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Analysis of Vegetation Changes in Rock Creek Park, 1991-2007

Natural Resource Technical Report NPS/NCR/NCRO/NRTR—2009/001

ON THE COVER
Staff from National Park Service and U.S. Geological Survey prepare to monitor vegetation plots in Rock Creek Park, Washington, D.C.
Photographed by: Jeff S. Hatfield

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Authors: Jeff S. Hatfield, Cairn C. Krafft
USGS Patuxent Wildlife Research Center, Laurel, Maryland 20708

Corresponding Authors:

Jeff S. Hatfield Email: jhatfield@usgs.gov
Phone: 301-497-5633 Fax: 301-497-5545

And

Cairn C. Krafft Email: ckrafft@usgs.gov
Phone: 301-497-5546 Fax: 301-497-5624

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Abstract

Vegetation data collected at Rock Creek Park every 4 years during 1991-2007 were analyzed for differences among 3 regions within the park and among years. The variables measured and analyzed were percentage of twigs browsed, percentage of canopy cover, species richness of herbaceous plants, number of tree seedlings in each of 7 height classes, tree seedling stocking rate for low deer density and high deer density areas, percentage of tree and shrub cover < 2 m in height, mean diameter at breast height (DBH) of trees $\geq$ 1 cm DBH, number of tree stems $\geq$ 1 cm DBH, species richness of trees and shrubs, and mean height of the 5 tallest trees in each plot quadrant. Repeated measures analysis of variance (ANOVA) was used to test for differences and, except for some differences in tree species composition among the 3 regions, no differences ($P > 0.01$) were found among the 3 regions in the variables discussed above. Many of the variables showed very significant differences ($P < 0.01$) among years, and causative factors should be investigated further. In addition, importance values were calculated for the 10 most important tree species in each region and changes over time were reported. Future sampling recommendations are also discussed.

Keywords

Browse, Forest, *Odocoileus virginianus*, Rock Creek Park, Vegetation, White-tailed deer.

Introduction

Rock Creek Park is a 702 ha natural area that lies within the boundaries of Washington, D.C. (Ferebee 2003). Long-term vegetation plots were established by the National Park Service (NPS) in 1991, as part of a region-wide effort to develop a vegetation monitoring plan. One of the goals of the monitoring was to determine the effect of white-tailed deer (*Odocoileus virginianus*) populations on the native vegetation, since white-tailed deer are known to have a major impact on other native plant communities (Russell et al. 2001, Horsley et al. 2003). While deer populations were beginning to grow rapidly in some regional parks (Rob Gibbs, Maryland National Capital Park and Planning Commission, personal communication, 1991), deer were just beginning to return to Rock Creek Park by 1991. Thus, the vegetation in Rock Creek Park was relatively undisturbed at the beginning of this study. Furthermore, it was thought that the data from Rock Creek Park could serve as baseline data for other regional parks that had similar vegetation communities. The plot protocol was designed by John Hadidian (personal communication, 1990) following Storm and Ross (1992).

Methods

The park was divided into 3 regions geographically (North, Central, and South) to insure that all areas of the park would be adequately sampled. Ten plots were randomly located within each region, but three of them were discarded and not replaced; a fourth was abandoned after the first year because it was obliterated by fallen trees. Therefore, there are data for n = 26 permanent plots. Data were gathered every 4 years (1991, 1995, 1999, 2003, and 2007), although not all variables were measured in each plot during each sampling event (e.g., 7 plots were not sampled completely during 1999 due to personnel constraints).

The plots are 20 m by 20 m square. Within the plot, smaller subplots were established to measure vegetation of different sizes: 10 m square quadrants for trees and overall canopy cover, 10 m linear transects for tree and shrub cover, 1 m square subplots for herbaceous vegetation and tree seedlings, and 1.7 m radius circular subplots to detect deer browsing.

