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Impacts of Deer Herbivory on Vegetation in Rock Creek Park, 2001-2009

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ON THE COVER
Paired fenced plot and unfenced control plot in Rock Creek Park, Washington, D.C.
Photographed by: Ken Ferebee

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Abstract

Starting in 2001, vegetation data have been collected annually in 16 study modules consisting of paired (1x4 m) fenced plots and unfenced control plots located in the upland forests of Rock Creek Park, Washington, D.C. Vegetation data collected from 2001-2009 have been analyzed to determine impacts of deer herbivory on vegetation in the park. Differences between fenced plots and unfenced control plots were analyzed for the following variables: cover provided by various groups of species (woody, herbaceous, native, non-native, trees, shrubs, and woody vines), as well as by individual dominant species, vegetation thickness (a measure of percent cover projected horizontally that provides information on the vertical distribution of vegetation), and species richness overall and for groups of species (woody, herbaceous, native, non-native, trees, shrubs, and woody vines). The analyses were performed using repeated measures analysis of variance (ANOVA) and associated tests. Vegetation in plots protected from deer herbivory for 9 years showed significantly greater vegetative cover compared to plots not protected from deer herbivory. This effect was most pronounced for woody and shrub cover. Cover by the dominant species was not significantly greater in the fenced plots compared to the unfenced control plots, indicating that the significant differences observed for groups were not driven by single species within those groups. With respect to vegetation thickness, results indicate that protection from deer herbivory produced significantly higher levels of vegetation in the fenced plots compared to the unfenced control plots for both the Low (0-30 cm) and Middle (30-110 cm) height classes. Protection from deer herbivory has led to higher overall species richness and higher species richness for woody species, natives, and shrubs compared to plots not receiving protection. There is also evidence that plots protected from deer herbivory and those not receiving this protection are diverging over time with respect to a number of variables such as cover by woody and shrub species, cover in the lowest height class, and species richness of woody and native species. Recommendations were made regarding future sampling.

Keywords

Herbivory, vegetation thickness, *Odocoileus virginianus,* white-tailed deer, Rock Creek Park, Washington, D.C.

Introduction

Long-term vegetation monitoring conducted at Rock Creek Park in Washington, D.C., from 1991 through the present has shown significant degradation of the quality of the Park's interior upland forest over this time (Hatfield and Krafft 2009). Woody cover and species richness have decreased significantly. Tree seedling numbers have decreased significantly over time (except for the lowest height class of 0-10 cm), accompanied by significant decreases in stocking rates. Stocking rates for the Park are all below the 67% rate recommended by Stout (1998) to provide adequate forest regeneration. In addition, twig browse has increased significantly over the same timeframe. All of these long-term monitoring results are consistent with browsing by white-tailed deer (*Odocoileus virginianus*) and suggest deer browse has had negative impacts on the forest understory at Rock Creek Park.

Impacts of deer browsing on forest vegetation in the Eastern United States have been demonstrated through the use of both deer enclosures and exclosures. Tilghman (1989) used enclosures to document deer impacts to forests in northwestern Pennsylvania, adding known densities of deer to 65-ha forested sites. She found that at the end of 5 years, plots with the highest deer densities experienced decreases in woody stem height, density, and species composition. The significance of these differences depended on factors such as level of disturbance (typically significant for areas that had been clearcut and not significant for uncut areas), height class, and species sensitivity to deer browse. In a similar 65-ha enclosure study in northwestern Pennsylvania, Horsley et al. (2003) observed over the course of 10 years that deer herbivory altered the trajectory of vegetation development. As deer densities increased species richness decreased, as did heights and densities of a number of preferred forage species. Species avoided by deer actually increased with increasing deer densities. In an exclosure study designed to identify impacts of deer on the abundance and diversity of breeding bird populations, McShea and Rappole (2002) documented significant increases in woody cover, stem density, and species richness in exclosures compared to unfenced control sites when deer were excluded from 4-ha forested plots in northern Virginia for 9 years.

In order to document experimentally whether deer herbivory is causing the detrimental impacts observed in the long-term vegetation monitoring plots, a series of herbivory study modules consisting of paired fenced plots and unfenced control plots was installed in Rock Creek Park in the summer of 2000. Sixteen of the herbivory study modules have been monitored annually since 2001. An earlier analysis of the first 4 years of data (Rossell et al. 2007) documented significant negative impacts of deer herbivory on woody and native cover and species richness, as well as vegetation thickness (vertical structure) less than 1m in height. The current report extends the period of analysis from 4 to 9 years (2001-2009), and examines the data from the standpoints of tree, shrub, woody vines, and dominant species, as well as the groups analyzed by Rossell et al. (woody, herbaceous, native, and non-native).

Methods

The herbivory study was conducted in the upland forests of the approximately 1,211-ha Rock Creek Park administrative unit located within Washington, D.C. Mapping conducted by The Nature Conservancy (TNC 1998) indicates that upland forest occupies 923 ha of the administrative unit. Most of the upland forest is characterized as *Fagus grandifolia-Quercus alba*/*Podophyllum peltatum* (beech-white oak/mayapple) Forest, with a canopy dominated by *Fagus grandifolia* (American beech), *Quercus alba* (white oak), and *Liriodendron tulipifera* (tuliptree). TNC lists *Ilex opaca* (American holly) and *Cornus florida* (eastern dogwood) as sub-canopy dominants, and also talks about a shrub layer dominated by *Viburnum acerifolium* (mapleleaf viburnum) and a fairly diverse herbaceous layer that was sparse to dense depending on soil type, disturbance history and moisture level. Two variants were noted for this forest association in Rock Creek Park, a mixed oak/beech variant on drier sites and a beech-tulip poplar variant on more mesic sites.

This study uses a paired plot design in which deer are excluded from the fenced study plots, whereas the control study plots remain unfenced and vulnerable to deer herbivory. Since the paired plots are correlated, statistical analyses were conducted on the differences between the paired plots rather than the actual plot values.

Field Methods

During the summer of 2000, 20 herbivory study modules were established in Rock Creek Park (Figure 1). Study modules were established at random locations in the park's interior upland forest habitat (Rossell et al. 2007). Each module consists of two 1x4 m study plots. One of the study plots is surrounded by a 1.5x4.6 m exclosure constructed of welded wire fence with a mesh size of 5x10 cm. Exclosures are 2.4 m tall with occasional openings where the bottom of the fence is not in contact with the uneven ground surface, thereby excluding deer, but not small herbivores. A gate at one end of the rectangular exclosure allows access for sampling. The paired unfenced control plot is located 1.5m from the fenced study plot, on the side where vegetation most closely resembled that in the fenced plot at the time of installation.

Sampling has been conducted annually in the herbivory study modules since 2001, primarily during the months of July and August. Over the course of the study, four modules have been abandoned for various reasons (e.g., module was positioned too close to a stream bank and eroded away, or the exclosure was crushed by a tree). Analyses were conducted on data collected from the remaining 16 study modules. Two principle types of quantitative data were collected during the herbivory study, cover data and vegetation thickness (a horizontal projection of cover used to estimate vertical distribution of vegetation).

Cover data were collected using the point intercept method (Elzinga, C.L. et al. 1998). The sampling apparatus used for cover data consisted of two wooden spreaders with 10 4-m sections of tape measure, one attached every 10 cm. One end of the tape measures was attached permanently to one of the spreaders. The other end of the tape measures could be threaded through the vegetation and then clicked into place in a notch on the opposite spreader, ultimately providing 10 parallel 4-m lengths of tape measure. The benefit of using this apparatus rather than a more fixed sampling frame was that it provided the flexibility needed to set up in areas of varying plant density and height. Reproducibility of spreader location from year to year was addressed by equipping spreaders with a ring bolt at each end that could be slipped onto fixed sections of rebar marking the study plot corners at the end of the study plot nearer the exclosure gate. The opposite spreader was positioned temporarily at the same distance from the exclosure fence using candy cane stakes. Cover data were collected by lowering a plumb bob down through the layers of vegetation up to 2 m in height. Any species (or nearest identifiable taxon) touched by the vertical string (or the tip of the plumb bob for prostrate vegetation) was recorded as a hit at that location. Locations lacking in living vascular vegetation were recorded as the first substrate cover class encountered by the plumb bob (e.g., litter, soil, wood). Vegetation was measured in this way every 20 cm along each of the 10 tape measures for a total of 200 locations per study plot. Percent cover was calculated for each species by dividing the total number of hits for that species by 200 and multiplying by 100 to obtain a percentage.

Taxonomic identifications were made using Brown and Brown (1984, 1999). Final nomenclature follows the US Department of Agriculture PLANTS database (USDA, NRCS 2011). Species classifications regarding origin (native versus non-native) and life form (tree, shrub, woody vine, and herbaceous) generally follow the PLANTS database, except where it was possible to use Brown and Brown or the comprehensive Rock Creek Park plant species list (Fleming and Kanal 1995) to obtain more local information. Data were summed by various groupings of species (i.e., woody, herbaceous, native, non-native, tree, shrub, and woody vine) to determine impacts of protection from deer herbivory on different components of the forest vegetation. Dominant species were identified for further analysis as all species providing at least 5% cover (arithmetic mean) during at least one sampling event.

