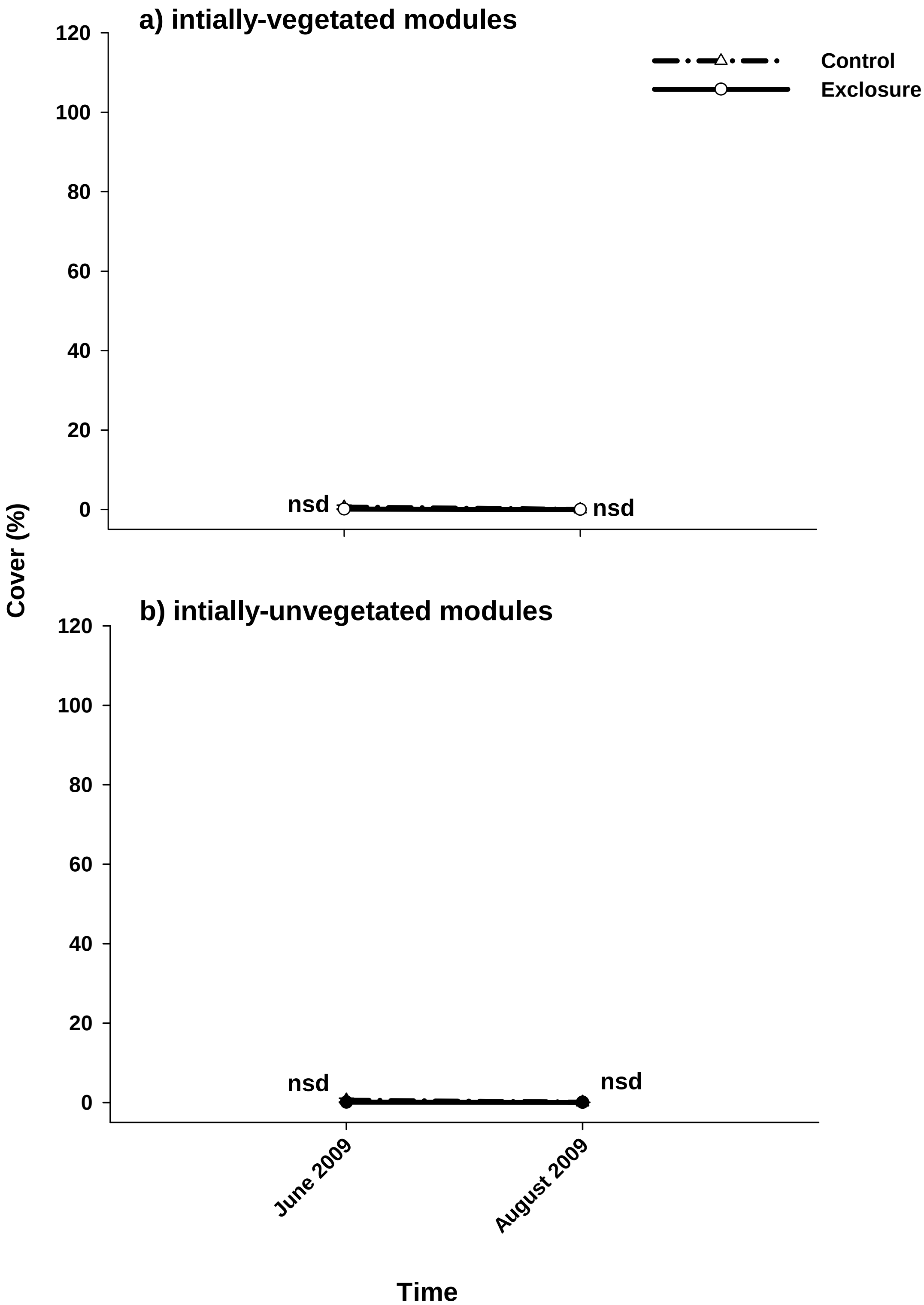

Figure 8. Total cover by non-natives during the first growing season of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Total cover by non-natives represents the sum of cover values for all individual non-native species. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd. See the text for more details on the analysis.