Data Collection and Summary

***Photographic Documentation*:** Three photographs were taken each year – one of the plot center, one from a plot corner, and one from outside that plot to show the entire plot as well as possible. These photographs are not analyzed in this report because they are qualitative in nature.

***Canopy Cover*:** The density of the canopy was measured using a concave spherical densiometer (Model C, Robert E. Lemmon, Forest Densiometers). The densiometer was mounted on a tripod at the center of each quadrant, measurements were taken standing at the center of each quadrant, and four estimates were taken at each point. The Percentage of Cover (measured with the densiometer) within each of the four tree quadrants per plot was averaged.

***Trees*:** The plot was divided into four 10-m square quadrants. All trees $\geq$ 1 cm diameter at breast height (DBH, 1.4 m from the ground) were identified to species, and the DBH was measured. The 5 tallest trees in each quadrant were marked for further measurement: Height was estimated with a clinometer (1991-2007) or laser rangefinder (2007); vigor was recorded as Healthy, Injured, or Dead; injuries were further identified as Broken or Dead Top, Broken Limbs, Disease, Insect Damage, Missing Bark (from buck rubs), Exotic Vines, and Other.

The following data were recorded and DBH and Height were averaged across the four tree quadrants within each plot:

- Species: 6-letter code, comprised of the first 3 letters of the genus and first three letters of the species epithet.
- Diameter at Breast Height (DBH, 1.4m) for all stems $\geq$ 1 cm DBH.
- Height (5 tallest trees only).
- Vigor: Live = 1, Dead = 2, Injured = 3.
- Injury: [numeric codes for the eight/nine types].
- Summarized as mean DBH, Number of Stems, Height, and Species Richness per tree quadrant.

***Woody Cover < 2 m in Height*:** Two 10 m line transects were randomly located within each plot each year sampled. All woody plants < 2 meters in height that intercepted the line transect were identified and the number of centimeters over which they intercepted the transect was recorded.

The following data were recorded and averaged across the two 10 m transects per plot:

- Species (6-letter code, as with trees).
- Cover (distance along transect covered by each species).
- Summarized as mean Percentage Cover and Species Richness per transect.

***Herbaceous Plants and Tree Seedlings*:** During 1991-1995, four 1-m square contiguous subplots (2x2 m) were established at the quadrant centers, and four were established in the middle of the plot (*n* = 20 subplots per plot). During 1999-2003 (and 2007 following recommendations from Hatfield, 2005) only 1 subplot was measured per quadrant (*n* = 4 subplots per plot). During 1991-2003 the height of all vegetation identified was categorized into one of eight Height Classes as defined by Hadidian (Height Class 1: 0-10 cm; 2: 10-25 cm; 3: 25-50 cm; 4: 50-75 cm; 5: 75-100 cm; 6: 100-125 cm; 7: 125-150 cm; and Height Class 8: > 150 cm). The Height Class, Number of Individuals (within each height class), and Percent Cover (within each height class) was measured for each woody and herbaceous species identified. Although in 2007, only Percent Cover (not by height class) was measured for herbaceous plants following discussions with NPS staff. Percent Cover in 2007 was determined by ocular estimation using a 1-m square quadrat frame subdivided into 100 cells. Also, in 2007, the actual heights of each tree seedling were measured, although for analysis (see below), we categorized these data for comparison to previous years. Finally, the percentage of ground covered by rock/soil, litter, or moss/lichen was also estimated, although we have not analyzed these data here.

For herbaceous species, the following data were recorded and averaged across the four 1 m x 1 m subplots per plot:

- Species (as above).
- Summarized as mean Species Richness per subplot.

For tree seedlings, the following data were recorded and averaged across the 1 m x 1 m subplots in each plot (20 per plot in 1991 and 1995, 4 per plot in 1999 through 2007):

- Species (as above).
- Height Class (8 classes as defined above).
- Summarized as mean Number of Individuals and Species Richness per subplot.