Vegetation thickness is a horizontal projection of cover designed to provide estimates of the vertical distribution of vegetation, which can be useful in assessing the ability of habitat to provide cover for wildlife (Rossell et al. 2007). It is also referred to as horizontal cover or foliage volume (Nudds 1977; Noon 1981). Vegetation thickness was estimated for three height classes, Low (0-30 cm), Middle (30-110 cm) and High (110-190 cm). Estimates were obtained using a drop cloth of clear acetate marked with a grid system 8 squares wide by 19 squares high (Noon 1981). Since each square of the grid measures 10x10 cm, the dimensions of the grid are 80x190 cm. The drop cloth was used by attaching it with binder clips to the exclosure fence on the long side between the fenced plot and the unfenced control plot. Cover estimates were made by a sampler kneeling 1 m away from the study plot, looking through the vegetation in the study plot and estimating what percentage of each square on the drop cloth was obscured by vegetation. A total number of squares was recorded for each height class in that grid location. By repositioning the grid in 5 adjacent locations, vegetation thickness data were obtained for the entire 4 m-long study plot. Final vegetation thickness estimates were obtained for each height class by dividing the sum of covered squares for that height class by the total number of squares in that height class, and multiplying by 100 to obtain a percentage. Vegetation thickness estimates were obtained in this way for both the fenced plot and the unfenced control plot within the module.

Species richness was determined based on the cover data for each study plot, and represents the number of species (or taxa not otherwise represented in the study plot) providing cover during that sampling event.

Data Analysis

Differences between paired fenced plots and unfenced control plots were calculated and analyzed for a variety of variables using mixed model repeated measures analysis of variance (SAS, 2003, PROC MIXED) to compare data among years (2001-2009). Variables analyzed were: cover by

various groups of species (woody, herbaceous, natives, non-natives, trees, shrubs, woody vines) and individual dominant species, vegetation thickness, and species richness overall and for woody, herbaceous, native, non-native, trees, shrubs, woody vines. Cover data (including vegetation thickness) were transformed prior to analysis using a natural log transformation to improve normality. 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 among years 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 and unfenced control plots for each year (alpha = 0.05 after Bonferroni correction).
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Results and Discussion

Results of the ANOVA's conducted on the differences between fenced plots and unfenced control plots for assorted cover variables (woody, tree, shrub, woody vine, herbaceous, native, non-native, and cover by individual dominant species), vegetation thickness (percent cover projected horizontally rather than vertically), and assorted species richness variables (overall, woody, tree, shrub, woody vine, herbaceous, native and non-native) are provided in Table 1. These *P*-values refer to whether the differences between fenced plots and unfenced control plots behave the same or differently depending on the year. They should provide an indication of whether fenced – unfenced control plot differences in percent plant cover, vertical distribution of plant cover, and species richness are increasing over time as the vegetation in the two types of plots diverges due to the reduction in deer herbivory pressure experienced by the fenced plots compared to the ambient deer herbivory pressure experienced by the unfenced control plots.

Table 2 provides means and standard errors for the differences between fenced and unfenced control plots, as well as Tukey test results indicating whether the differences vary significantly across years. In the case of the cover variables, back-transformation from the natural log produces an estimate of the ratio of (fenced+1)/(unfenced control+1), rather than the difference of fenced - unfenced control.

Also of particular importance to this study are the associated least square means and t-tests that indicate the significance of differences between the fenced plots and unfenced control plots, since these reflect whether the treatment (protection from herbivory) is having a significant effect in any given year. Significance of the differences between fenced plots and unfenced control plots (alpha = 0.05 after Boneferroni correction) is indicated in Figures 2 through 4. Although the statistical tests were conducted on the differences between the paired plots rather than their actual values, the graphs in Figures 2 through 4 display the arithmetic means of the fenced plots and unfenced control plots (± 1 standard error) for ease of interpretation.

A species list is provided in the Appendix. This list contains the 84 distinct taxa (79 species and 5 genera not otherwise represented by species) identified in the herbivory study plots from 2001-2009.

Vegetative Cover

Cover data were analyzed for a number of different groups as well as individual dominant species to determine the impacts of deer herbivory on various components of the forest vegetation.

Woody Cover

Woody cover was provided by 50 distinct taxa, 38 (76%) of which are native, 11 (22%) are non-native, and 1 (2%) are of unknown origin (Appendix). All four of the species meeting the dominant species criterion of providing at least 5% cover in at least one sampling event were woody species: *F. grandifolia*, *V. acerifolium*, *Lindera benzoin* (northern spicebush), and *Hedera helix* (English ivy).

In the baseline year of 2001, woody cover did not differ significantly between fenced plots and unfenced control plots (Figure 2a). By the following year, however, there was significantly greater woody cover in the fenced plots than in their unfenced control plots. Woody cover has remained significantly higher in the fenced plots than the unfenced control plots through 2009, the most recent year for which vegetation data have been analyzed. Means from 2008 and 2009 are somewhat lower than a peak observed in 2007, but since this is reflected in data from both the fenced plots and unfenced control plots, it does not appear to be related to deer herbivory. Results of the ANOVA and Tukey tests (Tables 1 and 2) indicate that differences in woody cover between fenced plots and unfenced control plots have increased significantly over time with respect to 2001. Woody cover results indicate that protection of the fenced plots from deer herbivory has produced an increase in woody cover over time greater than that achieved in the unfenced control plots.

Herbaceous Cover

Over the nine-year period during which the data for these analyses were collected, herbaceous cover was provided by 34 taxa, 27 (79%) of which are native, 5 (15%) are non-native, and 2 (6%) are of unknown origin (Appendix). None of the 34 provided sufficient cover to meet the dominant species threshold of at least 5% cover in at least one sampling event.

Although levels of herbaceous cover occur at relatively lower levels in the upland forests of Rock Creek Park compared to woody cover, after three years of protection from deer herbivory, herbaceous cover in the fenced plots was significantly greater than in the unfenced control plots (Figure 2b). This was true for five of the six most recent years of data. ANOVA and Tukey results (Tables 1 and 2) indicate that, although the fenced plot – unfenced control plot difference estimates increased over time, the increases were not sufficient to achieve statistical significance.

Native Cover

Native cover was provided by 65 (77%) of the 84 taxa identified in the study plots during the 9 years over which these data were collected. Three of the four species meeting the dominant species criterion, *F. grandifolia*, *V. acerifolium*, and *L. benzoin*, are native.

Cover by native species was significantly greater in the fenced plots than in the unfenced control plots for all years of data collection, 2001-2009 (Figure 2c). Conclusions attributing this to a treatment effect of protection of the fenced plots from herbivory would have been stronger had baseline data indicated lack of significance in the baseline condition followed by the development of significant differences over time. Collection of data in 2000, the year in which the exclosures were installed, might have provided the baseline needed to draw stronger conclusions regarding the cause of the significant differences in native cover between fenced plots and unfenced control plots. Results of the Tukey tests (Table 2) indicate that for native cover the fenced plot – unfenced control plot differences have increased over time with respect to the (2001) baseline, with the significance varying by year.

Non-Native Cover

Non-native cover was provided by 16 species, representing 19% of the 84 taxa identified in the study plots. Only one of the species meeting the dominant species criterion, *H. helix*, was a non-native.

Cover by non-natives did not differ significantly between fenced plots and unfenced control plots until the last two years of the study, when fenced plot means were significantly greater than unfenced control plot means (Figure 2d). Although the differences between fenced plots and unfenced control plots did increase over time, the results of the ANOVA and Tukey tests (Tables 1 and 2) did not indicate any significant differences with respect to the 2001 baseline data. These results indicate that protection from deer herbivory in the fenced plots has had only a limited effect on their non-native cover during the time period under examination.

Tree Cover

Data were also analyzed separately for trees, shrubs, and woody vines in an effort to provide a richer understanding of the results for woody cover. Tree cover during 2001-2009 was provided by 26 taxa, 23 (88%) of which were native, 2 (8%) non-native, and 1 (4%) of unknown origin (Appendix). Only one tree species, *F. grandifolia*, provided sufficient cover to meet the dominant species threshold of at least 5% cover in at least one sampling event. *F. grandifolia* was analyzed separately and will be addressed further in the section on cover by individual dominant species.

The tree data indicate that although tree cover was not significantly greater in the fenced plots than in the unfenced control plots in 2001 or during some of the early years of the study, by 2005 and in subsequent years, differences between fenced plots and unfenced control plots have been significant, with significantly more tree cover in the fenced plots compared to the unfenced control plots (Figure 2e). Results of the ANOVA and Tukey tests (Tables 1 and 2) indicate that differences between fenced plots and unfenced control plots increased over time for tree cover, although this increase was not statistically significant. Tree cover results indicate a significant treatment effect of protection from deer herbivory, with less of a divergence between fenced plots and unfenced control plots than observed for woody cover overall.

Shrub Cover

Shrub cover was provided by 14 species, 10 (71%) percent of which were native, and the remaining 4 (29%) were non-native (Appendix). Two species, *V.acerifolium* and *L.benzoin*, provided at least 5% cover in at least one sampling event, and were analyzed separately. They will be addressed further in the results for dominant species.

Statistically, the shrub cover data exhibited a pattern similar to that observed for woody cover. Differences between fenced plots and unfenced control plots were not significant in the first year of the study, but by the second year of the study and in all subsequent years, shrub cover was significantly greater in the fenced plots compared to the unfenced control plots (Figure 2f). ANOVA and Tukey results for shrub cover (Tables 1 and 2) show a significant increase in the differences between fenced plots and unfenced control plots over time with respect to 2001, reflecting a greater divergence and more pronounced impact between fenced plots and unfenced control plots than that observed for tree cover.

Woody Vine Cover

Woody vine cover was provided by 10 species, consisting of 5 (50%) native species, and 5 (50%) non-native species (Appendix). The percentages of native and non-natives species for woody vines are distinctly different from those observed for the other life forms, reflecting an issue Rock Creek Park has worked to address through herbicidal control of its non-native woody vines. Only one woody vine species, *H. helix*, met the dominant species criterion of at least 5% cover in at least one sampling event.