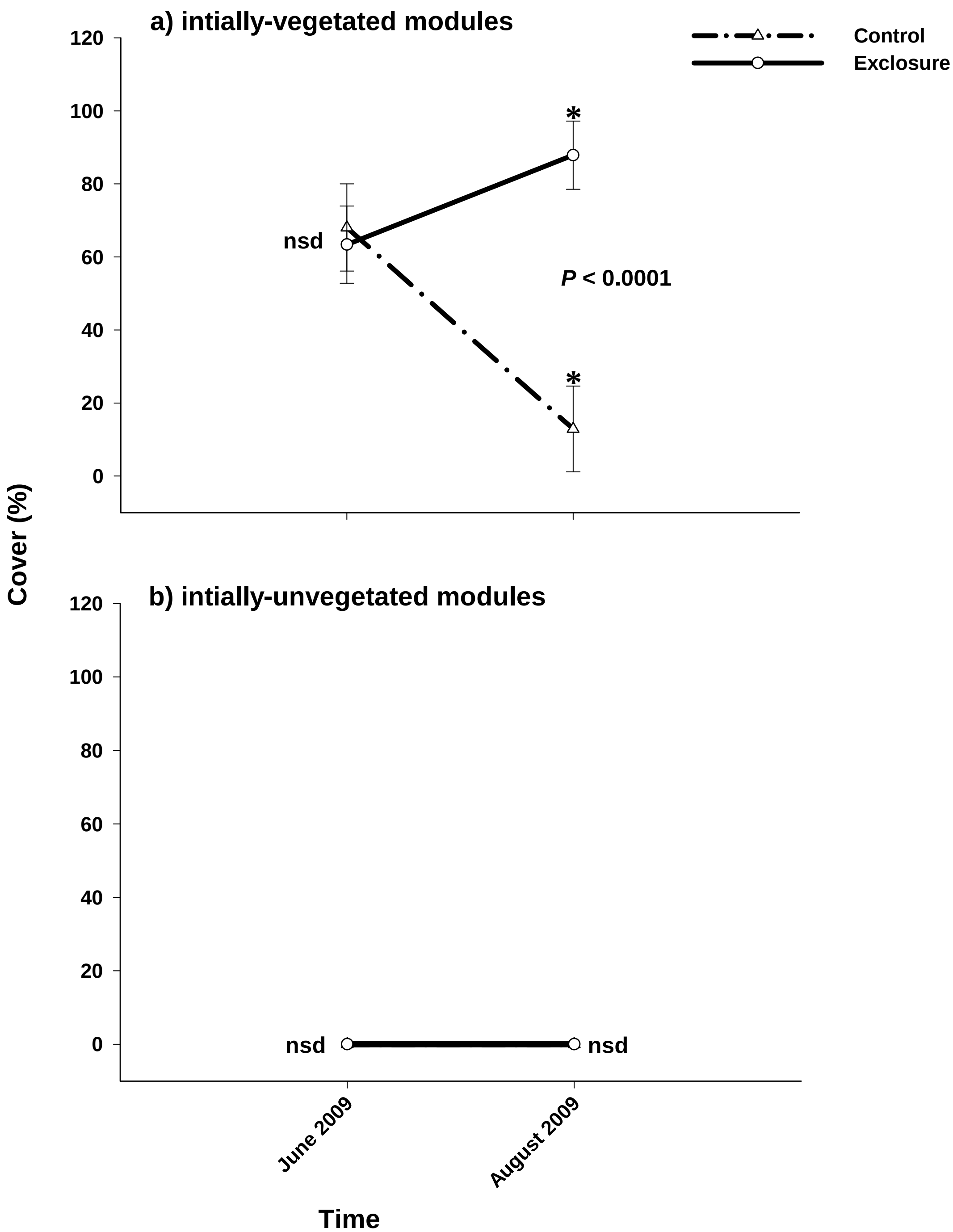

Figure 9. Cover by *Zizania aquatica* (annual wildrice) during the first growing season of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd.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