***Browsing*:** Two 1.7 m radius circular subplots were established at randomly selected direction and distance from the plot center each year sampled. The number of browsed twigs and the number of unbrowsed twigs of each woody species were counted and recorded. Twigs were defined as growth from the most recent year that is $\geq$ 2.5 cm when unbrowsed.

The following data were recorded and averaged across the two 1.7 m radius circular subplots per plot:

- Species (as above).
- Number of twigs browsed.
- Number of twigs unbrowsed.
- Summarized as mean Percentage of Twigs Browsed per subplot.

Data Analysis

Repeated measures analysis of variance (ANOVA), implemented with the mixed models procedure within SAS (2003), was used to test for differences among Regions, Years, and their interaction for each variable (Littell et al. 1996). The variables analyzed were determined in conjunction with NPS staff. The subject factor for each ANOVA was plot nested within region. Four variance-covariance structures were modeled (compound symmetry, autoregressive, Toeplitz, and unstructured) and the best model was selected via AIC_c comparisons (Littell et al. 1996). Residuals were tested for normality (Kery and Hatfield 2003) and, for many variables, a natural log transformation was used to help achieve normality. The variables analyzed with repeated measures ANOVA are shown in Table 1.

For the Tree Seedling Counts and Species Richness, Height Class was also included in the model, along with the various interactions. A separate variance was fit for each seedling Height Class using the group option in SAS due to a pattern of different variances among Height Classes. Least square means and Tukey's multiple comparison procedure were used to sort out significant differences ($P < 0.05$) among years for all variables.

To calculate tree seedling Stocking Rates, we followed the recommendations of Stout (1998) except for one modification as discussed below. We performed this analysis both for Stout's low deer density recommendation (10 weighted tree seedlings per 3.14 m^2 plot) and her high deer density recommendation (30 weighted tree seedlings per 3.14 m^2 plot).

In the tree seedling Stocking Rate calculations, the number of tree seedlings is weighted by Height Class, and Stout recommends a weighting of 1 for seedling heights < 30 cm, 2 for heights 30-100 cm, 15 for heights 100-150 cm, and 30 for heights > 150 cm . However, Height Classes in our data set were given in 25 cm intervals, so we chose to use a weighting of 2 for heights 25-100 cm. Otherwise, the weights are identical to that recommended by Stout (1998). This modification to the seedling height weights may lead to slightly higher stocking rate estimates for Rock Creek Park, but the bias is probably small and this modification is conservative, given the low stocking rates found in Rock Creek Park (see results below). Since actual seedling heights were measured in 2007, future calculations of stocking rate could be done without this modification.

We also ran all ANOVAs separately for native vs. exotic species, but we do not report these results below because the data from exotic species were too sparse for ANOVA analyses, and the ANOVA results for the native species data were qualitatively similar to the results for natives and exotics combined. Hence, we only report results for natives and exotics combined.

We also calculated Importance Values (Storm and Ross 1992) for the 10 most important tree species in each of the 3 regions of Rock Creek Park as of 1991, and then graphed the Importance Values for each region for each of the 4 years. Importance Values are calculated by taking the sum of the relative dominance, relative frequency, and relative density of each tree species over the plots in each region, and as such, they represent a summary measure indicative of the "importance" of each species in the tree community in each region. Increases or decreases in the Importance Value of a species imply that the tree community is changing over time.

Results and Discussion

Importance Values for the 10 most important tree species in Rock Creek Park (as of 1991) are graphed in Figure 1 for the 3 regions (North, Central, and South) and 5 years (1991, 1995, 1999, 2003, and 2007) from the data collected at Rock Creek Park. The Appendix shows the best ANOVA model selected for each variable analyzed using the repeated measures analysis and whether a natural log transformation was used. The results of the ANOVAs for each model selected are reported in Table 1, and the least square means, standard errors (SEs), and Tukey comparisons among years are reported in Table 2. Means and SEs of log-transferred variables were back-transformed before reporting in Table 2.