With respect to cover by woody vines, differences between fenced plots and unfenced control plots did not become significant until 2004, the fourth year of the study. During the period of 2004 through 2009, fenced plots exhibited significantly greater woody vine cover compared to unfenced control plots (Figure 2g). ANOVA and Tukey results for woody vine cover show that although differences between fenced plots and unfenced control plots have increased over time, these increases did not achieve statistical significance (Tables 1 and 2). These results indicate that protection of vegetation in the fenced plots has led to greater woody vine cover compared to the unprotected control plots, although the divergence between the fenced plots and unfenced control plots for this variable is not so pronounced as observed for overall woody and shrub cover.

Cover by Individual Dominant Species

Only four species met the dominant species criterion of providing at least 5% cover during at least one sampling event: *F. grandifolia*, *V. acerifolium*, *L. benzoin*, and *H. helix*. These four species received the same analytical treatment described for the other variables. Fenced plot means were typically greater than the unfenced control plot means for all four species; however, none of these differences was statistically significant (Figures 2 h-k). Based on the estimates provided in Table 2, fenced plot - unfenced control plot differences increased over time for all of the species except *H. helix,* which saw essentially no changes over time. ANOVA results (Table 1) indicate that the observed changes in fenced plot – unfenced control plot differences were significant for only two of the species, *F. grandifolia* and *V. acerifolium*. The strength of the results even for these two species is somewhat limited by the fact that in neither case did Tukey results show significant differences among years compared to the 2001 baseline data. Dominant species results indicate that protection of vegetation in the fenced plots for 9 years produced some improvement in cover, of mixed statistical significance, for *F. grandifolia* and *V. acerifolium*, weak but statistically insignificant improvement in cover for *L. benzoin*, and essentially no impact on cover by *H. helix*.

Vegetation Thickness

Vegetation thickness provides an estimate of the vertical distribution of vegetation through a horizontal projection of cover, rather than the vertical projection typical for cover data. Analyses of the vegetation thickness data indicate significant responses to protection of vegetation in the fenced plots for the Low and Middle height classes (0-30 cm and 30-110 cm, respectively). For the Low height class vegetation thickness did not differ significantly during the first two years of the study, but by the third year (2003) and in all subsequent years, vegetation thickness was significantly greater in the fenced plots than in the unfenced control plots (Figure 3a). In addition, ANOVA and Tukey test results (Tables 1 and 2) showed a steady and significant increase over time in fenced plot – unfenced control plot differences for vegetation thickness in the Low height class.

Vegetation thickness in the Middle height class started out with no significant differences between fenced plots and unfenced control plots for the first three years (Figure 3b). By the fourth year (2004) and in all subsequent years, vegetation thickness was significantly greater in the fenced plots than the unfenced control plots. Estimates for fenced plot – unfenced control plot differences in Middle height class vegetation thickness provided in Table 2 show increases over time. The statistical results for the Middle height class are not so strong as for the Low height class, however, since the increase in estimates is not accompanied by Tukey test results indicating a significant increase over time with respect to the baseline year of 2001.

Vegetation thickness in the High height class (110-190 cm) showed no significant differences between fenced plots and unfenced control plots in any of the years during 2001-2009 (Figure 3c). Although modest increases in the estimates for fenced plot – unfenced control plot differences are shown in Table 2, the Tukey test results do not indicate any significant differences in the estimates between years.

The vegetation thickness data analyses indicate that protection of the fenced plots from deer herbivory has to date produced the strongest revegetation in the Low height class, with a somewhat less pronounced effect in the Middle height class, and no statistically significant effect in the High height class. Continued monitoring should reveal to what extent the revegetation continues to work its way up the understory.

Species Richness

Species richness is defined for this study as the number of species (or distinct taxa) observed per 1x4 m study plot. It is used in conjunction with estimates of plant cover to provide insights into the health of the forest understory.

Overall Species Richness

Overall species richness reflects the total number of species (distinct taxa) identified per 1x4 m study plot. In the baseline year of 2001, there was no significant difference in overall species richness between fenced plots and unfenced control plots (Figure 4a). By 2002, and in all subsequent years through 2009, however, overall species richness was significantly greater in the fenced plots than the unfenced control plots. This appears to reflect both increases in overall species richness in the fenced plots with respect to 2001 levels as well as decreases in overall species richness in the unfenced control plots with respect to 2001 levels. Results of the repeated measures ANOVA (Table 1) show that the fenced plot – unfenced control plot differences in overall species richness vary significantly over time. Estimates of the fenced plot – unfenced control plot differences for overall species richness provided in Table 2 indicate that these differences have increased over time with respect to the baseline, although only one of the pairwise comparisons is statistically significant, that between 2001 (the baseline) and 2005.

Woody Species Richness

Fenced plot and unfenced control plot arithmetic means as well as the means for fenced plot – unfenced control plot differences for woody species richness are quite similar to those exhibited by overall species richness, indicating that most of the overall species richness has been contributed by the woody species, with a relatively small contribution from herbaceous species. Like overall species richness, woody species richness showed no significant differences between fenced plots and unfenced control plots in 2001, but by 2002 and in all subsequent years during 2001-2009, overall species richness was significantly greater in the fenced plots than in the unfenced control plots (Figure 4b). Also like overall species richness, the repeated measures ANOVA and Tukey tests (Tables 1 and 2) for woody species richness showed a significant year effect for the fenced plot – unfenced control plot differences, with the significance of the increases with respect to the 2001 baseline varying by year. Results indicate a somewhat more pronounced effect for woody species richness than overall, given a lower P-value (0.0025 compared to 0.0174) and the fact that two of the pairwise comparisons were significant, compared to only one for overall species richness.

Herbaceous Species Richness

Unlike the herbaceous cover data, which showed greater cover in the fenced plots compared to the unfenced control plots for 5 of the 6 most recent years of data, the results for herbaceous species richness showed a significant effect in only one year (Figure 4c). In addition, not only were there no significant differences over time for the fenced plot – unfenced control plot differences for herbaceous species richness (ANOVA $P = 0.7717$), but the estimates provided in Table 2 show little evidence of even non-statistically significant increases over time with respect to the 2001 baseline. Herbaceous species richness results indicate that protection of vegetation in the fenced plots from herbivory has had virtually no effect on this variable.

Native Species Richness

Native species richness results indicate a fairly pronounced impact on native species richness as the result of protection of vegetation from deer herbivory. Species richness for natives did not differ between fenced plots and unfenced control plots in 2001, the baseline year, but in each of the subsequent 8 years, species richness in the fenced plots was significantly greater than in the unfenced control plots (Figure 4d). ANOVA results indicate significant changes over time for the fenced plot – unfenced control plot differences ($P = 0.0136$), all of the fenced plot – unfenced control plot estimates are higher than that observed for the 2001 baseline, and the Tukey results show that these increases with respect to the baseline are significant for two of the years (2005 and 2008).

Non-Native Species Richness

Protection of vegetation from deer herbivory appears to have had virtually no impact on non-native species richness. Non-native species richness did not differ significantly between fenced plots and unfenced control plots in any of the 9 years from 2001-2009 (Figure 4e). The repeated measures ANOVA of fenced plot – unfenced control plot differences for non-native species richness showed no significant changes over time (P = 0.3473), fenced plot –unfenced control plot differences provided little evidence for increases over time, and none of the Tukey test pairwise comparisons indicated any significant differences (Tables 1 and 2).

Tree Species Richness

Protection of vegetation from deer herbivory in the fenced plots produced a less pronounced effect for tree species than for all species combined, or woody species. Tree species richness was significantly greater in the fenced plots than the unfenced control plots in only 3 of the 9 years examined (Figure 4f), unlike the situation for overall richness, woody species richness, and native species, for which species richness in the fenced plots significantly exceeded that in the unfenced control plots in all 8 years after the 2001 baseline. In addition, although estimates for fenced plot –unfenced control plot differences indicate some increases over time with respect to the 2001 baseline, results of the repeated measures ANOVA (P = 0.0677) and Tukey tests indicate none of these changes over time have been statistically significant.

Shrub Species Richness

Statistical results for shrub species richness indicate that protection from deer herbivory has had a fairly strong impact on shrub species richness, with fenced plot means significantly exceeding unfenced control plot means in 4 of the last 7 years (Figure 4g). Repeated measures ANOVA results (Table1) indicate a significant year effect for fenced plot –unfenced control plot differences (P = 0.0075). Estimates in Table 2 indicate an increase over time for fenced plot – unfenced control plot differences with respect to the baseline, although this increase was statistically significant in only one year (2008).

Woody Vine Species Richness

Results indicate little impact of protection from deer herbivory on the species richness of woody vines in the fenced plots compared to vegetation in the unfenced control plots. Woody vine species richness in the fenced plots significantly exceeded levels in the unfenced control plots in only 1 of the 9 years of data analyzed (Figure 4h), repeated measures ANOVA (Table1) showed no significant year effect (P = 0.4936), and Tukey test results (Table 2) indicate that none of the extremely minor increases observed in fenced plot –unfenced control plot estimates differed significantly from the 2001 baseline.

Conclusions

Data from the first 9 years of the Rock Creek Park herbivory study indicate that deer herbivory is having significant negative impacts on forest vegetation in the park.

Cover results show that the exclusion of deer herbivory for 9 years resulted in significantly greater plant cover in the fenced plots compared to the unfenced control plots for woody species, herbaceous species, native species, non-native species, trees, shrubs, and woody vines. The most pronounced impacts of protection from deer herbivory on cover were exhibited by woody cover, shrub cover, and native cover and the least impact was exhibited by non-native cover. Differences between fenced and unfenced control plots have increased significantly over time with respect to 2001 data for cover by woody species and shrub species, with more limited results for natives. These results indicate that for these groups of species, protection from deer herbivory has not only produced significant differences, but that the differences are increasing over time with continued protection. The remaining groups showed no significant changes over time with respect to the 2001 baseline.