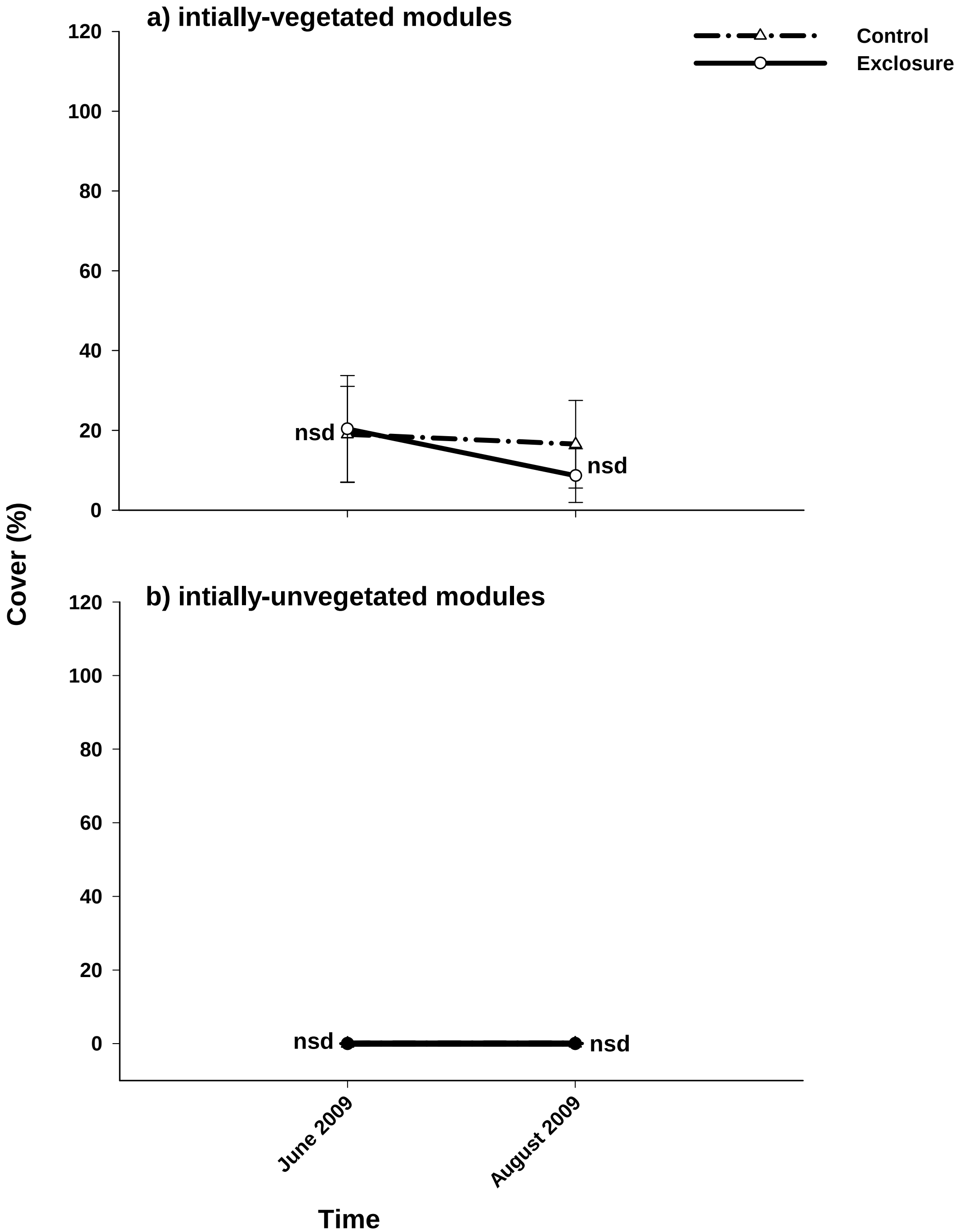

Figure 10. Cover by *Peltandra virginica* (green arrow arum) during the first growing season of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by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