There were significant yearly differences in the Percentage of Twigs Browsed, with much higher proportions of twigs browsed in 1999 and 2003. There were also significant yearly differences in Percentage of Canopy Cover, with 1995 being higher (probably due to sampling in a different month that year).

Most of the variables shown in Table 1 have very significant differences among years ($P < 0.01$) and most of these variables show consistent declines (or increases as in the case of Mean Tree DBH) over the period 1991-2007.

Concerning the Tree Seedling Counts and Species Richness, the Height Class by Year interaction is the term of interest. In the means comparison for that interaction term, the letter groupings in

Table 2 compare among Years for each Height Class and among Height Class for each Year. Mean Tree Seedling Counts and Species Richness generally declined over time for the various Height Classes except for Height Class 1, the smallest seedlings.

The mean tree seedling Stocking Rates declined significantly from 1991-2007 (Table 2). The annual stocking rates in Rock Creek Park were all below the 67% Stocking Rate recommended by Stout (1998).

The Mean Tree DBH increased significantly during 1991-2007, while the Number of Stems $\geq$ 1 cm DBH and Species Richness declined during this same period. If this is not due to a change in sampling procedures, these results suggest that many smaller stems died or disappeared between 1995 and 1999, along with diameter growth of the remaining trees. The Mean Height of the 5 tallest trees per plot quadrant showed no obvious pattern during 1991-2007, suggesting that this may not be a useful variable to measure in a mature forest.

It is not possible to discern causes from these data for the significant differences found among some of these vegetation variables in Rock Creek Park over the time period 1991-2007. Some of these changes are consistent with what would be expected due to browsing pressure from deer, but other causative factors are also possible. For example, the decline in dogwood (*Cornus florida*) evident in the Importance Values shown in Figure 1 could, and probably is, due to disease, such as dogwood anthracnose (*Discula destructiva*) afflicting this species. Deer exclosure plots (see Rossell et al. 2005) would be the only way to experimentally test for whether deer are the causative factor for some of the changes observed in these data.

Future Sampling Recommendations

Several sampling recommendations come about from these analyses of the Rock Creek Park vegetation data collected for 1991-2007. First, it is useful to note that the 26 plots established in 1991 generated data that were powerful enough to detect changes in many of the vegetation variables over time. Thus, this number of plots is clearly sufficiently powerful to detect such changes at Rock Creek Park.

Changes in sampling intensity or time have occurred since the plots were first established in 1991, and this may have had an adverse effect on the analyses. For example, the Canopy Cover was measured in a different month in 1995, and this may have resulted in a significant difference obtained for that variable that year. In the future, care should be taken to always perform the measurements during the same time period as in previous years, so as to not introduce unnecessary variation in the data. Future sampling of vegetation in Rock Creek Park would benefit from having a detailed protocol describing exactly how sampling is done.

Another problem was that all of the plots were not measured in all years, particularly in 1999, possibly leading to some of the differences seen in that year for the variables analyzed with the ANOVAs (Tables 1-2), and also probably leading to some of the differences observed in that year for the importance values (Figure 1). Future sampling efforts should strive to measure all of