Four species met the dominant species criterion of providing at least 5% cover in at least one sampling event. These consisted of one tree species, *F. grandifolia*, two shrub species, *V. acerifolium* and *L. benzoin*, and one woody vine, *H. helix*. All but *H. helix* are native. No significant differences were observed between fenced plots and unfenced control plots for the four individual dominant species, indicating that observed differences are due to the combined effects of a number of species within the groups rather than being driven by single species. Fenced plot – unfenced control plot differences showed some non-statistically significant increases over time for all of the dominants except *H. helix*, although statistical results were at best mixed for *F. grandifolia* and V. *acerifolium*, and insignificant for *L. benzoin*.

Results for vegetation thickness showed significantly more vegetation present in the fenced plots compared to the unfenced control plots for the Low and Middle height classes (0-30 cm and 30-110 cm, respectively). Differences for the High height class (110-190 cm) were not significant. Differences between fenced plots and unfenced control plots showed steady, significant increases over time for the Low height class. Significant, but less pronounced increases were observed in the Middle height class, with no significant increases in the differences between fenced plots and unfenced control plots observed in the High height class.

Species richness was significantly greater in fenced plots than unfenced control plots for overall species richness as well as for woody species and natives, with more mixed results for shrubs and trees. By contrast, herbaceous species, woody vines, and non-natives showed little or no evidence for significantly greater species richness in the fenced plots compared to the unfenced control plots. Fenced plot – unfenced control plot differences for overall species richness and species richness for woody species, natives, and shrubs showed some increases with respect to 2001 data, with the significance of those increases varying by year. This indicates that for these groups of species, species richness is diverging over time between the fenced plots and unfenced control plots. For the remaining categories (herbaceous species, non-natives, trees, and woody vines) differences between fenced plots and unfenced control plots showed no significant differences over time, although trees and woody vines did exhibit some non-statistically significant increases in fenced plot – unfenced control plot differences over time with respect to the baseline values.

The 9-year exclusion of deer from the fenced plots in Rock Creek Park has resulted in significantly greater cover, vegetation thickness, and species richness for vegetation in the fenced plots compared to that in the unfenced control plots that received no protection from deer herbivory. Results have been most pronounced for cover by woody species, shrubs, and natives, species richness overall and for woody and native species, and vegetation thickness for the Low height class. In each case, results included both evidence for significantly higher levels in the fenced plots compared to unfenced control plots, as well as significant evidence for the divergence of the vegetation in the fenced plots and unfenced control plots over time.

With respect to the future, continued monitoring of the deer herbivory study modules in Rock Creek Park is recommended. If deer populations are reduced, differences between the fenced plots and unfenced control plots would be expected to decrease over time as vegetation in the unfenced control plots experiences a reduction in pressure from deer herbivory. Continued monitoring would document these changes. Periodic monitoring of exclosure integrity is recommended so that damaged exclosures can be repaired or reconstructed as needed. Since the number of herbivory study modules has already decreased from 20 to 16, every effort should be made to avoid further losses. Although it is currently possible to document the low rates of tree seedling regeneration in Rock Creek Park based on stocking rates calculated using data from the 26 unfenced long-term monitoring plots (Hatfield and Krafft 2009), the addition of tree seedling density measurements to the herbivory study is recommended. This would permit statistical comparisons of stocking rates in the paired fenced plots and unfenced control plots and provide a more direct measure of the impacts of deer herbivory on stocking rates. Collection of the data by species could also provide insights into possible impacts of deer herbivory on species composition of forest regeneration. If financial resources are limited for sampling the herbivory plots, the combination of cover and tree seedling density would be recommended for future documentation rather than cover and vegetation thickness. This combination of data should be adequate to document significant impacts due to deer herbivory in the Park.

Acknowledgements

Special thanks go to K. Ferebee, J. Kish and other staff at Rock Creek Park, and D. Pavek at the NPS Center for Urban Ecology, for help with data collection, acquisition, and interpretation. We greatly appreciate the funding received from the National Park Service which made this report possible.

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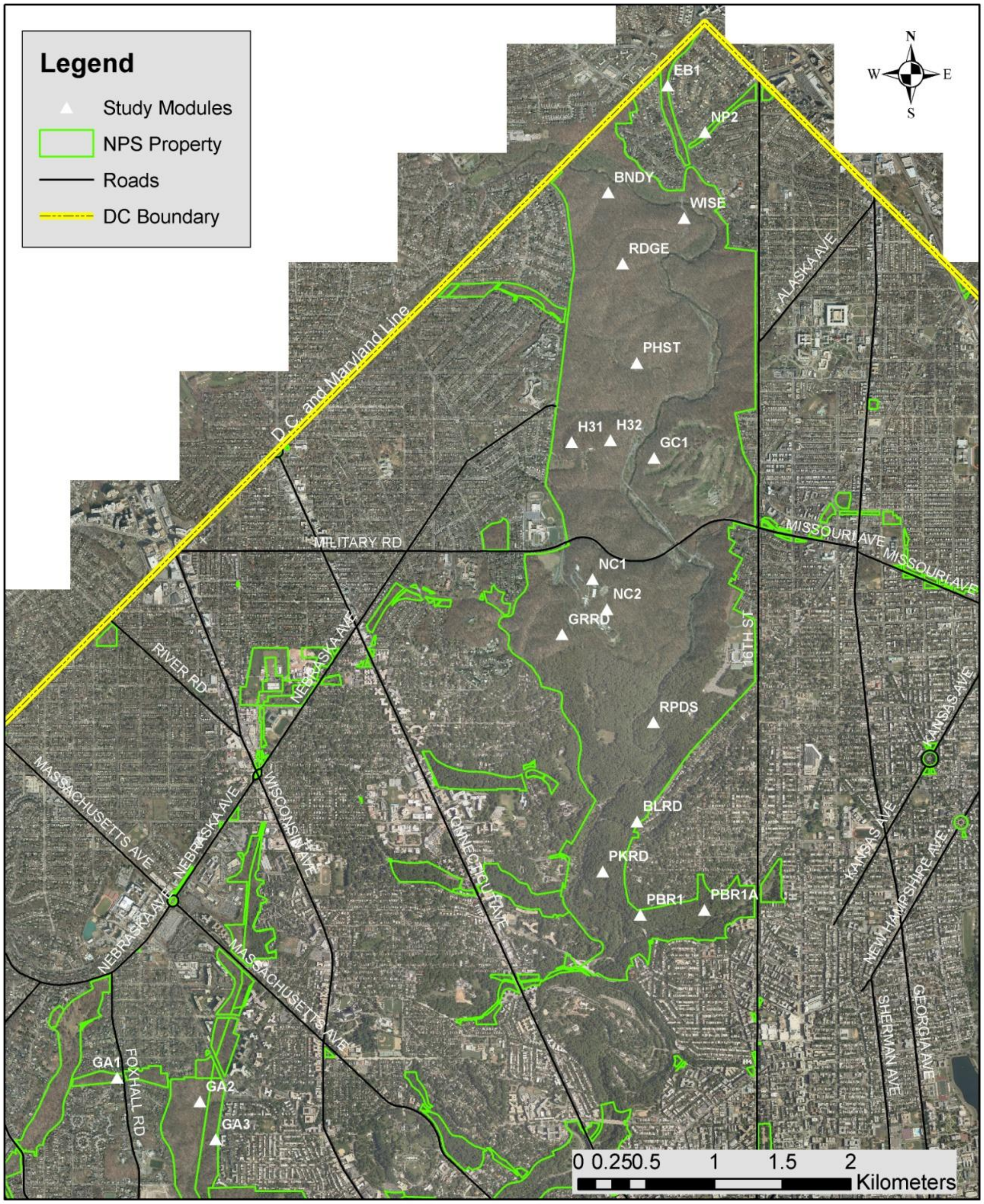


Figure 1. Location of the herbivory study modules in Rock Creek Park. Four study modules (EB1, NP2, PBR1, and PBR1A) abandoned between 2001 and 2004 were not included in this analysis.