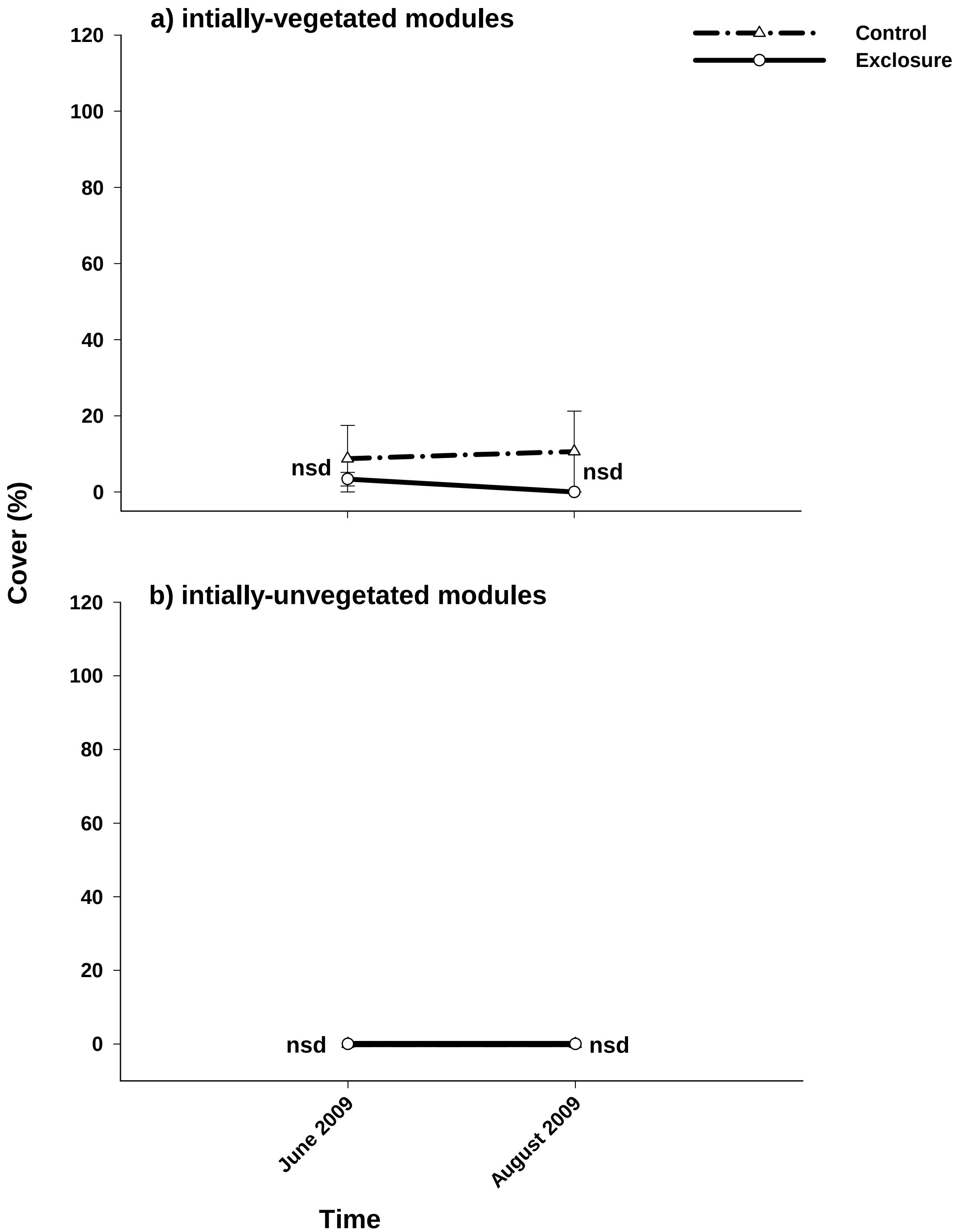

Figure 11. Cover by *Pontedaria cordata* (pickerelweed) during the first growing season of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is denoted by nsd.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