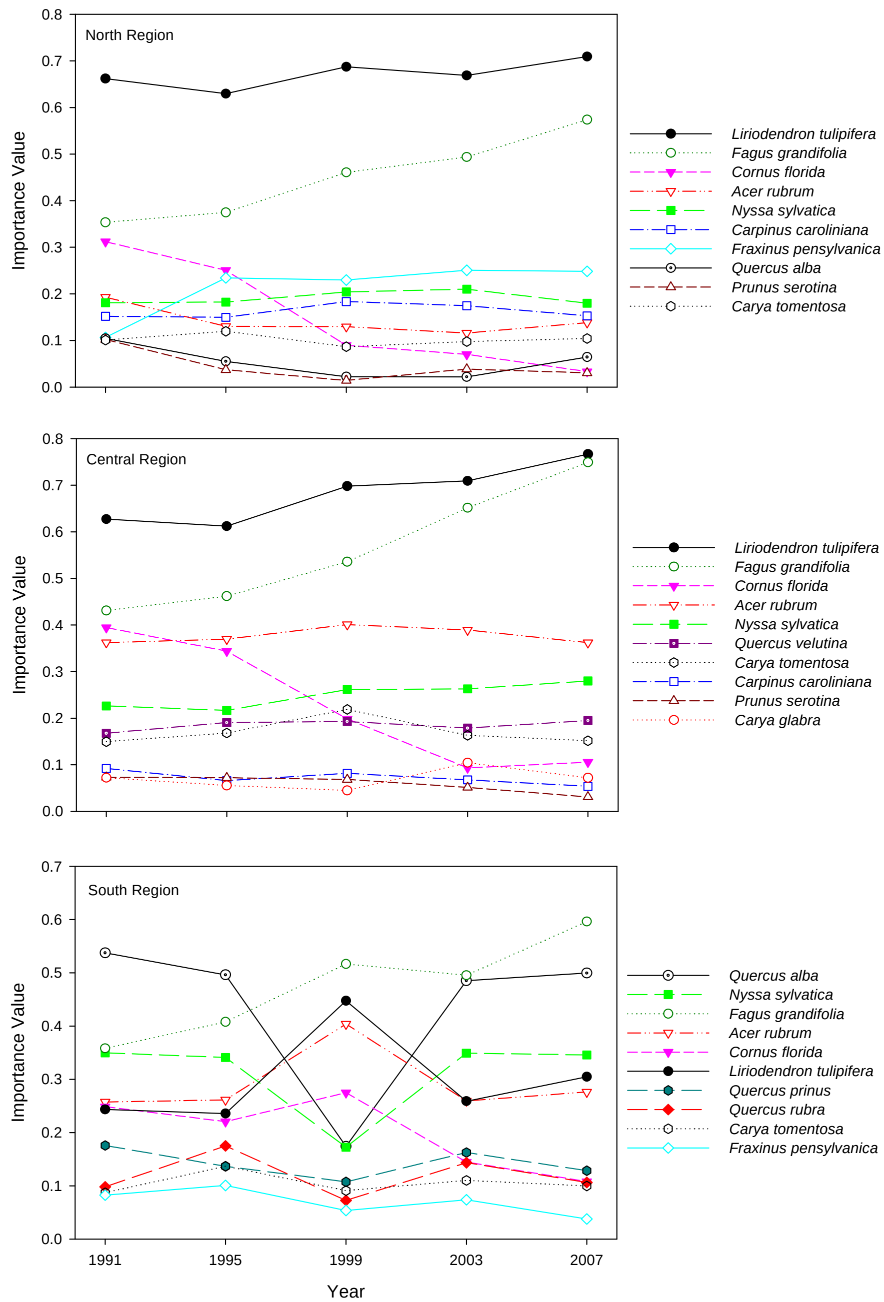

Figure 1. Importance values for the 10 most important tree species in each region of Rock Creek Park, 1991-2007, ordered in the legends from most important to least important species at the beginning of the study (1991). Note that importance values in the south region in 1999 are skewed because 6 plots were not measured that year.