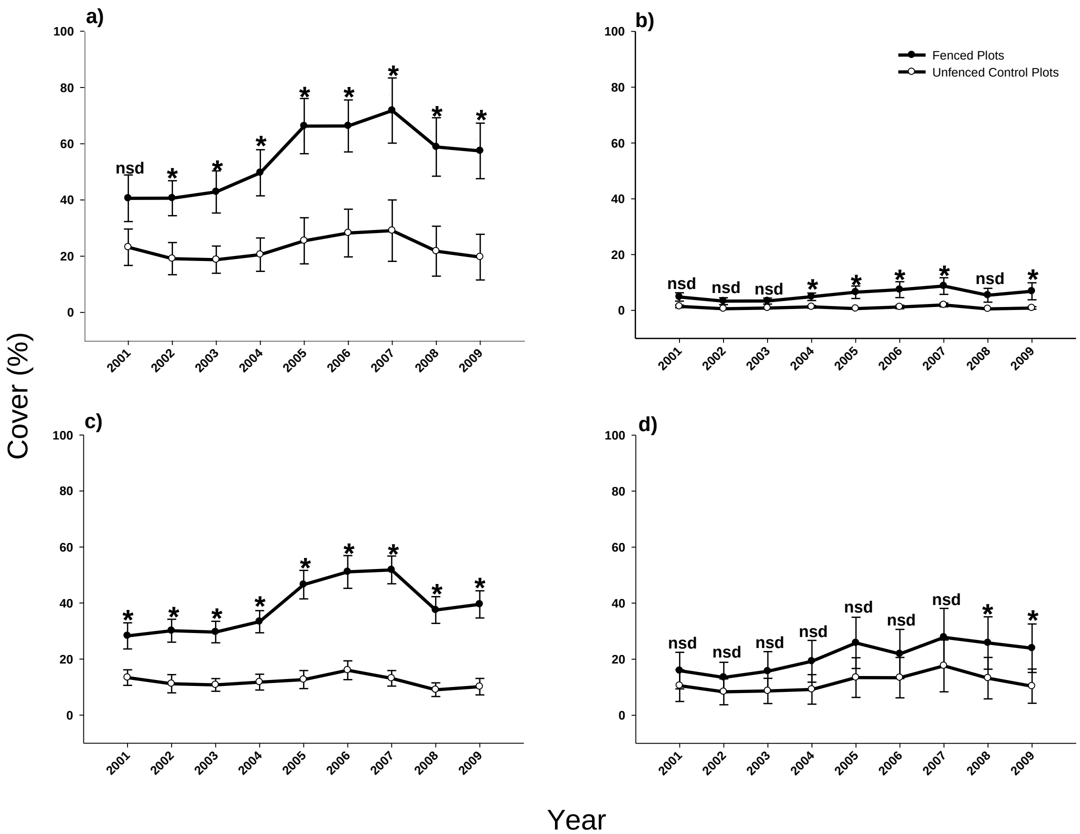


Figure 2. Cover by a) woody species, b) herbaceous species, c) native species, d) non-native species, e) trees, f) shrubs, g) woody vines, h) *F. grandifolia*, i) *V. acerifolium*, j) *L. benzoin*, and k) *H. helix* in the herbivory study plots at Rock Creek Park. Data points represent arithmetic means ± 1 SE. An * indicates significant difference between fenced plots and unfenced control plots within that year. No significant difference within a year is denoted by nsd. See the text for more details on the analysis.

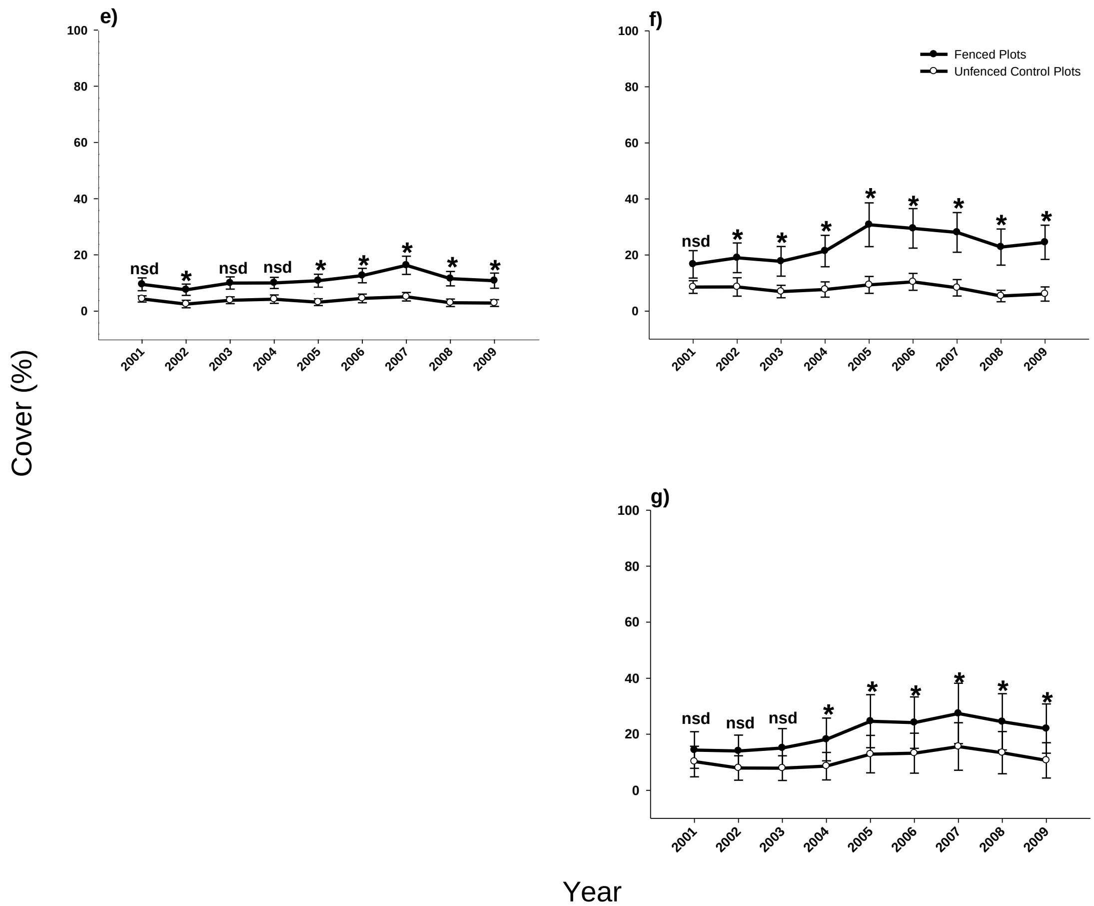


Figure 2 (continued). Cover by a) woody species, b) herbaceous species, c) native species, d) non-native species, e) trees, f) shrubs, g) woody vines, h) *F. grandifolia*, i) *V. acerifolium*, j) *L. benzoin*, and k) *H. helix* in the herbivory study plots at Rock Creek Park. Data points represent arithmetic means ± 1 SE. An * indicates significant difference between fenced plots and unfenced control plots within that year. No significant difference within a year is denoted by nsd. See the text for more details on the analysis.

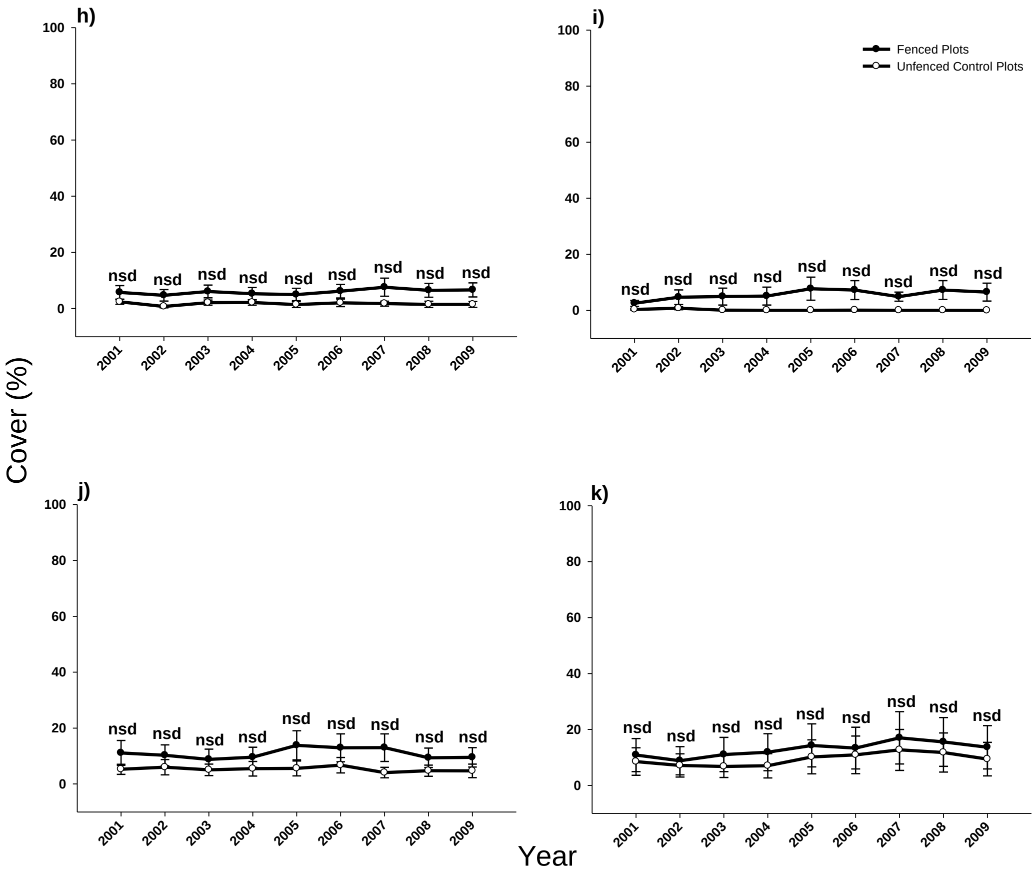


Figure 2 (continued). Cover by a) woody species, b) herbaceous species, c) native species, d) non-native species, e) trees, f) shrubs, g) woody vines, h) *F. grandifolia*, i) *V. acerifolium*, j) *L. benzoin*, and k) *H. helix* in the herbivory study plots at Rock Creek Park. Data points represent arithmetic means ± 1 SE. An * indicates significant difference between fenced plots and unfenced control plots within that year. No significant difference within a year is denoted by nsd. See the text for more details on the analysis.