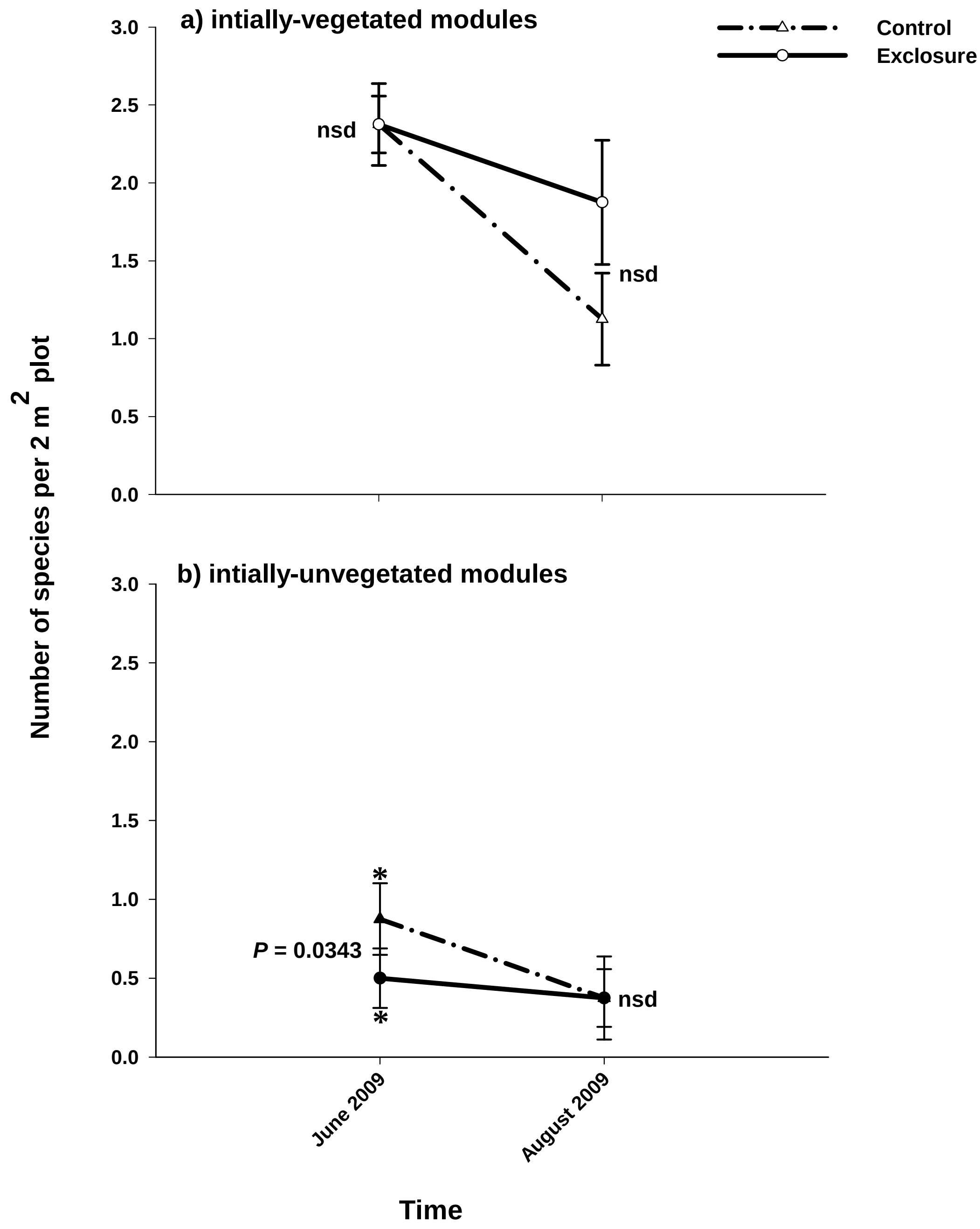

Figure 12. Species richness (number of species per 2-m^2 sampling plot) during the first growing season of the herbivory study for a) the initially-vegetated modules and b) the initially-unvegetated modules at Kingman Marsh. Data points represent arithmetic means ± 1 SE. No significant difference is 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) for each variable. See text for descriptions of the vegetation variables and for details concerning the ANOVA models.

	Fixed Effects Terms in ANOVA Model					
	Habitat[1]		Month[2]		Habitat x Month	
Variable[3]	*F*	*P*	*F*	*P*	*F*	*P*
Difference (Excl.-Control) in Log Total Vegetative Cover (%)	3.85	0.0700	13.56	0.0025	4.04	0.0641
Difference (Excl.-Control) in Log Total Native Cover (%)	2.22	0.1583	10.84	0.0053	6.68	0.0217
Difference (Excl.-Control) in *Zizania aquatica* Cover (%)	21.48	0.0004	29.14	<0.0001	29.14	<0.0001
Difference (Excl.-Control) in *Peltandra virginica* Cover (%)	0.30	0.5947	1.40	0.2569	1.37	0.2618
Difference (Excl.-Control) in Log *Pontedaria cordata* Cover (%)	0.07	0.7974	4.03	0.0643	4.03	0.0643
Difference (Excl.-Control) in Log Species Richness	1.98	0.1809	4.11	0.0622	0.04	0.8471

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

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

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

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