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													
	Region[1]		Year[2]		Region × Year		Height Class[3]		Region × Height Class[3]		Year × Height Class[3]		Region × Year × Height Class[3]	
Variable	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Twigs Browsed (%)	0.90	0.4193	45.07	<0.0001	1.95	0.0627								
Canopy Cover (%)	0.08	0.9221	4.46	0.0026	3.69	0.0010								
Herbaceous Plants- Species Richness	3.79	0.0367	3.43	0.0142	1.24	0.2911								
Tree Seedlings- Species Richness	1.10	0.3382	16.47	<0.0001	2.69	0.0071	22.18	<0.0001	0.65	0.7945	3.38	<0.0001	1.18	0.1961
Tree Seedlings- Counts	1.56	0.2179	13.59	<0.0001	3.34	0.0012	18.25	<0.0001	0.66	0.7849	3.94	<0.0001	1.26	0.1209
Stocking Rate (low deer density)	0.54	0.5857	6.96	<0.0001	2.44	0.0196								
Stocking Rate (high deer density)	0.48	0.6229	8.05	<0.0001	1.25	0.2785								
Woody Cover < 2 m in height- Species Richness														
Trees and shrubs	0.05	0.9485	6.90	<0.0001	0.55	0.8154								
Trees only	0.36	0.7027	19.21	<0.0001	0.44	0.8955								
Shrubs only	0.26	0.7724	3.52	0.0104	0.68	0.7037								
Woody Cover < 2 m in height- Cover (%)														
Trees and shrubs	0.37	0.6938	32.28	<0.0001	0.65	0.7347								
Trees only	0.52	0.6001	24.28	<0.0001	1.31	0.2479								
Shrubs only	0.55	0.5825	9.24	<0.0001	1.31	0.2484								
Trees ≥ 1cm DBH- Species Richness	0.18	0.8335	22.81	<0.0001	0.38	0.9272								

Trees ≥ 1cm DBH- DBH	1.34	0.2817	31.01	<0.0001	1.18	0.3508
Trees ≥ 1cm DBH- Stem Counts	0.78	0.4684	16.21	<0.0001	0.68	0.7080
Trees ≥ 1cm DBH- Heights of 5 tallest trees per plot quadrant	2.49	0.1037	5.66	0.0005	4.50	0.0002

[1]Three regions within Rock Creek Park (North, Central, and South).

[2]Five years of data collection (1991, 1995, 1999, 2003, and 2007).

[3]Tree seedling counts only, 7 Height Classes (Height Class 8 was combined with 7 due to sparseness of data).

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 ($P > 0.05$). Within each column, tree seedling species richness means with the same upper case letter superscript are not significantly different among height classes ($P > 0.05$). Within each column, tree seedling count means with the same upper case letter superscript are not significantly different among height classes ($P > 0.05$). Back-transformed estimates are presented for variables that were log transformed for analysis.

Variable	1991	1995	1999	2003	2007
Twigs Browsed (%) [1]	1.19^{c} (0.18)	1.97^{c} (0.20)	19.02^{ab} (0.18)	27.02^{a} (0.19)	10.82^{b} (0.19)
Canopy Cover (%)	88.06^{b} (0.93)	92.62^{a} (0.83)	89.31^{b} (0.95)	89.40^{b} (0.81)	90.30^{ab} (0.81)
Herbaceous Plants- Species Richness [1]	0.49^{ab} (0.07)	0.62^{a} (0.07)	0.28^{b} (0.08)	0.40^{ab} (0.07)	0.51^{ab} (0.07)
Tree Seedlings- Species Richness [1]					
Height Class 1	0.32^{aAB} (0.06)	0.45^{aA} (0.06)	0.27^{aAB} (0.06)	0.45^{aA} (0.06)	0.56^{aA} (0.06)
Height Class 2	0.59^{aA} (0.06)	0.44^{aA} (0.06)	0.37^{aA} (0.07)	0.29^{aAB}(0.06)	0.29^{aAB} (0.06)
Height Class 3	0.36^{aA} (0.03)	0.23^{abAB} (0.03)	0.12^{bAB}.04)	0.09^{bBC} (0.04)	0.09^{bBC} (0.04)
Height Class 4	0.16^{aB}(0.02)	0.10^{abBC}(0.02)	0.07^{abcAB}0.02)	0.03^{bcBC} (0.02)	0.00^{cC}(0.02)
Height Class 5	0.11^{aBC} (0.01)	0.05^{bC} (0.01)	0.01^{bB} (0.01)	0.00^{bC} (0.01)	0.00^{bC} (0.01)
Height Class 6	0.07^{aC} (0.01)	0.04^{abC} (0.01)	0.04^{abB}(0.01)	0.00^{bC} (0.01)	0.01^{bC}(0.01)
Height Class 7	0.06^{aC} (0.01)	0.03^{aC} (0.01)	0.03^{aAB} (0.02)	0.01^{aC} (0.01)	0.02^{aC} (0.01)
Tree Seedlings- Counts [1]					
Height Class 1	0.50^{aABC} (0.10)	0.70^{aA} (0.10)	0.32^{aA} (0.12)	0.64^{aA} (0.10)	1.05^{aA} (0.10)
Height Class 2	1.02^{aA} (0.09)	0.61^{abA} (0.09)	0.46^{abA} (0.10)	0.41^{bAB} (0.09)	0.40^{bAB} (0.09)
Height Class 3	0.51^{aA} (0.05)	0.29^{abAB} (0.05)	0.14^{bA} (0.05)	0.12^{bABC} (0.05)	0.10^{bB} (0.05)
Height Class 4	0.18^{aB} (0.02)	0.11^{abBC} (0.02)	0.07^{abcA} (0.02)	0.03^{bcBC} (0.02)	0.00^{cB} (0.02)
Height Class 5	0.12^{aBC} (0.01)	0.05^{bC} (0.01)	0.01^{bA} (0.02)	0.00^{bC} (0.01)	0.00^{bB} (0.01)
Height Class 6	0.07^{aC} (0.01)	0.04^{abC} (0.01)	0.04^{abA} (0.01)	0.00^{bC} (0.01)	0.01^{bB} (0.01)