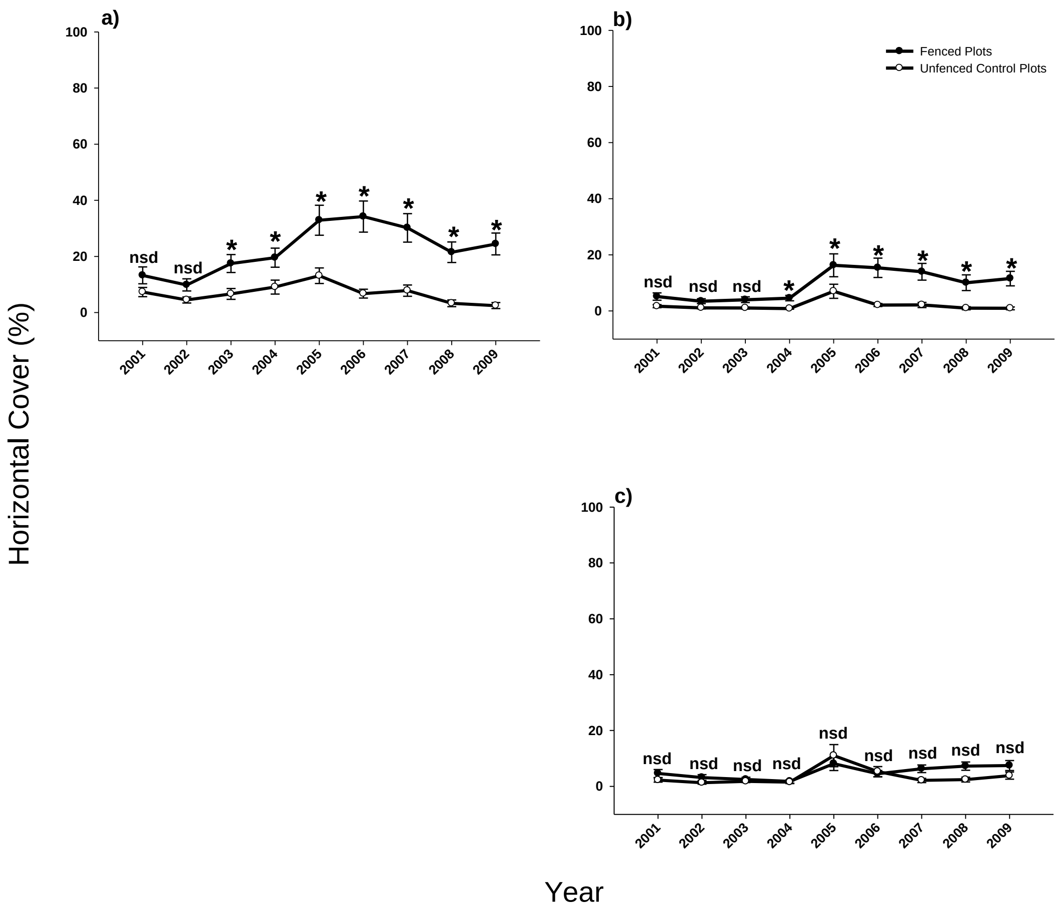


Figure 3. Vegetation thickness (cover projected horizontally) in a) Low (0-30 cm), b) Middle (30-110 cm), and c) High (110-190 cm) height classes in the herbivory study plots at Rock Creek Park. Data points represent arithmetic means ± 1 SE. An * indicates significant difference between fenced plots and unfenced control plots within that year. No significant difference within a year is denoted by nsd. See the text for more details on the analysis.

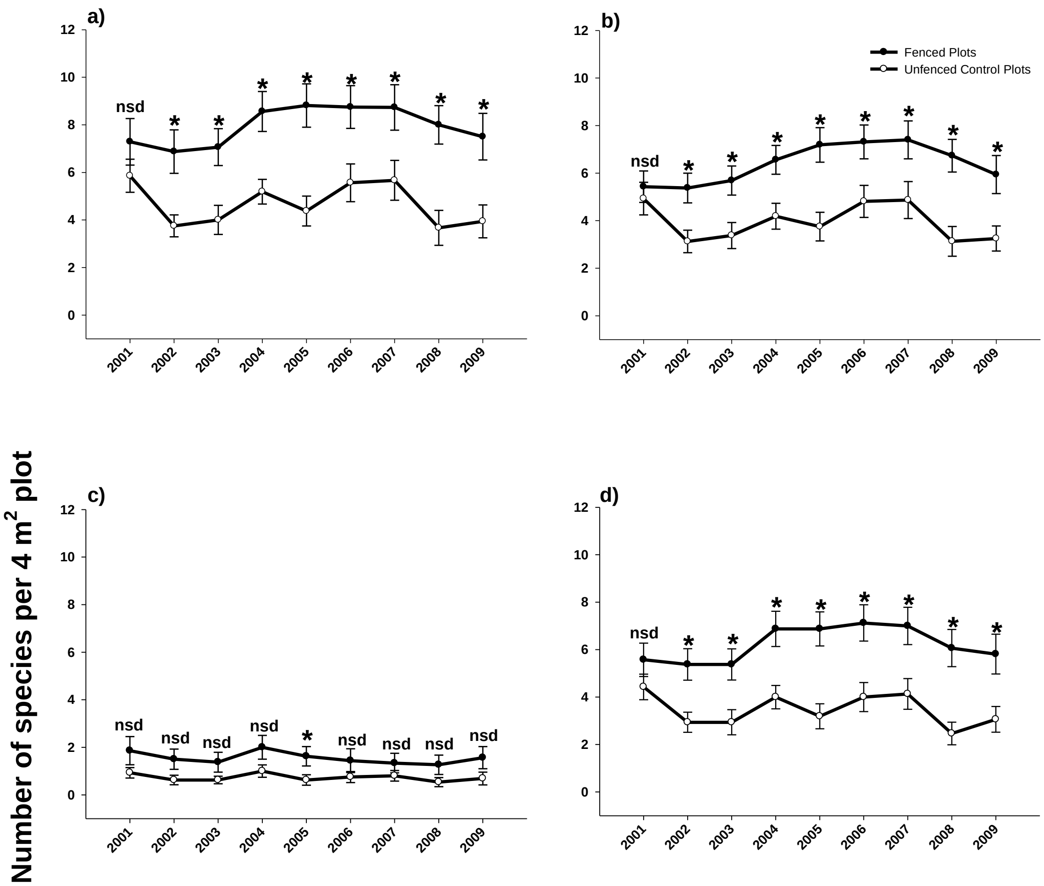
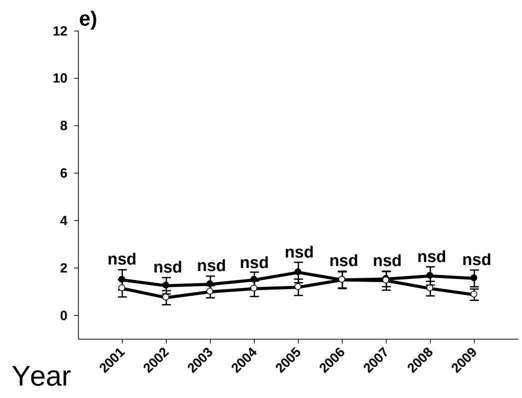


Figure 4. Species richness for a) all species combined, b) woody species, c) herbaceous species, d) native species, e) non-native species, f) trees, g) shrubs, and h) woody vines in the herbivory study plots at Rock Creek Park. Data points represent arithmetic means ± 1 SE. An * indicates significant difference between fenced plots and unfenced control plots within that year. No significant difference within a year is denoted by nsd. See the text for more details on the analysis.