Height Class 7	0.07^{aC} (0.02)	0.03^{aC} (0.02)	0.03^{aA} (0.02)	0.01^{aBC} (0.02)	0.02^{aB} (0.02)
Stocking Rate % (low deer density) [1]	31.00^{a} (0.34)	22.46^{a} (0.34)	9.52^{ab} (0.40)	3.53^{b} (0.35)	4.82^{b} (0.35)
Stocking Rate % (high deer density) [1]	11.01^{a} (0.31)	5.75^{ab} (0.31)	1.58^{c} (0.37)	0.53^{c} (0.32)	2.26^{bc} (0.32)
Woody Cover < 2 m in height- Species Richness [1]					
Trees and shrubs	5.89^{a} (0.09)	4.24^{b} (0.09)	3.88^{b} (0.10)	3.18^{b} (0.09)	3.15^{b} (0.09)
Trees only	3.51^{a} (0.08)	2.25^{b} (0.08)	1.80^{bc} (0.09)	1.62^{bc} (0.08)	1.36^{c} (0.08)
Shrubs only	2.25^{a} (0.11)	1.73^{a} (0.11)	1.94^{a} (0.12)	1.41^{a} (0.11)	1.74^{a} (0.11)
Woody Cover < 2 m in height- Cover (%)[1]					
Trees and shrubs	46.24^{a} (0.15)	42.74^{a} (0.15)	19.64^{b} (0.17)	12.03^{c} (0.15)	13.90^{bc} (0.15)
Trees only	27.53^{a} (0.18)	18.57^{a} (0.19)	7.21^{b} (0.21)	5.47^{b} (0.19)	5.87^{b} (0.19)
Shrubs only	11.92^{a} (0.27)	12.08^{a} (0.27)	8.13^{ab} (0.29)	2.89^{c} (0.27)	4.23^{bc} (0.27)
Trees $\geq$ 1cm DBH- Species Richness	5.71^{a} (0.33)	5.64^{ab} (0.33)	5.09^{bc} (0.34)	4.85^{c} (0.33)	4.13^{d} (0.33)
Trees $\geq$ 1cm DBH- DBH [1]	7.12^{c} (0.08)	7.82^{c} (0.09)	9.36^{b} (0.09)	10.13^{b} (0.09)	11.26^{a} (0.09)
Trees $\geq$ 1cm DBH- Stem Counts	21.09^{a} (1.83)	20.18^{a} (1.93)	15.02^{b} (1.51)	14.19^{b} (1.39)	12.07^{c} (1.31)
Trees $\geq$ 1cm DBH- Heights of 5 tallest trees per plot quadrant [1]	16.09^{ab} (0.06)	15.43^{ab} (0.05)	16.77^{a} (0.05)	14.43^{b} (0.05)	16.73^{a} (0.05)

[1]Back-transformed from natural log (variable+1).

the plots every year in which data collection is undertaken. Deviation from past sampling protocol introduces unnecessary variation and will obscure interpretation of differences over time.