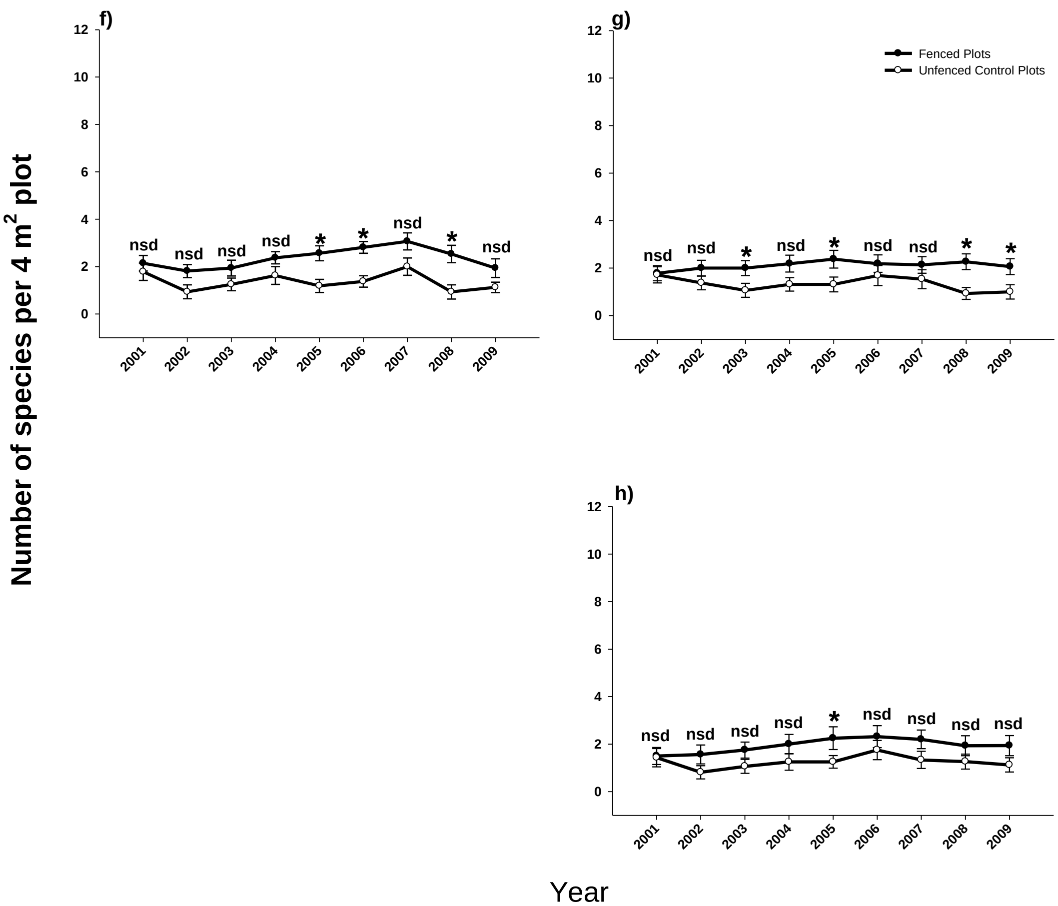


Figure 4 (continued). Species richness a) overall, b) for woody species, c) herbaceous species, d) native species, e) non-native species, f) trees, g) shrubs, and h) woody vines in the herbivory study plots at Rock Creek Park. Data points represent arithmetic means ± 1 SE. An * indicates significant difference between fenced plots and unfenced control plots within that year. No significant difference within a year 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					
	Year[1]		Height Class[2]		Year x Height Class	
Variable[3]	*F*	*P*	*F*	*P*	*F*	*P*
Difference (Fenced-Unfenced Control) in Log Woody Cover (%)	3.36	0.0048				
Difference (Fenced-Unfenced Control) in Log Herbaceous Cover (%)	0.67	0.7151				
Difference (Fenced-Unfenced Control) in Log Native Cover (%)	2.07	0.0662				
Difference (Fenced-Unfenced Control) in Log Non-Native Cover (%)	1.91	0.0935				
Difference (Fenced-Unfenced Control) in Log Tree Cover (%)	0.86	0.5496				
Difference (Fenced-Unfenced Control) in Log Shrub Cover (%)	2.73	0.0339				
Difference (Fenced-Unfenced Control) in Log Vine Cover (%)	0.90	0.5259				
Difference (Fenced-Unfenced Control) in Log *Fagus grandifolia* Cover (%)	2.20	0.0499				
Difference (Fenced-Unfenced Control) in Log *Lindera benzoin* Cover (%)	2.06	0.0606				
Difference (Fenced-Unfenced Control) in Log *Viburnum acerifolium* Cover (%)	6.21	0.0033				
Difference (Fenced-Unfenced Control) in Log *Hedera helix* Cover (%)	0.27	0.9754				
Difference (Fenced-Unfenced Control) in Log Vegetation Thickness (%)	3.91	0.0010	6.44	0.0048	2.37	0.0061
Difference (Fenced-Unfenced Control) in Overall Species Richness	2.71	0.0174				
Difference (Fenced-Unfenced Control) in Woody Species Richness	3.65	0.0025				
Difference (Fenced-Unfenced Control) in Herbaceous Species Richness	0.60	0.7717				
Difference (Fenced-Unfenced Control) in Native Species Richness	2.55	0.0136				
Difference (Fenced-Unfenced Control) in Non-Native Species Richness	1.13	0.3473				
Difference (Fenced-Unfenced Control) in Tree Species Richness	1.89	0.0677				
Difference (Fenced-Unfenced Control) in Shrub Species Richness	2.78	0.0075				
Difference (Fenced-Unfenced Control) in Vine Species Richness	0.93	0.4936				

[1]Nine years (2001 - 2009).

[2]Three height classes for vegetation thickness (Low: 0-30 cm, Middle: 30-110 cm, High: 110-190 cm).

[3]The transformation natural log (Fenced+1) - natural log (Unfenced Control+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 estimates received a natural log transformation to improve normality. Back-transformed estimates are presented for variables that were log transformed for analysis, resulting in a ratio of (fenced+1)/(unfenced control+1).

Variable	*2001*	*2002*	*2003*	*2004*	*2005*
Plant Cover (%)					
Woody [1]	2.06^{b} (1.27)	3.18^{ab} (1.27)	3.00^{ab} (1.27)	3.13^{ab} (1.27)	4.24^{a} (1.27)
Herbaceous [1]	1.79^{a} (1.29)	1.81^{a} (1.28)	1.68^{a} (1.28)	2.10^{a} (1.28)	2.66^{a} (1.28)
Native [1]	2.28^{b} (1.30)	3.59^{ab} (1.28)	3.32^{ab} (1.28)	3.54^{ab}(1.28)	4.88^{a} (1.28)
Non-Native [1]	1.57^{ab} (1.31)	1.75^{ab} (1.31)	1.48^{b}(1.31)	2.18^{ab} (1.31)	2.07^{ab} (1.31)
Tree [1]	1.74^{a} (1.39)	2.71^{a} (1.38)	2.26^{a} (1.38)	2.47^{a} (1.38)	2.85^{a} (1.38)
Shrub [1]	1.66^{b} (1.28)	2.17^{ab} (1.26)	2.55^{ab} (1.26)	3.04^{ab} (1.26)	3.77^{a} (1.26)
Woody Vine [1]	1.62^{a} (1.23)	1.77^{a} (1.22)	1.80^{a} (1.23)	2.09^{a} (1.23)	2.00^{a} (1.23)
Fagus grandifolia [1]	1.23^{a}(1.41)	2.00^{a}(1.40)	1.48^{a}(1.40)	1.36^{a} (1.40)	1.71^{a}(1.40)
Lindera benzoin [1]	1.15^{a} (1.28)	1.31^{a}(1.28)	1.38^{a} (1.28)	1.53^{a} (1.28)	1.76^{a} (1.28)
Viburnum acerifolium [1]	1.10^{abc} (1.19)	0.77^{d} (1.21)	0.91^{cd}(1.24)	0.82^{cd}(1.25)	1.18^{bcd}(1.36)
Hedera helix [1]	1.06^{a} (1.06)	1.04^{a} (1.06)	1.10^{a} (1.06)	1.12^{a} (1.06)	1.11^{a} (1.06)
Vegetation Thickness (%) [1,2]					
Low	1.70^{c} (1.35)	1.77^{c} (1.33)	2.54^{bc} (1.33)	2.34^{bc}(1.33)	3.01^{bc}(1.33)
Middle	2.06^{ab} (1.35)	1.87^{b} (1.33)	2.21^{ab} (1.33)	2.57^{ab}(1.33)	2.45^{ab}(1.33)
High	1.28^{a} (1.35)	1.65^{a} (1.33)	1.09^{a} (1.33)	1.11^{a}(1.33)	1.02^{a} (1.33)

Table 2 (continued). 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).

Variable	*2001*	*2002*	*2003*	*2004*	*2005*
Species Richness					
Overall	1.42^{b} (0.82)	3.07^{ab} (0.80)	2.98^{ab} (0.79)	3.31^{ab} (0.79)	4.38^{a} (0.79)
Woody	0.52^{b} (0.70)	2.24^{ab} (0.68)	2.33^{ab} (0.68)	2.30^{ab} (0.68)	3.39^{a} (0.68)
Herbaceous	0.84^{a} (0.36)	0.86^{a} (0.34)	0.78^{a} (0.34)	0.99^{a} (0.35)	1.01^{a} (0.35)
Native	1.16^{b} (0.67)	2.44^{ab} (0.65)	2.44^{ab} (0.65)	2.88^{ab} (0.65)	3.69^{a} (0.65)
Non-Native	0.44^{a} (0.34)	0.50^{a} (0.33)	0.31^{a} (0.33)	0.38^{a} (0.33)	0.63^{a} (0.33)
Tree	0.31^{a} (0.39)	0.88^{a} (0.37)	0.69^{a} (0.37)	0.75^{a} (0.37)	1.38^{a} (0.37)
Shrub	0.19^{b} (0.32)	0.63^{ab} (0.31)	0.94^{ab} (0.31)	0.88^{ab} (0.31)	1.06^{ab}(0.31)
Woody Vine	0.12^{a} (0.35)	0.75^{a} (0.34)	0.69^{a} (0.34)	0.75^{a} (0.34)	1.00^{a} (0.34)

Table 2 (continued). 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).

Variable	*2006*	*2007*	*2008*	*2009*
Plant Cover (%)				
Woody [1]	4.06[a] (1.27)	4.20[ab] (1.27)	4.82[a] (1.27)	5.45[a] (1.27)
Herbaceous [1]	2.10[a] (1.28)	2.05[a] (1.28)	1.99[a] (1.28)	2.17[a] (1.28)
Native [1]	4.09[ab] (1.28)	4.61[ab] (1.29)	4.93[ab] (1.29)	5.53[ab] (1.28)
Non-Native [1]	1.79[ab] (1.31)	2.09[ab] (1.31)	2.51[ab] (1.31)	2.67[a] (1.31)
Tree [1]	2.74[a] (1.38)	2.74[a] (1.38)	3.34[a] (1.38)	2.84[a] (1.38)
Shrub [1]	3.02[ab] (1.26)	3.94[a] (1.26)	4.11[a] (1.26)	4.54[a] (1.27)
Woody Vine [1]	2.22[a] (1.23)	2.15[a] (1.23)	2.05[a] (1.23)	2.42[a] (1.22)
Fagus grandifolia [1]	1.74[a] (1.40)	1.75[a] (1.41)	1.93[a] (1.41)	2.09[a] (1.40)
Lindera benzoin [1]	1.34[a] (1.28)	1.77[a] (1.28)	1.53[a] (1.28)	1.76[a] (1.27)
Viburnum acerifolium [1]	1.24[abcd] (1.34)	1.31[abcd] (1.38)	1.86[a] (1.33)	1.74[ab] (1.32)
Hedera helix [1]	1.08[a] (1.06)	1.07[a] (1.06)	1.11[a] (1.06)	1.09[a] (1.06)
Vegetation Thickness (%) [1,2]				
Low	5.78[ab] (1.33)	5.22[abc] (1.34)	6.32[ab] (1.34)	8.96[a] (1.34)
Middle	4.70[ab] (1.33)	5.30[ab] (1.34)	4.40[ab] (1.34)	5.73[a] (1.34)
High	1.12[a] (1.33)	2.04[a] (1.34)	2.14[a] (1.34)	1.81[a] (1.34)

Table 2 (continued). 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).

Variable	*2006*	*2007*	*2008*	*2009*
Species Richness				
Overall	3.17^{ab} (0.79)	3.02^{ab} (0.80)	4.08^{ab} (0.81)	3.57^{ab} (0.80)
Woody	2.48^{ab} (0.68)	2.53^{ab} (0.69)	3.36^{a} (0.69)	2.80^{ab} (0.68)
Herbaceous	0.69^{a} (0.35)	0.48^{a} (0.35)	0.72^{a} (0.35)	0.86^{a} (0.34)
Native	3.13^{ab} (0.65)	2.74^{ab} (0.66)	3.32^{a} (0.66)	2.75^{ab} (0.65)
Non-Native	0.00^{a} (0.33)	0.12^{a} (0.34)	0.51^{a} (0.34)	0.69^{a} (0.33)
Tree	1.44^{a} (0.37)	1.06^{a} (0.38)	1.44^{a} (0.38)	0.81^{a} (0.37)
Shrub	0.50^{ab} (0.31)	0.65^{ab} (0.31)	1.24^{a} (0.31)	1.06^{ab} (0.31)
Woody Vine	0.56^{a} (0.34)	0.81^{a} (0.34)	0.66^{a} (0.34)	0.81^{a} (0.34)

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

Appendix. Species list from Rock Creek Park herbivory study plots, 2001-2009. List consists of 79 species and 5 genera not otherwise represented by species.

Scientific Name[1]	***Common Name***[1]	***Origin***[2]	***Form***[2]
Acer negundo L.	boxelder	native	tree
Acer palmatum Thun.	Japanese maple	non-native	tree
Acer platanoides L.	Norway maple	non-native	tree
Acer rubrum L.	red maple	native	tree
Acer saccharum Marsh.	sugar maple	native	tree
Actaea racemosa L. var. *racemosa*[3]	black bugbane	native	herbaceous
Alliaria petiolata (M. Bieb.) Cavara & Grande	garlic mustard	non-native	herbaceous
Amphicarpaea bracteata L. (Fernald)	American hogpeanut	native	herbaceous
Ampelopsis brevipedunculata (Maxim.) Trautv.	Amur peppervine	non-native	woody vine
Arisaema triphyllum (L.) Schott	Jack in the pulpit	native	herbaceous
Asimina triloba (L.) Dunal	pawpaw	native	tree
Aster L. spp.	aster	unknown	herbaceous
Carya alba (L.) Nutt.[4]	mockernut hickory	native	tree
Carya cordiformis (Wangenh.) K. Koch	bitternut hickory	native	tree
Carya glabra (Mill.) Sweet	pignut hickory	native	tree
Carex virescens Muhl. Ex Willd.	ribbed sedge	native	herbaceous
Celastrus orbiculatus Thunb.	Oriental bittersweet	non-native	woody vine
Circaea lutetiana L. ssp. *canadensis* (L.) Asch. & Magnus[5]	broadleaf enchanter's nightshade	native	herbaceous
Cornus florida L.	flowering dogwood	native	tree
Carpinus caroliniana Walter	American hornbeam	native	tree
Desmodium glabellum (Michx.) DC.	Dillenius' ticktrefoil	native	herbaceous
Desmodium nudiflorum (L.) DC.	nakedflower ticktrefoil	native	herbaceous
Dioscorea quaternata J.F.Gmel.	fourleaf yam	native	herbaceous
Dioscorea villosa L.	wild yam	native	herbaceous

Appendix (continued). Species list from Rock Creek Park herbivory study plots, 2001-2009. List consists of 79 species and 5 genera not otherwise represented by species.

Scientific Name[1]	***Common Name***[1]	***Origin***[2]	***Form***[2]
Duchesnea indica (Andrews) Focke	Indian strawberry	non-native	herbaceous
Euonymus alatus (Thunb.) Siebold	burningbush	non-native	shrub
Euonymus americanus L.	bursting-heart	native	shrub
Euonymus fortunei (Turcz.) Hand.-Maz.	winter creeper	non-native	woody vine
Eurybia divaricata (L.) G.L.Nesom	white wood aster	native	herbaceous
Fagus grandifolia Ehrh.	American beech	native	tree
Fraxinus americana L.	white ash	native	tree
Fraxinus pennsylvanica Marsh.	green ash	native	tree
Galium triflorum Michx.	fragrant bedstraw	native	herbaceous
Gaylussacia baccata (Michx.) K. Koch	black huckleberry	native	shrub
Geum canadense Jacq.	white avens	native	herbaceous
Glechoma hederacea L.	ground ivy	non-native	herbaceous
Hamamelis virginiana L.	American witchhazel	native	tree
Hedera helix L.	English ivy	non-native	woody vine
Humulus japonicus Siebold & Zucc.	Japanese hop	non-native	herbaceous
Huperzia lucidula (Michx.) Trevis[7]	shining clubmoss	native	herbaceous
Ilex opaca Aiton	American holly	native	tree
Impatiens L. spp.	touch-me-knot	native	herbaceous
Kalmia latifolia L.	mountain laurel	native	shrub
Lindera benzoin (L.) Blume	northern spicebush	native	shrub
Liriodendron tulipifera L.	tuliptree	native	tree
Lonicera fragrantissima Lindl. & Paxton	sweet breath of spring	non-native	shrub
Lonicera japonica Thunb.	Japanese honeysuckle	non-native	woody vine
Luzula echinata (Small) F.J.Herm.	hedgehog woodrush	native	herbaceous

Appendix (continued). Species list from Rock Creek Park herbivory study plots, 2001-2009. List consists of 79 species and 5 genera not otherwise represented by species.

***Scientific Name*[1]**	***Common Name*[1]**	***Origin*[2]**	***Form*[2]**
Maianthemum racemosum L. Link ssp. r*acemosum*[8]	feathery false lily of the valley	native	herbaceous
Maianthemum stellatum (L.) Link[9]	starry false lily of the valley	native	herbaceous
Malus Mill. spp.	apple	unknown	tree
Medeola virginiana L.	Indian cucumber	native	herbaceous
Mitchella repens L.	partridgeberry	native	herbaceous
Nyssa sylvatica Marsh.	blackgum	native	tree
Osmorhiza longistylis (Torr.) DC.	longstyle sweetroot	native	herbaceous
Parthenocissus quinquefolia (L.) Planch.	Virginia creeper	native	woody vine
Podophyllum peltatum L.	mayapple	native	herbaceous
Polystichum acrostichoides (Michx.) Schott	Christmas fern	native	herbaceous
Polygonatum biflorum (Walter) Elliot	smooth Solomon's seal	native	herbaceous
Polygonum perfoliatum L.	Asiatic tearthumb	non-native	herbaceous
Prunus serotina Ehrh.	black cherry	native	tree
Quercus alba L.	white oak	native	tree
Quercus prinus L.	chestnut oak	native	tree
Quercus rubra L.	northern red oak	native	tree
Quercus velutina Lam.	black oak	native	tree
Rhododendron periclymenoides (Michx.) Shinners	pink azalea	native	shrub
Rubus allegheniensis Porter	Allegheny blackberry	native	shrub
Rubus flagellaris Willd.	northern dewberry	native	shrub
Rubus phoenicolasius Maxim.	wine raspberry	non-native	shrub
Sanguinaria canadensis L.	bloodroot	native	herbaceous
Sanicula canadensis L.	Canadian blacksnakeroot	native	herbaceous
Sassafras albidum (Nutt.) Nees	sassafras	native	tree

Appendix (continued). Species list from Rock Creek Park herbivory study plots, 2001-2009. List consists of 79 species and 5 genera not otherwise represented by species.

Scientific Name[1]	***Common Name***[1]	***Origin***[2]	***Form***[2]
Smilax glauca Walter	cat greenbrier	native	woody vine
Smilax rotundifolia L.	roundleaf greenbrier	native	woody vine
Stellaria pubera Michx.	star chickweed	native	herbaceous
Toxicodendron radicans (L.) Kuntze	eastern poison ivy	native	woody vine
Ulmus americana L.	American elm	native	tree
Uvularia L. spp.	bellwort	native	herbaceous
Vaccinium pallidum Aiton	Blue Ridge blueberry	native	shrub
Viburnum acerifolium L.	mapleleaf viburnum	native	shrub
Viburnum dentatum L.	southern arrowwood	native	shrub
Viburnum dilatatum Thunb.	linden arrowwood	non-native	shrub
Viola L. spp.	violet	unknown	herbaceous
Vitis aestivalis Michx.	summer grape	native	woody vine

[1] Nomenclature follows the US Department of Agriculture PLANTS database (USDA, NRCS 2011).

[2] Species classifications regarding origin and life form are based on classifications in the PLANTS database.

[3] *Cimicifuga racemosa* (L.) Nutt. synonym.

[4] *Carya tomentosa* (Lam.) Nutt. synonym.

[5] *Circaea quadrisulcata* (Maxim.) Franch. & Savigny var. c*anadensis* (L.) H. Hara synonym.

[6] *Aster divaricatus* L. synonym.

[7] *Lycopodium lucidulum* Michx. synonym.

[8] *Smilacina racemosa* (L.) Desf. synonym.

[9] *Smilacina stellata* (L.) Desf. synonym.

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