Another change in sampling intensity that occurred over time was that, in 1991-1995, 20 1 m × 1 m subplots were measured per plot for tree seedlings, while only 4 such plots were measured during 1999-2007. We recommend continuing with the smaller number of subplots per plot, since the change appears to have had little effect on the ANOVAs, except perhaps in variances.

Finally, it should be noted that much of the vegetation data collected at Rock Creek Park are either too detailed (e.g., tree vigor codes) or categorically too sparse (e.g., vine data) and probably not useful for statistical analysis, although these data may be useful for anecdotal information. It is recommended that the park no longer measures these variables unless some use is found for them (e.g., tree vigor codes could prove useful for documenting the effects of some future disease outbreak).

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Appendix. AIC_c values (smaller is better), transformations and variance groupings for each repeated measures analysis of variance (ANOVA). The 4 variance-covariance structures fit were unstructured (UN), compound symmetry (CS), Toeplitz (TO), and autoregressive (AR) order 1. AIC_c values of each model selected are shown in bold.

Variable		Transformation	Variance Groups	UN	CS	TO	AR(1)
Twigs Browsed (%)		natural log (% browsed + 1)	none	306.0	307.6	303.8	**300.6**
Canopy Cover (%)		none	none	614.9	**613.7**	616.0	615.5
Herbaceous Plants- Species Richness		natural log (richness + 1)	none	82.5	77.5	**76.9**	81.0
Tree Seedlings- Species Richness		natural log (richness + 1)	seedling height class	NA[1]	**-1038.4**	NA[1]	-946.6
Tree Seedlings- Counts		natural log (count + 1)	seedling height class	NA[1]	**-655.7**	NA[1]	-563.8
Stocking Rate (low deer density)		natural log (% low stock + 1)	none	NA[1]	428.1	430.5	**427.2**
Stocking Rate (high deer density)		natural log (% high stock + 1)	none	NA[1]	416.7	418.7	**412.9**
Woody Cover < 2 m height- Species Richness							
	Trees and shrubs	natural log (richness + 1)	none	134.7	129.4	124.9	**121.2**
	Trees only	natural log (richness + 1)	none	120.4	**112.4**	117.3	113.4
	Shrubs only	natural log (richness + 1)	none	149.2	147.9	138.6	**134.3**
Woody Cover < 2 m in height- Cover (%)							
	Trees and shrubs	natural log (% cover + 1)	none	247.9	**242.7**	245.7	243.2
	Trees only	natural log (% cover + 1)	none	318.4	**295.1**	301.3	300.9
	Shrubs only	natural log (% cover + 1)	none	329.8	325.3	317.8	**314.0**
Trees $\geq$ 1cm DBH- Species Richness		none	none	342.3	**335.4**	336.3	340.3
Trees $\geq$ 1cm DBH- DBH		natural log (dbh + 1)	none	**-21.0**	-11.2	-18.7	-19.0
Trees $\geq$ 1cm DBH- Stem Counts		none	none	**654.7**	694.8	667.8	663.0
Trees $\geq$ 1cm DBH- Heights of 5 tallest trees per plot quadrant		natural log (height + 1)	none	-35.5	**-48.7**	-46.9	-45.6

[1] Not applicable (NA) because this model did not converge or did not run.

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National Park Service
U.S. Department of the Interior

National Capital Region Office
Washington, D.C. 20007

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